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S3 – Guideline on Treatment of Patients with Severe and Multiple Injuries

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a. p.	Anteroposterior
AAST	American Association for the Surgery of Trauma
ABC	Assessment of blood consumption
ABCD	Airway/Breathing/Circulation/Disability
ACS	Abdominal compartment syndrome
ACS COT	American College of Surgeons Committee on Trauma
ACTH	Adrenocorticotropic hormone
AIS	Abbreviated Injury Scale
AJ	Ankle joint
ALI	Acute lung injury
ALS	Advanced Life Support
APC	Apheresis platelet concentrate
aPTT	Activated partial thromboplastin time
ArbStättV	Workplace Regulation
ARDS	Acute respiratory distress syndrome
ASIA-IMSOP	American Spinal Injury Association – International Medical Society of Paraplegia
ASR	Workplace Directive
ASS	Acetyl salicylic acid
AT	Antithrombin
ATLS®	Advanced Trauma Life Support
AUC	Area under the curve
AWMF	Association of Scientific Medical Societies in Germany
ÄZQ	Medical Center for Quality in Medicine
BÄK	German Medical Association
BE	Base excess, base deviation
BG	Berufsgenossenschaftliches [Statutory Accident Insurance Company]
BGA	Blood gas analysis
BLS	Basic Life Support
BP	Blood pressure
BS	Body surface
BW	Body weight
C 1-7	Cervical spine
CA	Contrast agent

Ca^{++}	Calcium
CCT	Cranial computed tomography/tomogram
CEBM	Oxford Centre for Evidence Based Medicine
CI	Confidence interval
CK-MB	Creatine kinase MB
COPD	Chronic obstructive pulmonary disease
CPAP	Continuous positive airway pressure
CPP	Cerebral perfusion pressure
CPR	Cardiopulmonary resuscitation
CRASH	Clinical Randomization of Antifibrinolytics in Significant Hemorrhage
CS	Cervical spine
CST	Cosyntropine stimulation test
CT	Computed tomography/tomogram
CTA	CT angiography
DC	Damage control
DDAVP	Desmopressin
DGAI	German Society of Anesthesiology and Intensive Care Medicine
DGNC	German Society of Neurosurgery
DGU	German Trauma Society
DIC	Disseminated intravasal coagulopathy
DIVI	German Interdisciplinary Association for Intensive and Emergency Care
DL	Definitive laparotomy
DO_2I	Oxygen delivery index
DPL	Diagnostic peritoneal lavage
DSA	Digital subtraction angiography
DSTC	Definitive surgical trauma care
EAES	European Association for Endoscopic Surgery
EAST	Eastern Association for the Surgery of Trauma
ECG	Electrocardiogram
EL	Evidence level
EMS	Emergency medical systems
EMT	Emergency Medical Technician
ENT	Otorhinolaryngology therapy
ER	Emergency room
ERC	European Resuscitation Council

ERG	Electroretinogram
ETC	European Trauma Course
FÄ/FA	Specialist physician
FAST	Focused assessment with ultrasonography for trauma
FFP	Fresh frozen plasma
FR	French (equals 1 Charrière [CH] and thus ⅓ mm)
GCS	Glasgow Coma Scale/Score
GoR	Grade of Recommendation
GOS	Glasgow Outcome Scale
h	Hour
Hb	Hemoglobin
HES	Hydroxy ethyl starch
HFS	Hannover fracture scale
ICP	Intracranial pressure
ICU	Intensive care unit
IFOM	Institute for Research in Operative Medicine (IFOM)
INR	International Normalized Ratio (subsequent standardization for Quick value)
INSECT	Interrupted or Continuous Slowly Absorbable Sutures – Evaluation of Abdominal Closure Techniques
ISS	Injury severity score
ICU	Intensive care unit
IU	International unit
IVP	Intravenous pyelography
L 1-5	Lumbar spine
LÄK	German regional medical association
LEAP	Lower Extremity Assessment Project
LISS	Less invasive stabilization system
LoE	Level of Evidence
LS	Lumbar spine
LSI	Limb Salvage Index
MAL	Mean axillary line
MCI	Mass casualty incident
MCL	Medioclavicular line
MESS	Mangled Extremity Severity Score
MILS	Manual in-line stabilization

MPH	Miles per hour
mrem	Millirem (equals 0.01 millisievert)
MRI	Magnetic resonance imaging
MRT	Medical radiologic technologist
MSCT	Multi-slice helical computed tomography
NaCl	Sodium chloride
NASCIS	National Acute Spinal Cord Injury Study
NASS CDS	National Automotive Sampling System Crashworthiness Data System
NEF	Emergency physician vehicle
NISSSA	Nerve injury, Ischemia, Soft-tissue injury, Skeletal injury, Shock and Age of patient
NS	Paranasal sinuses
n. s.	Not significant
OMS	Oral and maxillofacial surgery
OP	Operation/surgery
OPSI	Overwhelming Postsplenectomy Syndrome
OR	Odds ratio
pAOD	Peripheral arterial occlusive disease
PASG	Pneumatic anti-shock garment
PC	Platelet concentrate
PCC	Prothrombin complex concentrate
PHTLS®	Prehospital Trauma Life Support
PMMA	Polymethyl methacrylate
POVATI	Postsurgical Pain Outcome of Vertical and Transverse Abdominal Incision
PPV	Positive predictive value
PRBC	Packed red blood cells
PSI	Predictive Salvage Index
PTFE	Polytetrafluorethylene
PTS	Polytrauma Score
PTT	Partial thromboplastin time
QM	Quality management
RCT	Randomized controlled trial
RISC	Revised Injury Severity Classification
ROSC	Return of spontaneous circulation
ROTEM	Rotational thromboelastometry

RöV	German X-ray Ordinance
RR	Relative risk
RSI	Rapid sequence induction
RTA	Road traffic accident
RTH	Rescue helicopter
RTS	Revised trauma score
RTW	Ambulance
RX	X-ray
S	Spine
SAGES	Society of American Gastrointestinal and Endoscopic Surgeons
SBP	Systolic blood pressure
SCIWORA	Spinal Cord Injury Without Radiographic Abnormality
SIRS	Systemic inflammatory response syndrome
START	Simple Triage And Rapid Treatment
T 1-12	Thoracic vertebrae
TARN	Trauma audit and research network
TASH-Score	Trauma Associated Severe Hemorrhage Score
TBI	Traumatic brain injury
TEE	Transthoracic/transesophageal echocardiography
TEG	Thromboelastography
TIC	Trauma-induced coagulopathy
tPA	Tissue-specific plasminogen activator
Trali	Transfusion-associated acute lung failure
TRGS	Technical Rules for Hazardous Substances
TRIS	Tris(hydroxymethyl)aminomethane
TRIS	Trauma Injury Severity Score Method
TS	Thoracic spine
TTAC	Trauma Team Activation Criteria
i. v.	Intravenous
VEP	Visually evoked potential
WMD	Weighted mean difference

A Rationale und goals

Introduction

Medical guidelines are systematically developed decision aids for service providers and patients on the appropriate method applicable in specific health problems [1]. Guidelines are important tools for providing a rational and transparent basis for decisions in medical care [2]. Through imparting knowledge, they are intended to contribute towards improving care [3].

The process of developing guidelines must be systematic, independent and transparent [2]. Guideline development for Level 3 guidelines follows the criteria according to the AWMF/ÄZQ [German Medical Center for Quality in Medicine] specifications including all elements of systematic development [4].

Table 1: AWMF table of levels for guideline development [4].

Level 1	**Experts group:** A representatively formed group of experts from the Scientific Medical Society draws up a guideline in informal consensus, which is approved by the board of the society.
Level 2	**Formal evidence research or formal consensus finding:** Guidelines are developed from formally assessed statements in scientific literature or discussed and approved in one of the proven formal consensus processes. Formal consensus processes consist of the nominal group process, the Delphi method and the consensus conference.
Level 3	**Guideline including all elements of systematic development:** Formal consensus finding, systematic literature search and evaluation, and classification of studies and recommendations according to the criteria of evidence-based medicine, clinical algorithms, outcome analysis, decision analysis.

The present guideline is a Level 3 guideline.

Starting position

Accidents are the most common cause of death in children and young adults [5]. In 2007, 8.22 million people were injured in accidents and 18,527 people suffered a fatal accident according to statistics from the German Federal Institute for Occupational Safety and Health (*Bundesanstalt für Arbeitsschutz und Arbeitsmedizin*) [6]. The management of a severely injured person is typically an interdisciplinary task. It presents a major challenge to those involved in the provision of care because of the sudden occurrence of the accident situation, the unpredictability of the number of injured persons and the heterogeneity of the patient population [7].

An S1 guideline was issued by the German Society of Trauma Surgery in 2002 on the management of multiply injured patients and those with severe injuries. However, there is no up-to-date, general, comprehensive, evidence-based guideline. This was the rationale for drawing up an interdisciplinary guideline for the management of multiply injured patients and those with severe injuries.

Requirements of the guideline

The guideline must meet the following fundamental requirements:

- Guidelines for the treatment of polytrauma and patients with severe injuries are aids in decision-making in specific situations, based on the current state of scientific knowledge and on procedures proven in practice.
- Due to its complexity, there is no single ideal concept for the treatment of polytrauma and patients with severe injuries.
- Guidelines need to be constantly monitored and adapted to the current state of knowledge.
- Using the recommendations in this guideline, it should be possible to treat the vast majority of severely injured/multiply injured patients.
- Routine monitoring of treatment and monitoring the effect of treatment are necessary.
- Regular discussion with all involved (physicians, nursing staff, patients, if possible patients' families) should make the goals and methods of treatment of polytrauma and patients with severe injuries transparent.

Aims of the guideline

This interdisciplinary S3 guideline is an evidence-based and consensus-based tool with the aim of improving the management of multiply injured patients and those with severe injuries. The recommendations are intended to contribute towards the optimization of structural and process quality in hospitals and in prehospital management and, through their implementation, help to improve outcome quality in terms of case fatality rate or quality of life.

The guideline, which is based on the current state of scientific knowledge and on procedures proven in practice, is intended to provide a decision-making aid in specific situations. The guideline can be used not only in the acute treatment situation and in the debriefing but also in discussions about local protocols by the quality circles in individual hospitals. Legal (and insurance) aspects and those relevant to billing are not explicitly dealt with in this guideline. The regulations of the German Social Code Book (*Sozialgesetzbuch*) (SBG VII) apply.

The guideline should be an interdisciplinary decision-making aid. For this reason, it is also suitable for drawing up new treatment protocols in individual hospitals and for revising protocols already in existence.

The aim of the guideline is to support the care of the vast majority of severely injured persons. Individual patients with defined pre-existing concomitant diseases or specific injury patterns may not all be adequately covered due to their specific problems.

The guideline is intended to stimulate further discussion to optimize the care of severely injured persons. Constructive criticism is therefore expressly welcomed. Ideally, any amendments should be briefly summarized, backed up by references and forwarded to the publisher.

Apart from the terms of reference of this guideline, it is intended to draw up interdisciplinary recommendations on the ongoing process management of severely injured persons during the acute and post-acute phase.

A.1 Publisher/experts/medical societies/authors

The responsibility for this guideline lies with the German Trauma Society (*Deutsche Gesellschaft für Unfallchirurgie e. V.).*

The following medical societies were involved in drawing up the guideline:

German Society of General and Visceral Surgery (*Deutsche Gesellschaft für Allgemein- und Viszeralchirurgie e. V.*)
German Society of Anesthesiology and Intensive Care Medicine (*Deutsche Gesellschaft für Anästhesiologie und Intensivmedizin e. V*)
German Society of Endovascular and Vascular Surgery (*Deutsche Gesellschaft für Gefäßchirurgie und Gefäßmedizin e.V.*)
German Society of Hand Surgery (*Deutsche Gesellschaft für Handchirurgie e.V.*)
German Society of Oto-Rhino-Laryngology, Head and Neck Surgery (*Deutsche Gesellschaft für HNO-Heilkunde, Kopf- und Hals-Chirurgie e.V.*)
German Society of Oral and Maxillofacial Surgery (*Deutsche Gesellschaft für Mund-, Kiefer- und Gesichtschirurgie e.V.*)
German Society of Neurosurgery (*Deutsche Gesellschaft für Neurochirurgie e.V.*)
German Society of Thoracic Surgery (*Deutsche Gesellschaft für Thoraxchirurgie e.V.*)
German Trauma Society (*Deutsche Gesellschaft für Unfallchirurgie e.V.*)
German Society of Urology (*Deutsche Gesellschaft für Urologie e.V.*)
German Radiology Society (*Deutsche Röntgengesellschaft e.V.*)

Moderation, coordination and project management

The German Trauma Society as the lead medical association has devolved central coordination for this guideline to the Institute for Research in Operative Medicine (*Institut für Forschung in der Operativen Medizin*) (IFOM). The tasks were:

- coordination of the project group
- methods support and quality assurance
- systematic literature search
- procurement of literature
- data administration
- structural and editorial harmonization of the guideline texts

- coordination of necessary discussions, meetings, and consensus conferences
- administration of financial resources

Main treatment phase responsibilities

The guideline was divided into 3 main treatment phases: prehospital, emergency room, and emergency surgery. Coordinators were assigned responsibility for each of these treatment phases. The tasks were:

- establishing the contents of the guideline
- screening and evaluating the literature on the different treatment strategies for multiply injured patients and those with severe injuries, drawing up and coordinating the guideline texts

The AWMF, represented by Professor I. Kopp, provided methods guidance in drawing up the guideline.

A.2 Target user group

The guideline's target user group is primarily the physicians and all other medical professionals involved in the management of a multiply injured patient or one with severe injuries. The recommendations relate to adult patients. Recommendations on the care of children and adolescents are only given occasionally in the guideline.

B Methods

The guideline project was first announced in December 2004 and again in May 2009.

The guideline on the “Treatment of multiply injured patients and those with severe injuries” was developed according to a binding process with a structured plan. It is the result of a systematic literature search and critical evaluation of the evidence from available data using scientific methods as well as discussion with experts in a formal consensus procedure.

B.1 Literature search and selection of evidence

The key questions for the systematic literature search and evaluation were formulated on the basis of preliminary work during 2005. The literature searches were carried out in the MEDLINE database (via PubMed) using medical keywords (Medical Subject Headings/MeSH), partly supplemented by a free text search. The filter recommended in PubMed was used to identify systematic reviews. Supplementary searches were conducted in the Cochrane Library (CENTRAL) (in this case with keywords and text words in the title and abstract). The publication period selected was 1995-2010, and German and English as the publication languages.

The literature searches were carried out partly by the Institute for Research in Operative Medicine (IFOM) and partly by the authors themselves. The results of the literature searches, sorted according to topic, were forwarded to the individual authors responsible for each topic.

The underlying key questions, the literature searches carried out with date and number of hits and, if applicable, search limitations were documented and can be found in the appendix to the separate Methods Report.

Selection and evaluation of the relevant literature

The authors of each chapter selected and evaluated the literature included in the guideline. This was carried out according to the criteria of evidence-based medicine. Sufficient randomization, allocation concealment, blinding and the statistical analysis were taken into account.

The evidence statement for the recommendations was based on the evidence classification of the Oxford Center of Evidence-Based Medicine (CEBM), March 2009 version. In formulating the recommendations, priority was given to studies with the highest level of evidence available (LoE).

Table 2: CEBM evidence classification [9]

Level	**Studies on therapy/prevention/etiology**
1a	Systematic review of randomized controlled trials (RCT)
1b	An RCT (with narrow confidence interval)
1c	All or none principle
2a	Systematic review of well-planned cohort studies
2b	A well-planned cohort study or a low-quality RCT
2c	Outcome studies, ecological studies
3a	Systematic review of case-control studies
3b	Individual case-control study
4.	Case-series or low-quality cohort/case-control studies
5.	Expert opinion without explicit critical appraisal of the evidence or based on physiology/bench research

Three grades of recommendation (GoR) were possible (A, B, O). The wording of the key recommendation employs “must” “should” or “can” as appropriate. In determining the GoR, in addition to the underlying evidence, benefit-risk evaluations were also taken into account, as were the directness and homogeneity of the evidence along with clinical expertise [2].

B.2 Formulating the recommendation and finding consensus

The medical societies involved each nominated at least one delegate who, as a representative of that subject discipline, participated in drawing up the guideline. Each medical society had a vote in the consensus process.

The recommendations and the grades of recommendation were approved in 5 consensus conferences (April 18-19, 2009, June 30, 2009, September 8, 2009, November 26-27, 2009 and February 01, 2010):

The course of action at these conferences, assisted by the TED (electronic voting) system, was in 6 steps:

- the opportunity to review the guideline manuscript before the conference and to compile notes on the proposed recommendations and grades;
- presentation and explanation from each author responsible on the pre-formulated proposals for recommendations;
- registration via moderators of participants' opinions and alternative proposals on all recommendations, with speaker contributions solely for clarification;
- voting on all recommendations and grades of recommendation and on the cited alternatives;
- discussion of the points on which no "strong consensus" could be reached in the first round;
- final voting.

Most of the recommendations were approved with "strong consensus" (agreement of > 95% of participants). Areas in which no strong consensus could be reached are marked in the guideline and the various positions are expounded. In classifying the consensus strength, the following consensus grades were decided on in advance [9]:

- strong consensus: > 95% of participants agreed
- consensus: > 75-95% of participants agreed
- majority consensus: > 50–75% of participants agreed
- no consensus: < 50% of participants agreed

The records of the meetings can be viewed at the Institute for Research in Operative Medicine (IFOM). The Delphi method was then applied to recommendations for which no consensus could be reached in the consensus conferences. A detailed methods report is available for viewing on the AWMF website and has been filed at the Institute for Research in Operative Medicine (IFOM).

B.3 Distribution and implementation

The guideline is to be distributed in the following ways:

- via the internet: AWMF website (http://www.awmf-online.de) and the websites of the medical societies and professional organizations involved in the guideline
- via printed media:
  - Publication of the guideline as a manual/book by the DGU. A copy will be made available to all hospitals involved in the DGU Trauma Network. In addition, all hospitals involved will be notified in writing about where and how the guideline can be viewed on the AWMF homepage.
  - Publication of extracts of the guideline and of implementation strategies in journals of the medical societies involved.
  - To simplify use of the guideline, a summary of the guideline containing the key recommendations is also to be published in the Deutsches Ärzteblatt [German medical journal].
- via conferences, workshops, professional training courses offered by the medical societies involved.

Various complementary measures are to be implemented in this guideline. In addition to the presentation of the recommendations at conferences, a link to topic-specific professional training courses is planned.

In addition, implementation at all the German hospitals involved in the trauma network is to be evaluated approximately one year after publication of the guideline. In particular, it should be recorded how the guideline has been used and what practical suggestions the participants have gained from their experience to pass on to other users.

B.4 Quality indicators and evaluation

The audit filters were developed as criteria for quality management for the DGU Trauma Registry. Based on the available audit filters, the following criteria were established for this guideline:

Process quality for evaluation in the prehospital phase:

- duration of prehospital time between accident and hospital admission for severely injured patients with ISS ≥ 16 [∅min ± SD]
- intubation rate in patients with severe chest injury (AIS 4-5) by the emergency physician [%, n/total]
- intubation rate in patients with suspected traumatic brain injury (unconscious, Glasgow Coma Scale [GCS] ≤ 8) [%, n/total]

Process quality for evaluation of emergency room management:

- time between hospital admission and performance of a chest X-ray in severely injured patients (ISS ≥ 16) [∅ min ± SD]
- time between hospital admission and performance of an ultrasound scan of the abdomen/chest in cases of severe trauma (ISS ≥ 16) [∅ min ± SD]
- time until performance of a computed tomography (CT) scan of the cranium (CCT) in pre-hospital unconscious patients (GCS ≤ 8) [∅ min ± SD]
- time until performance of a full-body CT scan on all patients, if carried out [∅ min ± SD]
- time from emergency admission arrival to completion of diagnostic study in severely injured persons if this has been completed normally (ISS ≥ 16) [∅ min ± SD]
- time from emergency admission arrival to completion of diagnostic study in severely injured persons if this has been interrupted due to emergency (ISS ≥ 16) [∅ min ± SD]

Outcome quality for overall evaluation:

- standardized mortality rate: observed mortality divided by the expected prognosis based on RISC (Revised Injury Severity Classification) in severely injured persons (ISS ≥ 16)
- standardized mortality rate: observed mortality divided by the expected prognosis based on TRISS (Trauma Injury Severity Score Method) in severely injured persons (ISS ≥ 16)

The routine recording and evaluation of these data offer a vital opportunity to monitor improvements in quality in the management of multiply injured patients and those with severe injuries. It is not possible to ascertain from this which effects are due to the guideline. Quality indicators should continue to be developed based on the aforementioned criteria.

B.5 **Validity and updating of guideline**

This guideline is valid until December 2014. The German Trauma Society is responsible for introducing an updating process. The cooperation of the German Society of Plastic, Reconstructive and Esthetic Surgeons (*Deutsche Gesellschaft der Plastischen, Rekonstruktiven und Ästhetischen Chirurgen*) and of the German Society of Burns Medicine (*Deutsche Gesellschaft für Verbrennungsmedizin*) and the thematic inclusion of burns, large skin/soft tissue defects and nerve defect injuries (including plexus injuries) is additionally planned for this updating.

B.6 **Funding of the guideline and disclosure of potential conflicts of interests**

Reimbursement monies for the methods support, costs for literature acquisition, costs for organizing the consensus conferences, and costs of materials were provided by the German Trauma Society and the Institute for Research in Operative Medicine (IFOM) of the University of Witten/Herdecke. The participants’ travel costs arising from the consensus process were covered by those medical societies/organizations sending representatives or by the participants themselves.

All participants in the consensus conference disclosed potential conflicts of interest in writing. A summary of declarations of potential conflicts of interest from all coordinators, medical society delegates, draft authors, and organizers can be found in the appendix to the separate Methods Report of this guideline. Furthermore, the forms used to disclose potential conflicts of interest can be requested from the Institute for Research in Operative Medicine (IFOM).

Grateful thanks are extended to the coordinators of the individual subsections, the authors and participants in the consensus process for their wholly voluntary work.

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1 Prehospital

1.1 Introduction

Within the structured emergency services, the professional treatment of severely injured patients starts right at the accident scene. The subsequent course can be set at this stage. So, even for this initial treatment phase, it is expedient and necessary to develop the clearest priorities and strategies for dealing with the situation. Due to the difficult environmental conditions in the prehospital emergency situation, the evidence level is low yet the full diversity of experience and expert knowledge is considerable. Moreover, the benefit-risk evaluation is disputed in a number of interventions, not least in considering the point at which an essentially indicated intervention should be carried out, for example, in the prehospital phase or only once admitted to hospital. Finally, the polarization between “stay and treat” and “load and go” also plays a role here. In addition, a large amount of scientific knowledge has been gained from different emergency systems and its transferability to specific situations in Germany is often ambiguous.

Those active on the spot want a highly specific recommendation with broad validity but this desire is in conflict with the unfortunately often weak data available and the resulting unreliable conclusions. This desire can only be met by achieving a consensus among the experts, on the understanding that scientific uncertainty continues to exist in such areas and that there are differences between different emergency systems and cultures.

The structuring of the prehospital guideline section is based on several considerations. Basically, the management of a (potentially) severely injured patient involves a sequence of actions that follow certain priorities. Every detail and individual step of the sequence itself cannot be evidence-based with proof of general validity. Moreover, many individual circumstances relating to the actual patient have to be considered so that not all possible sequence models can be depicted. The contents of the guideline were therefore not oriented to a specific sequence algorithm but focused instead on individual aspects. These sections concentrate on anatomic regions (head, chest, abdomen, spine, extremities, and pelvis). In the prehospital phase, very few invasive interventional options are available; of these the most important (volume replacement, airway management, chest drain) are dealt with in terms of indications and implementation.

The individual aspects, interventions, and guidelines must be embedded in a general pathway of action that sets priorities and prescribes action pathways and sequences. A framework of this kind can be provided by programs such as Prehospital Trauma Life Support (PHTLS), Advanced Trauma Life Support (ATLS), European Trauma Course (ETC), and others. As such programs already exist and the individual steps cannot be individually scientifically proven, as indicated above, the attempt was not made to develop such a program in this guideline package. The individual guidelines are not intended to replace these programs but to represent the aspects embedded in them.

Besides directly treating the individual patient, general aspects also play a role in the prehospital phase. On the one hand, a decision must be made about the designated hospital. It must be able to treat all acute, life-threatening injuries immediately and independently. The initial-treating hospital must have clear, well-ordered transfer strategies for injuries which require a special structure or expertise. In addition to the increasing number of trauma networks being set up, the recommendations in the White Paper of the German Trauma Society [1] may be of great benefit here [2]. The resulting local and regional regulations can provide the emergency physician with additional support when selecting a suitable designated hospital. Besides the hospital structure, however, organizational and logistical circumstances, weather and road conditions or the time of day can also be significant in addition to purely medical considerations. Inextricably linked to this is the question of whether the patient is in fact severely injured. Criteria for this purpose are defined which are aligned to actual detected or suspected injuries, impairment of vital functions or mechanisms of injury. Finally, a balance must be found between the desire to underestimate as few patients as possible and the consequence of classifying too many patients unnecessarily as severely injured (overtriage). Conversely, although undertriage reduces the number of unnecessary emergency room alerts, it is at the cost of having underestimated more genuinely severely injured patients. The latter is viewed by many as the more critical model. Every trauma center should come to an agreement about this within its network or with the emergency services in its area.

The mass casualty incident represents a rare yet particularly challenging situation. Until the arrival of the on-duty lead emergency physician, the emergency physician who arrives on the scene first must take over this function. The switch from individual medical care to triage represents a special challenge and the algorithm should provide support here.

Many important, central domains are dealt with in the present edition of the prehospital polytrauma guideline. But some major topics, for example, pain therapy or prehospital management of traumatic brain injury, are not included. These are to be drawn up in future stages of guideline development, as well as other topics that are requested by the users.

Overall, the rapid, smoothly running medical care of (severely) injured patients is the focus of all action. In this context, the emergency services must work hand-in-hand with the hospitals. To this end, the 2008 Key Points Paper [3] on emergency medical management of patients in hospital and prehospital demands that definitive clinical treatment shall be achieved within 90 minutes for major emergency medical clinical pictures such as a severely injured patient. To make this possible, a time of 60 minutes from emergency call to hospital admission must be achieved. The scope of emergency physician care must be aimed at these targets.

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1.2 Airway management, ventilation and emergency anesthesia

Summary

Endotracheal intubation and ventilation, and hence definitive securing of the airways, with the aim of the best possible oxygenation and ventilation of the patient, is a central therapeutic measure in emergency medicine [80]. The basic vital functions directly linked to survival have to be secured. The “A” for airway and “B” for breathing are First Aid measures found in established standards on trauma care and therefore have a particular value in terms of weighting in both the prehospital and the early hospital management [3, 74, 107].

Variations in the emergency medical services (EMS) internationally pose a problem. Whereas paramedics are often used in the Anglo-American region, the emergency physician system is widely used in continental Europe. But even here there are differences. In Germany, (specialist) physicians in all disciplines can be involved in the emergency service after acquiring an appropriate additional qualification but in Scandinavian countries this is mainly the prerogative of anesthesiologists [9]. Consequently, the evaluation of international studies on the topic of securing the airway in the prehospital phase reveals that emergency services personnel have different levels of training. Depending on the personnel employed and how commonly they perform intubation, a high rate of esophageal intubations is found in up to 12% of cases in the literature [20]. In addition, there is a high rate of failed intubations (up to 15%) [99]. In paramedic systems, non-guideline-compliant airway management is more common [39]. Due to the different clinical routine of the users, negative outcomes in particular cannot be transferred directly from paramedic systems to the German emergency services and emergency physician system [60, 89]. In the Federal Republic of Germany, the agreed minimum qualification of “Additional qualification in emergency medicine” and the introduction of emergency anesthesia in the emergency physician system offers a different scenario compared to the Anglo-American paramedic system.

The following features of the prehospital setting can and must influence the establishing of indications and planning of anesthesia, intubation and ventilation:

- level of experience and routine training of emergency physician
- circumstances of the medical emergency (e.g., patient is trapped, rescue time)
- type of transport (land-based versus air support)
- transport time
- concomitant injuries around the airway and anything (assessable) that impedes intubation

Depending on the individual case, the indication to carry out or not to carry out prehospital anesthesia, intubation/airway management and ventilation ranges between the extremes of “advanced training level, long transport time, simple airway” and “little experience, short transport time, predicted difficult airway management”. In any event, sufficient oxygenation must be secured by appropriate measures.

If no methodologically high-quality studies were available, a recommendation would still be issued by a consensus of experts if clinically relevant. The following recommendations cover emergency anesthesia, airway management and ventilation in the prehospital phase and emergency room management.

Key recommendations

Emergency anesthesia, endotracheal intubation, and ventilation must be carried out in the prehospital phase in multiply injured patients with apnea or gasping (<6 breaths per minute).	**GoR A**
Emergency anesthesia, endotracheal intubation, and ventilation should be carried out in the prehospital phase in multiply injured patients with the following indications: ▪ **hypoxia (SpO_2 < 90%) despite oxygenation and after exclusion of tension pneumothorax** ▪ **severe traumatic brain injury (GCS < 9)** ▪ **trauma-associated hemodynamic instability (SYS-BP < 90 mmHg)** ▪ **severe chest injury with respiratory insufficiency (breathing rate > 29 breaths per minute)**	**GoR B**
The multiply injured patient must be preoxygenated before anesthesia.	**GoR A**
The in-hospital endotracheal intubation, emergency anesthesia and ventilation must be carried out by trained, experienced anesthesiologists.	**GoR A**

Explanation:

Severe multiple injuries have a serious effect on the integrity of the human body in its entirety. In addition to the acute trauma consequences for the individual body sections, it causes a mediator-mediated whole-body reaction, i.e. Systemic Inflammatory Response Syndrome (SIRS) [26, 54]. Tissue oxygenation takes on special significance in this damage cascade. Tissue oxygenation can only be achieved if uptake, transport and release of oxygen are guaranteed. Oxygen uptake is only possible if the airway is secured, and endotracheal intubation is the gold standard according to the current European and non-European guidelines [32, 73, 74]. A severe impairment of consciousness due to a traumatic brain injury with a Glasgow Coma Score (GCS) < 9 is regarded as an intubation indication [8]. Endotracheal intubation for the consciousness-impaired trauma patient with a GCS ≤ 8 is also recommended both prehospital and in-hospital according to the guideline of the Eastern Association for the Surgery of Trauma (EAST) [32] and other training programs (e.g., ATLS® [3]). Hypoxia and hypotension are the "lethal duo" which induces secondary damage particularly in polytrauma with traumatic brain injury [18, 19, 52, 87, 90]. It must be further pointed out that even patients with a GCS of 13 or 14, who were intubated endotracheally in the prehospital phase, displayed abnormal cerebral computed tomography (38%) and intracranial bleeding (28%) [36]. In a prehospital cohort study, it was shown that endotracheal intubation has a positive effect on survival following severe traumatic brain injury [56]. Another retrospective study showed a reduced case fatality rate for children with severe traumatic brain injury who were intubated by emergency physicians in the prehospital phase as compared to those receiving care on Basic Life Support (BLS) and delayed intubation in regional trauma centers [91]. If consideration is limited to a pediatric patient population, the prehospital endotracheal intubation in this study was carried out by emergency medical personnel with good transferability to the German emergency physician system. Using the Trauma and Injury Severity Score (TRISS) method, another study also confirms that prehospital endotracheal intubation leads to improved outcomes in survival and neurologic function [38]. Another paper further showed an improvement in measured systolic blood pressure, oxygen saturation and end-tidal carbon dioxide (etCO_2 compared to the baseline values prior to prehospital intubation in patients with severe traumatic brain injury [11].

Current review papers, however, refer to heterogeneous patient collectives, differing emergency services systems and differently trained users and therefore do not always come to a positive conclusion about intubation [9, 12, 25, 31, 60, 62, 69, 74, 98, 100]. The EAST guideline group also tackled this problem. In the “Guidelines for Emergency Intubation immediately following traumatic injury”, it was claimed that there are no randomized controlled trials on this research question. On the other hand, however, the authors of the EAST Guideline also found no studies that could present an alternative treatment strategy proven to be effective. In summary, endotracheal intubation was assessed overall as such an established procedure in hypoxia/apnea that, despite a lack of scientific evidence, a Grade A recommendation was formulated [73]. Other indications for endotracheal intubation (e.g., chest injury) are controversial issues in the literature [78]. There was evidence that hypoxia and respiratory insufficiency were a consequence of severe chest injury (multiple rib fractures, pulmonary contusion, unstable chest wall). Endotracheal intubation is recommended if the hypoxia cannot be remedied by oxygenation, by the exclusion of tension pneumothorax, and by basic airway management procedures [32]. Prehospital endotracheal intubation in patients with severe chest injury is suitable for preventing hypoxia and hypoventilation, which are associated with secondary neurologic damage and extremely severe consequences for the rest of the body. However, with difficult, prolonged intubation attempts and the associated hypoventilation and danger of hypoxia, endotracheal intubation itself can cause procedure-related secondary harms or even death. A database analysis of the Trauma Registry of the German Trauma Society showed no advantage in prehospital endotracheal intubation in patients with chest injury without respiratory insufficiency [78]. However, severe chest injury with respiratory insufficiency does present an indication for prehospital endotracheal intubation whereby the decision to intubate should be dependent on the respiratory insufficiency and not on the (suspected) diagnosis of severe chest injury, which is associated with a certain degree of uncertainty [7].

Endotracheal intubation is included as an “Advanced Life Support” procedure in the prehospital action algorithms of various training programs (e.g., PHTLS® [71]. Using a scoring system to evaluate management problems plus the relevant autopsy reports, a series of fatal traffic accidents were retrospectively analyzed to characterize the effectiveness of prehospital care and potentially avoidable fatal incidents [76]. This flagged up an extended “prehospital and early in-hospital care period” and a “lack of airway securing using intubation” as factors which led to the incidence of avoidable fatal incidents [76].

A retrospective cohort study of 570 intubated patients compared to 8,137 non-intubated patients showed that the prehospital intubated patients had a prehospital phase which was between 5.2-10.7 minutes longer than the non-intubated patients [24]. The effect of early intubation within 2 hours following trauma on the incidence of subsequent organ failure was evaluated in a prospective non-randomized study [97]. Despite a significantly higher degree of injury, there was a lowered incidence of organ failure and lower case fatality rate in the group of patients who were endotracheally intubated “early” within 2 hours following trauma, compared to the “later” intubated patients. The following factors must therefore be taken into account in selecting the best time to introduce anesthesia and endotracheal intubation: injury pattern, personal experience of the emergency physician/anesthesiologist, environmental conditions, transport distance, available equipment and complications associated with the procedure. Taking these points into consideration, the definitive care that the multiply injured patient should receive is emergency anesthesia with endotracheal intubation and ventilation. With the appropriate indication and appropriate training level, endotracheal intubation should be performed prehospital but, at the latest, during emergency room management. According to the analysis of data from the Trauma Registry of the German Trauma Society, out of 24,771 patients, 31% were unconscious at the accident scene (GCS < 9), 19% had severe hemodynamic instability (systolic blood pressure < 90 mmHg) and, overall, 55% of patients were endotracheally intubated by the emergency physician during the prehospital phase [77]. According to this analysis, in the case of 9% of multiply injured patients, it was necessary to discontinue the emergency room phase in hospital in favor of an emergency intervention/surgery; a total of 77% of multiply injured patients received surgery and 87% needed intensive care [77]. Due to a traumatic brain injury and/or chest injury, many multiply injured patients required intensive care ventilation and invasive ventilation therapy and all required adequate pain relief. In the study mentioned, the mean ventilation period for multiply injured patients was 9 days [77].

In order to prevent the harmful effects of hypoxia and hypoventilation, emergency anesthesia and endotracheal intubation and ventilation should be introduced prehospital or, at the latest, during emergency room care for the appropriate indication and with the appropriate training level. A large retrospective study using a trauma registry from a Level I trauma center studied 6,088 patients who received endotracheal intubation within the first hour following hospital admission [88]. In addition, according to this trauma registry, a further 26,000 trauma patients were endotracheally intubated after the first hour of hospital care on the day of admission. In the hands of experienced anesthesiologists, the “rapid sequence induction” proved in these cases to be an effective, safe procedure in hospital care: no patient died as a result of endotracheal intubation. Of 6,088 patients, 6,008 were successfully intubated orotracheally (98.7%) and a further 59 nasotracheally (0.97%). Only 17 patients (0.28%) had to have a cricothyroidotomy and 4 patients (0.07%) received an emergency tracheotomy. Following the endotracheal intubation, 3 more patients received an emergency tracheotomy during the course [88]. In another retrospective study of a monocenter trauma registry, 1,000 trauma patients (9.9% out of 10,137 patients) who had been endotracheally intubated within 2 hours of admission to the Trauma Center were studied [85]. At < 1%, the incidence of surgically securing the airway was uncommon in this study as well. Aspiration occurred in 1.1% of cases of endotracheal intubation.

Early intubation was seen as safe and effective by the authors [85]. These data also confirm that endotracheal intubation of trauma patients is a safe procedure in the hands of trained personnel. Another retrospective study from a paramedic-supported system with 175 endotracheally intubated patients showed a success rate of 96.6% with a markedly higher cricothyroidotomy rate of 2.3% [37]. In 1.1% of cases, the patient was ventilated by bag-valve-mask during transfer to hospital. There were 5 instances found of right mainstem dislocation (2.9%) and 2 cases of tube dislocation (1.1%). No case of failed intubation was documented.

In a retrospective study of a trauma registry, 3,571 prehospital endotracheal intubations in trauma patients were compared with 746 in the emergency room phase [6]. The endotracheal intubation first carried out during emergency admission was associated with a higher risk of a fatal course compared both to non-intubated patients (odds ratio [OR] 3.1; 95% confidence interval [-CI]; 2.1–4.5, $p < 0.0001$) and to patients who had already been endotracheally intubated in the prehospital phase (OR 3.0; 95% CI: 1.9–4.9, $p < 0.0001$) [6]. In addition, it was shown that patients who had been endotracheally intubated in the prehospital phase did not have a higher risk of dying than non-intubated patients in the emergency room phase (OR: 1.1; 95% CI: 0.7–1.9; $p = 0.6$). The authors concluded that the patients who were endotracheally intubated during emergency admission should have already been intubated in the prehospital phase [6].

In a prehospital cohort study with comparable injury severity (ISS 23 versus 24) and similar duration of care (27 versus 29 min, p = n.s.), 60 patients were treated by emergency services personnel (emergency medical technician [EMT], intubation rate 3%) and 64 patients in Advanced Life Support mode by emergency physicians (intubation rate 100%). Oxygen saturation was significantly improved upon arrival in hospital (SaO_2: 86 versus 96; $p = 0.04$) and systolic blood pressure was significantly higher (105 versus 132 mmHg, $p = 0.03$). There was no difference in all-cause case fatality rate (42% versus 40%, $p = 0.76$). However, a sub-group analysis showed a significant survival advantage for those patients with a GCS between 6 and 8 who had been treated by an emergency physician (case fatality rate: 78 versus 24%, $p < 0.01$; OR 3.85, 95% CI: 1.84–6.38, $p < 0.001$). The authors concluded that the case fatality rate is reduced by a prehospital emergency physician system offering rapid sequence induction, sufficient oxygenation and circulation drug therapy particularly for patients with clouded consciousness [56].

In the German-speaking emergency physician system, pediatric and adult emergency patients can be endotracheally intubated with a very high success rate if this procedure is carried out by experienced and trained personnel. In a prospective study over a period of 8 years, 4% of all pediatric emergency patients (82 out of 2,040 children) were endotracheally intubated [35]. Pediatric emergency callouts made up 5.6% of all emergency calls (2,040 out of 36,677 emergency physician callouts). Anesthesiologists carried out 58 of the pediatric endotracheal intubations with a success rate of 98.3%. Based on the incidence, the known number of emergency physicians employed each year, and their absolute number of callouts, it was calculated that each emergency physician in the emergency physician service has a gap of, on average, 3 years between pediatric endotracheal intubations and 13 years between infant endotracheal intubations. These results show that endotracheal intubation in childhood is rare outside the hospital setting and special attention must therefore be paid to maintaining specialist expertise and appropriate training outside the emergency services and emergency physician service.

A prospective study of a cohort of 16,559 patients managed in the prehospital phase included 2,850 trauma patients of which 259 (9.1%) were endotracheally intubated. More than 2 attempts were required in 3.9% of cases before endotracheal intubation was successful, and there was a failed intubation in 3.9% of cases. A difficult airway was described in 18.2% of cases. In comparison, patients with cardiac arrest had a difficult airway in only 16.7% of cases. This study also showed a success rate of 98.0% by anesthesia-trained emergency physicians [94]. Another prospective study of an emergency physician system showed a success rate of 98.5% in 598 patients (of which 10% were trauma patients) [92]. In another prospective study, endotracheal intubation by anesthesia-trained emergency physicians achieved a 100% success rate in a collective of 342 patients [n = 235 (68.7%) trauma patients]. In this case, endotracheal intubation was successful at the first attempt in 87.4% of cases, at the second attempt in 11.1% and at the third attempt in 1.5% [48]. Another study of the German emergency physician system showed a success rate of 97.9% in prehospital endotracheal intubation of trauma patients [1].

In a retrospective cohort study with 194 patients with traumatic brain injury, there was a significant difference in the case fatality rate between patients treated with basic life support (BLS) procedures in the land-based emergency services and patients who were treated with advanced life support (ALS) procedures by anesthesiologists in the air-borne emergency services (25 versus 21 %, $p < 0.05$). In this study, the survival rate of patients with traumatic brain injury who were treated highly significantly with more invasive measures in the air rescue group (intubation 92 versus 36%, chest drain 5 versus 0%) was better than the survival rate of patients treated in the land-based emergency services (54 versus 44%, $p < 0.05$) [10].

Procedural-related complications

Regarding procedural-related complications, a retrospective study using data from a trauma registry showed that there was no higher risk of pneumonia developing in 271 prehospital and 357 in-hospital endotracheally intubated trauma patients [96]. Regarding epidemiological data, prehospital intubated patients showed a lower GCS (4 versus 8, $p < 0.001$) and a higher injury severity according to the ISS (25 versus 22, $p < 0.007$) but otherwise no differences in the patient characteristics. Nevertheless, although it was to be expected, there was no difference in the length of hospital stay for both patient collectives (15.7 versus 15.8 d), in the length of intensive care stay (7.6 versus 7.3 d), in the number of days on a ventilator (7.8 versus 7.2 d), in the case fatality rate (31.7 versus 28.2%), and in the rate of resistant bacteria (46% in each case). On average, it took 3 days until the onset of pneumonia in both groups and the pneumonia rate was also not significantly different in both groups [96]. However, a significantly increased rate of pneumonia following prehospital intubation compared to in-hospital intubation was observed in another study [86]. However, this had no influence on the 30-day case fatality rate and the number of days in intensive care. Moreover, the group of prehospital intubated patients had an increased injury severity. In another study, frequency of pulmonary complications was found to be related to injury severity but not to intubation mishaps [84]. It cannot be definitely proven that prehospital endotracheal intubation is related to the incidence of pulmonary complications. In a retrospective study of 244 patients endotracheally intubated in the prehospital phase by an emergency physician, desaturation with an $SpO_2 < 90\%$ was documented in 18% of cases and hypotension with systolic blood pressure < 90 mmHg in 13% of cases. The two complications did not occur in parallel in any of the cases [72]. Overall, a low complication rate can be accordingly assumed.

Preoxygenation

To avoid a fall in oxygen saturation during the introduction of anesthesia and endotracheal intubation, the multiply injured patient should, if practicable, be preoxygenated for up to 4 minutes with an oxygen concentration of 100% via a face mask with reservoir [74]. In a non-randomized controlled study of 34 intensive-care patients, the mean p_aO_2 was (T_0) 62 ± 15 mmHg at the start of preoxygenation, (T_4) 84 ± 52 mmHg after 4 minutes, (T_6) 88 ± 49 mmHg after 6 minutes and (T_8) 93 ± 55 mmHg after 8 minutes. The differences in p_aO_2 were significantly different between T_0 and $T_{4–8}$, but no statistical differences could be obtained between the p_aO_2 between T_4, T_6 and T_8. 24% of patients even showed a reduction in the p_aO_2 between T_4 and T_8. A longer period of preoxygenation for 4 to 8 minutes did not lead to any further marked improvement in arterial oxygen partial pressure and delayed securing the airway in critical patients [67, 68]. Accordingly, sufficient preoxygenation for 4 minutes has special importance in securing the airway in multiply injured patients.

Training

Key recommendation:

Emergency medical personnel must be regularly trained in emergency anesthesia, endotracheal intubation, and alternative ways of securing an airway (bag-valve-mask, supraglottic airway devices, emergency cricothyroidotomy).	**GoR A**

Explanation:

In a survey recently carried out among prehospital trained emergency physicians, they were questioned on their knowledge of and experience in endotracheal intubation and the alternative methods for securing an airway [93]. This survey included the responses from 340 anesthesiologists (56.1%) and 266 non-anesthesiologists. It revealed that all anesthesia-trained emergency physicians could demonstrate more than 100 endotracheal intubations performed in hospital in contrast to only 35% of non-anesthesiologists performing more than 100 in-hospital intubations. A similar picture emerges for alternative methods for securing an airway as well. 97.8% of anesthesia-trained emergency physicians had used alternative methods for securing an airway on more than 20 occasions while only 11.1% of non-anesthesia-trained emergency physicians had equivalent experience ($p < 0.05$). In addition, it emerges that only 27% of emergency equipment was equipped with CO2 monitors. From this study it can be concluded that there is an urgent training need for non-anesthesia-trained emergency physicians in endotracheal intubation, capnography and alternative methods for securing an airway [74]. Studies on first-year anesthesiology residents showed that more than 60 intubations were necessary in order to achieve a success rate of 90% within the first two endotracheal intubation attempts under standardized, optimum conditions in surgery [57]. However, as the success of alternative methods for securing an airway (e.g., supraglottic airways: laryngeal mask, laryngeal tube) can only be as good as the corresponding training level in this procedure and current evidence indicates that a corresponding training level is not available everywhere [93], endotracheal intubation continues to be the gold standard. This knowledge also illustrates that emergency medical personnel should be regularly trained in endotracheal intubation and alternative ways of securing an airway [74].

Alternative methods for securing an airway

Key recommendations

A difficult airway must be anticipated when endotracheally intubating a trauma patient.	**GoR A**
Alternative methods for securing an airway must be provided when anesthetizing and endotracheally intubating a multiply injured patient.	**GoR A**
Fiberoptic intubation must be available as an alternative when anesthetizing and endotracheally intubating in-hospital.	**GoR A**
If difficult anesthetization and/or endotracheal intubation are expected, an anesthesiologist must carry out or supervise this procedure in-hospital provided this does not cause a delay in an emergency life-saving measure. Suitable measures must be in place to ensure that an anesthesiologist is normally on site in time	**GoR A**
After more than 3 intubation attempts, alternative methods must be considered for ventilation and securing an airway.	**GoR A**

Explanation:

Due to the framework conditions, the endotracheal intubation of an emergency patient is markedly more difficult in the prehospital environment than in-hospital. A difficult airway must therefore always be anticipated when endotracheally intubating a trauma patient [74]. In a large study of 6,088 trauma patients, risk factors and difficulties in endotracheal intubation consisted of foreign bodies in the pharynx or larynx, direct injuries to the head or neck with loss of normal anatomy in the upper airway, airway edema, pharyngeal tumors, laryngospasms and a difficult pre-existing anatomy[88]. In another study, trauma patients presented difficult airway securing markedly more frequently (18.2%) than, for example, patients with cardiac arrest (16.7%) and patients with other diseases (9.8%). Reasons described for difficult airway management were the position of the patient (48.8% of cases), difficult laryngoscopy (42.7% of cases), secretion or aspiration in the oropharynx (15.9% of cases) and traumatic injuries (including bleeding/burns) in 13.4% of cases [94]. Technical problems occurred in 4.3% and other causes in 7.3% of cases. Further studies show a similar frequency of causes of difficult intubation (blood 19.9%, vomit 15.8%, hypersalivation 13.8%, anatomy 11.7%, changes in anatomy caused by trauma 4.4%, position of patient 9.4%, lighting conditions 9.1%, technical problems 2.9% [48]. In a prospective study with 598 patients, adverse events and complications occurred significantly more frequently in patients with severe injuries than non-traumatized patients ($p = 0.001$) [92]. At least one event was documented in 31.1% of traumatized patients. The number of attempts required for intubation was also significantly increased in traumatized patients ($p = 0.007$) [92].

An increased risk of difficult intubation exists particularly in patients with severe maxillofacial trauma (OR 1.9, 95% CI: 1.0–3.9, $p = 0.05$) [22]. Maxillofacial trauma even represents an independent factor for difficult airway management (OR 2.1, 95% CI: 1.1–4.4, $p = 0.038$). A retrospective analysis of a trauma registry over a period of 7 years identified 90 patients with severe maxillofacial injuries. Of these, 93% initially received definitive airway securing, in 80% of cases by means of endotracheal intubation and in 15% of cases through surgical airway securing [21]. On the basis of these available data, the trauma patient must definitely be assumed to be non-fasting. In addition, blood, vomit or other fluids associated with a more difficult intubation situation must be expected in the oropharynx to a greater extent. A high-performance suction unit must therefore be available as a matter of course. For structure- and process-related reasons, the possibility of a back-up procedure with an experienced anesthesiologist often does not exist in the prehospital setting but in-hospital the gold standard is generally to involve an anesthesiologist in the management when difficult intubations and anesthesia are expected. In a prospective cohort study, it was therefore shown that if an attending physician in anesthesiology was present at in-hospital emergency intubations, significantly fewer complications occurred (6.1 versus 21.7%, $p < 0.0001$) [81]. However, there was no difference in the ventilation-free days and the 30-day case fatality rate.

If endotracheal airway securing fails, an appropriate algorithm must be followed, reverting back to bag-valve-mask ventilation and/or alternative methods of securing an airway [4, 15, 49, 73, 74]. In a prospective study, intubation success was evaluated in 598 patients in an emergency physician system solely staffed by anesthesiologists. Endotracheal intubation was successful at the first attempt in 85.4% of all patients. Only 2.7% required more than two attempts, and 1.5% (n = 9) had supralaryngeal aids such as the Combitube (n = 7), laryngeal mask (n = 1) or an emergency cricothyroidotomy (n = 1) after the third unsuccessful intubation attempt [92]. The study illustrates that alternative methods must be provided even in highly professional systems [55].

In a retrospective study of 2,833 patients endotracheally intubated in-hospital at a Level I trauma center, it was shown that the risk of airway-associated complications was markedly increased with more than 2 intubation attempts: hypoxemia 11.8 versus 70%, regurgitation 1.9 versus 22%, aspiration 0.8 versus 13%, bradycardia 1.6 versus 21%, cardiac arrest 0.7 versus 11% [65]. Another study, which was prospective and multi-center, examined over an 18-month period how many intubation attempts (inserting the laryngoscope into the oral cavity) were necessary for successful endotracheal intubation in emergency patients [101]. In 94% of cases, endotracheal intubation was carried out by paramedics and in a further 6% by nurses or emergency physicians. Overall, 1,941 endotracheal intubations were carried out, of which 1,272 (65.5%) were in patients with cardiac arrest, 463 (23.9%) as intubation without drug administration in patients without cardiac arrest, 126 (6.5%) as intubations under sedation in patients without cardiac arrest, and 80 (4.1%) by means of rapid sequence induction using a hypnotic agent and a muscle relaxant. Over 30% of patients required more than one intubation attempt to achieve successful endotracheal intubation. More than 6 intubation attempts were not reported in any case. The cumulative success rate during the first, second and third intubation attempt was 70%, 85% and 90% in patients with cardiac arrest. It was thus markedly higher than in the other 3 patient subgroups with intact circulatory function (intubation without drugs: 58%, 69% and 73%; intubation under sedation: 44%, 63% and 75%; intubation by means of rapid sequence induction:

56%, 81% and 91%). The specific success rates of endotracheal intubation by paramedics, nurses and emergency physicians were not broken down further. The results of this study [101] show that the cumulative success rate of endotracheal intubation in a paramedic system is markedly below that of emergency physician systems staffed solely by anesthesiologists, whose rate is 97-100% [48, 92, 94]. However, the administration of drugs, as they are used during a rapid sequence induction (including muscle relaxants), helps to facilitate endotracheal intubation in patients without cardiac arrest and thus leads to a markedly higher intubation success. Both are frequently vital for survival in an emergency situation. According to the above-cited study results, alternative methods should be considered for securing an airway after more than 3 intubation attempts [4, 65]. Although fiberoptic procedures are only available in isolated cases in the prehospital phase, fiberoptic intubation must be available in-hospital. In all common guidelines and recommendations on emergency airway securing, (awake) fiberoptic intubation is considered a possible procedure for securing an airway if there is appropriate experience and appropriate environmental conditions [33, 46, 49, 59].

In contrast, emergency cricothyroidotomy is simply the last resort in a “cannot ventilate - cannot intubate” situation to secure ventilation and oxygenation in an emergency. In national and international recommendations and guidelines, emergency cricothyroidotomy has a firm place in prehospital and hospital phases and is indicated if alternative methods for securing an airway and bag-valve-mask ventilation are not successful [9, 46, 49, 70].

Monitoring emergency anesthesia

Key recommendation:

ECG, blood pressure measurement, pulse oxymetry and capnography must be used to monitor the patient for anesthesia induction, endotracheal intubation and emergency anesthesia.	**GoR A**

Explanation:

The German Society of Anesthesiology and Intensive Care Medicine (DGAI) lays down certain features for a "standard workplace" in its update to the directives on equipping the anesthesiology workplace [27]. Special attention must be paid to the often difficult prevailing circumstances (e.g., physical confines, unfavorable lighting conditions, limited resources) in prehospital emergency medicine and particularly in the care of trauma patients.

The following items of equipment should be available in the prehospital phase for carrying out and monitoring emergency anesthetization [74]: electrocardiogram (ECG), non-invasive blood pressure measurement, pulse oxymetry, capnography/capnometry, defibrillator, emergency respirator, and suction unit. Appropriate equipment must be provided based on the guideline "Airway Management" of the German Society of Anesthesiology and Intensive Care Medicine [15] and the German DIN standards for emergency physician vehicle (NEF) [28], rescue helicopter (RTH) [29] and ambulance (RTW) [30].

In-hospital, the directives of the DGAI must be followed in the emergency room and in the other hospital wards [27].

Emergency ventilation and capnography

Key recommendations

During endotracheal intubation in the prehospital and in-hospital phases, capnometry/capnography must be used for monitoring tube placement and then for monitoring dislocation and ventilation.	**GoR A**
Normoventilation must be carried out in endotracheally intubated and anesthetized trauma patients.	**GoR A**
From emergency room treatment onwards, ventilation must be monitored and controlled by frequent arterial blood gas analyses.	**GoR A**

Explanation:

In the prehospital and in-hospital phases, capnometry/capnography must always be used during endotracheal intubation for monitoring the placement of the tube and then to reduce incidence of dislocation and monitor ventilation. Capnography is an essential component here in monitoring the intubated and ventilated patient [74]. Normoventilation should be carried out in endotracheally intubated and anesthetized trauma patients. From emergency room treatment onwards, ventilation must be monitored and controlled by frequent arterial blood gas analyses.

Capnography for monitoring tube placement and dislocation

The most serious complication in endotracheal intubation is an unrecognized esophageal intubation, which can lead to the death of the patient. This is why, both prehospital and in-hospital, all methods must be applied to recognize esophageal intubation and remedy it immediately.

The percentage of esophageal intubations reported in the literature starts at less than 1% [100, 106] spanning 2% [40], 6% [75], and reaching almost 17% [53]. Moreover, a high case fatality rate was shown as a result of tube misplacement in the hypopharynx (33%) or in the esophagus (56%) [53]. Esophageal intubation is thus not a rare event and, particularly in recent years, various studies have examined this catastrophic complication of endotracheal intubation in Germany as well. In a prospective observational study, helicopter emergency physicians trained in anesthesiology identified an esophageal tube placement in 6 out of 84 (7.1%) trauma patients, who had been intubated by land-based emergency physicians before arrival of the helicopter, and an endobronchial tube placement in 11 (13.1%) [95]. The case fatality rate of esophageally intubated patients was 80% in this study. In another prospective study with 598 patients in a German emergency physician system, the rate of esophageal intubations by non-medical personnel or physicians before arrival of the actual emergency physician system was 3.2% [92]. Another prospective observational study revealed esophageal intubation in 5.1% of 58 patients, who had been intubated by the land-based emergency service or emergency physician before arrival of the helicopter emergency physician trained in anesthesiology [43]. In a study focusing on the admitting emergency room team, esophageal intubation was found in 4 out of 375 prehospital intubated and ventilated patients (1.1%) [41].

In a prospective observational study of 153 patients, evidence showed that none of the patients who had been monitored by capnography had an unrecognized misplaced intubation, but 14 out of the 60 patients (23.3%) not monitored by capnography had [83]. Capnography therefore belongs in the standard equipment of the anesthesiology workplace and has dramatically increased the safety of anesthesia.

In a prospective observational study with 81 patients (n = 58 severe traumatic brain injury [TBI], n = 6 maxillofacial trauma, n = 17 multiple injuries), markedly greater sensitivity and specificity was demonstrated by monitoring tube placement by capnography compared to auscultation only (sensitivity: 100 versus 94%; specificity: 100 versus 66%, $p < 0.01$) [44]. These data prove that capnography must always be used for monitoring tube placement.

A survey found that in Baden-Wurttemberg only 66% out of 116 emergency physician sites had capnography available in 2005 [42]. There is an urgent need here for optimization. In addition, it is unknown how often available capnography is actually used in prehospital endotracheal intubation, tube position verification, and emergency ventilation monitoring. The goal must be to reach a capnography rate of 100% in the prehospital and in-hospital phases. On the basis of the guideline “Airway Management” of the German Society of Anesthesiology and Intensive Care Medicine and the German DIN standards for emergency physician vehicles (NEF) [28], rescue helicopters (RTH) [29] and ambulances (RTW) [30] on the mandatory availability of capnography, the lack of appropriate equipment basically constitutes organizational negligence [42].

Capnography for normoventilation

The introduction of emergency anesthetization is not only used to maintain adequate oxygenation but also effective ventilation and thus the elimination of carbon dioxide (CO_2), which accumulates in the human metabolism. Both an accumulation of CO_2 (hypercapnia and hyperventilation) and hyperventilation with consecutive hypocapnia can cause damage particularly in patients with traumatic brain injury and must be avoided in the first 24 hours [14, 16]. This results in a vicious circle of elevated intracranial pressure, hypercapnia, hypoxemia, further cellular swelling/edema and subsequent further increase in intracranial pressure.

In a retrospective analysis of prehospital care data from 100 prehospital intubated and ventilated patients, it was shown that an $etCO_2 > 30$ mmHg was attained in 65 patients and an $etCO_2 \leq 29$ mmHg in 35 patients. A lower case fatality rate was noticeably more likely in normoventilated patients (case fatality rate: 29 versus 46%; OR 0.49, 95% CI: 0.1–1.1, $p = 0.10$) [17].

In a prospective observational study, only 155 out of 492 patients intubated and ventilated in the prehospital phase showed a $paCO_2$ between 30 and 35 mmHg in the initial arterial blood gas analysis (BGA) in the emergency room and were thus (according to the study protocol) normoventilated [102]. Eighty patients (16.3%) who were hypocapnic ($paCO_2 < 30$ mmHg), 188 patients (38.2%) who were mildly hypercapnic ($paCO_2$ 36–45 mmHg) and 69 patients (14.0 %) who were severely hypercapnic ($paCO_2 > 45$ mmHg) were ventilated. The injury severity of the severely hypercapnic patients ($paCO_2 > 45$ mmHg) was markedly higher and these patients also had hypoxia, acidosis or hypotension significantly more frequently compared to the other 3 groups. The case fatality rate of prehospital intubated and ventilated trauma patients both with and without TBI was specifically lowered by normoventilation (OR: 0.57, 95% CI: 0.33–0.99), with patients with isolated TBI gaining more markedly from normoventilation (OR: 0.31, 95% CI: 0.31–0.96). According to the available results, hyperventilation with consecutive hypocapnia ($paCO_2 < 30$ mmHg) in particular appears to be harmful in severely injured patients. These results make clear that, from emergency room treatment onwards, ventilation should be monitored and controlled by frequent arterial blood gas analyses.

In a prospective study of 97 patients, it was shown that patients monitored by capnography had a significantly higher rate of normoventilations (63.2 versus 20%, $p < 0.0001$) and significantly fewer hypoventilations (5.3 versus 37.5%, $p < 0.0001$) compared to patients who were ventilated without capnography monitoring but by using the 10-10 rule [47]. Capnography is thus an orientating procedure in emergency ventilation. When capnography is used for controlling ventilation, it must be taken into account that the correlation between $etCO_2$ and $paCO_2$ is nevertheless weak (r = 0.277) [104]. As a result of a prospective observational study with 180 patients, 80% of patients with an $etCO_2$ of 35–40 mmHg were indeed hypoventilated ($paCO_2$ > 40 mmHg). In a prospective study of 66 intubated and ventilated trauma patients, those patients in particular with high injury severity according to the ISS, hypotension, severe chest injury, and metabolic acidosis revealed a larger difference between $etCO_2$ and $paCO_2$ [61]. Thus, the arterial CO_2 ($paCO_2$) cannot always be directly inferred from the CO_2 ($etCO_2$) obtained by capnography [74]. This is due to the fact that good correlation between $etCO_2$ and $paCO_2$ under physiologic conditions is negatively affected by pulmonary shunt fractions in pulmonary contusions, atelectasis, hypotension and metabolic acidosis.

Thus, capnography primarily serves to evaluate tube placement and to monitor on-going ventilation, with ventilation control a secondary use. This was also briefly demonstrated in a retrospective cohort study with 547 trauma patients: all trauma patients and especially patients with severe TBI gained from $paCO_2$-controlled ventilation (OR: 0.33, 95% CI: 0.16–0.75). There was a significant survival advantage if $paCO_2$ was already between 30 and 39 mmHg on admission to the emergency room (OR 0.32, 95% CI: 0.14–0.75). In patients whose $paCO_2$ could only be brought into the target range during their stay in the emergency room, there was only a non-significant trend towards a lower case fatality rate (OR 0.48, 95% CI: 0.21–1.09). A markedly worse survival rate was shown by those trauma patients who initially had a $paCO_2$ of 30–39 mmHg but were then hypoventilated ($paCO_2$> 39 mmHg) or hyperventilated ($paCO_2$ < 30 mmHg) or who never attained the target goal of a $paCO_2$ of 30–39 mmHg during their stay in the emergency room. This study also illustrates that $paCO_2$ must not be freely inferred from $etCO_2$ [102].

Using capnography to check tube placement and to detect tube dislocations is advisable and essential. Capnography is the gold standard in standard anesthesia, and ventilation management is markedly better with capnography than without this procedure. There are limitations to ventilation management using capnography due to unpredictable shunt fractions. For this reason, ventilation must be managed by blood gas analysis as early as possible, in other words immediately upon admission to the emergency room.

Lung protective ventilation

In a prospective randomized study, ventilation with a small tidal volume (6 ml/kg BW) in patients with acute respiratory distress syndrome (ARDS) led to a significantly reduced case fatality rate and a lower incidence of barotrauma and improved oxygenation compared to ventilation with high tidal volume [2]. The multi-center randomized, controlled trial conducted by the ARDS network confirmed these results in a ventilation with low tidal volume and limiting plateau pressure to ≤ 30 cm H_2O in patients with ARDS [5]. Chest injuries are observed in around 60% of multiply injured patients with the corresponding consequences (e.g., pulmonary contusions, ARDS), and the development of an acute lung injury (ALI) as an independent factor is associated with the case fatality rate (case fatality rate of trauma patients with ALI [n = 93]: 23.7 versus without ALI [n = 190]: 8.4%, p < 0.01) [82]. Thus, lung protective ventilation with a tidal volume of 6 ml/kg BW and with the lowest possible peak pressures must be implemented as early as possible following endotracheal intubation [45].

Emergency anesthesia

Key recommendations

For endotracheal intubation in multiply injured patients, emergency anesthesia must be carried out as rapid sequence induction due to the usual lack of a fasting state and risk of aspiration.	**GoR A**
Etomidate should be avoided as an induction agent due to the associated side effects on adrenal function (ketamine is usually a good alternative here).	**GoR B**

Explanation:

Emergency anesthesia is frequently an unavoidable component of the proper care of a multiply injured patient. Anesthesia induction must be carried out in a structured way; if carried out improperly, it is associated with an increased risk of morbidity and case fatality rate [74]. In a retrospective study, compared to non-emergency intubation (n = 2,136), emergency intubation (n = 241) was linked to a markedly higher risk of severe hypoxemia ($SpO_2 < 70\%$: 25 versus 4.4%, $p < 0.001$), regurgitation (25 versus 2.4%, $p < 0.001$), aspiration (12.8 versus 0.8%), bradycardia (21.3 versus 1.5%, $p < 0.001$), arrhythmia (23.4 versus 4.1%, $p < 0.001$) and cardiac arrest (10.2 versus 0.7%, $p < 0.001$) [66].

In trauma patients, an airway is secured and anesthesia induction is normally carried out as rapid sequence induction (RSI) (ileus or crash induction) to secure an airway in the shortest possible time without aspiration if possible. In a prospective study, an evaluation was conducted over an 18-month period on how many intubation attempts (inserting the laryngoscope into the oral cavity) were necessary for successful endotracheal intubation in 1,941 emergency patients. The cumulative intubation success in patients with intact circulatory function differed greatly in the first 3 intubation attempts between patients who received intubation entirely without drugs (58%, 69% and 73%), intubation only under sedation (44%, 63% and 75%) or intubation by means of rapid sequence induction (56%, 81% and 91%) [101]. There was a high rate of failed intubations in other studies as well where no muscle relaxants were administered to optimize the intubation conditions during anesthesia induction for endotracheal intubation [34]. Drug-supported anesthesia induction in terms of rapid sequence induction is therefore vital for the success of endotracheal intubation.

Depending on the hemodynamic state of the patient, the injury pattern, and the personal experience of the physician, various induction hypnotic agents can be used here (e.g., etomidate, ketamine, midazolam, propofol, thiopental). Each of these drugs has its own pharmacologic profile and associated side effects (e.g., etomidate: superficial anesthesia, affects the adrenal function, ketamine: arterial hypertension, midazolam: slower onset of effect, superficial anesthesia, propofol: arterial hypotension, thiopental: releases histamine and triggers asthma, necrosis due to extravasation). Ketamine in particular can be used, also in combination with midazolam or low-dose propofol, for rapid sequence induction in patients with marked hemodynamic instability [51, 64, 74]. For analgesics, fentanyl or sufentanil is suitable for patients with stable circulation and ketamine for patients with unstable circulation [51, 64, 74].

Etomidate

Etomidate will be looked at in more detail below because important side effects have been discussed of late. In a retrospective analysis of the data from a trauma registry, the potentially negative effects from using etomidate in severe trauma were shown [105]. Etomidate was given to 35 out of 94 trauma patients (37%) during rapid sequence induction. There were no differences between the patients treated with and without etomidate in the demographic data (age: 36 versus 41 years), the cause of trauma, and the injury severity (injury severity score: 26 versus 22). After adjustment of the data (according to physiology, injury severity and transfusion), etomidate was linked to an increased risk of ARDS and multiple organ failure (adjusted OR: 3.9, 95% CI: 1.24–12.0). The trauma patients anesthetized with a single dose of etomidate also had a longer hospital stay (19 versus 22 d, $p < 0.02$), more ventilation days (11 versus 14 d, $p < 0.04$) and a longer intensive care stay (13 versus 16 d, $p < 0.02$).

In another retrospective study of a US trauma registry, the results of the cosyntropin stimulation test (CST) on 137 trauma patients in intensive care units were examined [23]. 61% of the trauma patients were non-responders. Age (51 ± 19 versus 50 ± 19 years), sex (male: 38 versus 57%), trauma mechanism and injury severity (injury severity score: 27 ± 10 versus 31 ± 12, Revised Trauma Score: 6.5 ± 1.5 versus 5.2 ± 1.8) did not differ significantly between responders and non-responders. In addition, the rate of sepsis/septic shock (20 versus 34%, $p = 0.12$), the need for mechanical ventilation (98 versus 94%, $p = 0.38$) and the case fatality rate (10 versus 19%, $p = 0.67$) did not differ between the two groups. However, there were significant differences in the incidence of hemorrhagic shock (30 versus 54%, $p < 0,005$), the need for vasopressors (52 versus 78%, $p < 0.002$), the incidence of coagulopathies (13 versus 41%, $p < 0.001$), the period in intensive care (13 ± 12 versus 19 ± 14, $p < 0.007$), the number of ventilation days (12 ± 13 versus 17 ± 17, $p < 0.006$) and the use of etomidate as an induction hypnotic agent (52 versus 71%, $p < 0.03$). The authors concluded that etomidate is one of the few modifiable risk factors for the development of adrenocortical insufficiency in critically ill trauma patients.

In another prospective, randomized study, after arriving in a Level I trauma center, trauma patients received either etomidate and succinylcholine or fentanyl, midazolam and succinylcholine for rapid sequence induction [50]. The baseline serum cortisol concentration was recorded before anesthesia induction and an ACTH (adrenocorticotropic hormone) test was carried out. Altogether, 30 patients were examined. The 18 patients in the etomidate group showed no significant differences compared to the 12 patients treated with fentanyl/midazolam with regard to the following patient characteristics (age: 42 ± 25 versus 44 ± 20 years, $p = 0.802$; Injury Severity Score: 27 ± 10 versus 20 ± 11 years, $p = 0.105$; baseline serum cortisol concentration: 31 ± 12 versus 27 ± 10 µg/dl, $p = 0.321$). The patients treated with etomidate showed a slight rise in serum cortisol concentration after the ACTH test compared to the patients treated with fentanyl/midazolam (4.2 ± 4.9 µg/dl versus 11.2 ± 6.1 µg/dl, $p < 0.001$). The patients treated with etomidate had a longer stay in intensive care (8 versus 3 d, $p = 0.011$), a longer period of ventilation (6.3 versus 1.5 d, p = 0.007) and longer hospital treatment (14 versus 6 d, p = 0.007). Two trauma patients in this study collective died, and both had been treated with etomidate. The authors concluded that other induction hypnotic agents instead of etomidate should be used for trauma patients.

Overall, the current data status shows rather unfavorable results for the use of etomidate in trauma patients. Thus, etomidate should only be used with great care and deliberation in the induction of trauma patients.

Procedure for endotracheal intubation with suspected cervical spine injury

Key recommendation:

Manual in-line stabilization should be carried out for endotracheal intubation with the cervical spine immobilization device temporarily removed.	**GoR B**

Explanation:

Normally, trauma patients, particularly multiply injured patients, are immobilized with a neck brace until a cervical spine fracture can be excluded by imaging technology. However, a correctly positioned cervical spine immobilization device restricts the mouth opening and thus the ability to insert a laryngoscope during an intubation maneuver. The cervical spine immobilization device prevents reclination of the head. Thus, it was possible in a prospective multi-center study to identify cervical spine immobilization as a cause of a more difficult endotracheal intubation [58]. For this reason, some users are replacing the cervical spine immobilization device in endotracheal intubation by manual in-line stabilization (MILS). In this case, the cervical spine is immobilized by another assistant using both hands to immobilize the cervical spine manually. The subsequent direct laryngoscopy under MILS was the standard of care in emergency situations for many years. However, there is controversy surrounding MILS and partially negative effects have been described [63, 79]. As an alternative to direct laryngoscopy, fiberoptic intubation as the gold standard can be performed on alert and spontaneously breathing patients in a stable cardiopulmonary condition by an experienced user in-hospital [13, 74].

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1.3 Volume replacement

Key recommendations:

Volume replacement should be introduced in severely injured patients, at a reduced level if there is uncontrollable bleeding, in order to keep the circulation at a low stable level and not exacerbate the bleeding.	**GoR B**
Volume replacement should be carried out with the aim of restoring normotension in hypotensive patients with traumatic brain injury.	**GoR B**
Normotensive patients do not require volume replacement but venous lines should be placed.	**GoR B**

Explanation:

Due to underperfusion from hemorrhaging and consecutively occurring traumatic-hemorrhagic shock, there is an imbalance between oxygen supply and demand in the tissue [83]. This disturbed microcirculation is held responsible for the occurrence of secondary damage following hemorrhagic shock. The goal of volume replacement should be to improve microcirculation and thus organ perfusion. Expert opinion therefore holds that aggressive volume replacement has a favorable effect on the outcome for acutely bleeding patients [1, 28, 53, 56]. This rationale for the prehospital phase has not been confirmed in randomized controlled trials. In a randomized controlled trial [83], prehospital patients were randomized either to receive or not receive volume replacement. 1,309 patients were included. There was no difference between the groups in terms of mortality, morbidity and long-term outcome [83].

In a retrospective study by Balogh et al. [8], 156 patients in shock receiving supranormal resuscitation were compared to patients receiving less treatment which was terminated at the oxygen delivery index (DO_2I) . Raised intraabdominal pressure, which is supposed to be associated with increased organ failure, was observed in the aggressive intervention group.

Another study by Bickell et al. [11] found a negative survival effect from volume replacement after bleeding. However, this study only included patients with penetrating torso injuries. 1,069 patients were included in the study. In this selected patient group, the introduction of volume replacement in the prehospital phase led to an increase in mortality from 30% to 38% and to an increase from 23% to 30% in post-operative complications in the group with prehospital volume replacement. The authors concluded from this that prehospital volume replacement should not be carried out and that surgical treatment should be started as quickly as possible. Many authors go along with this conclusion in reviews or experimental studies [9, 45, 48, 60, 67, 77, 82]. However, the authors always highlight there being uncontrollable intrathoracic or intraabdominal bleeding. In such a situation, surgery should be performed as rapidly as possible and not be delayed by prehospital interventions. The goal should be moderate volume replacement with “controlled hypotension” and a systolic blood pressure of about 90 mmHg should be aimed for

[10, 36, 51, 69]. However, even this is questioned in patients with cardiac damage or traumatic brain injury (TBI) [35, 51, 79]. On the other hand, other authors partly advocate aggressive volume replacement, often addressing a different set of patients with, for example, extremity injuries without uncontrollable bleeding [28, 52, 56, 61, 71]. More recent papers have been unable to confirm the results obtained by Bickell [44, 94].

The majority of papers recommend the introduction of intensive volume replacement upon arrival at the hospital and after surgery has begun or if there is controllable bleeding. Again, expert opinion indicates a target hematocrit value of 25-30% as the volume to be administered [12, 40, 55, 56]. Controlled studies on this topic do not exist.

The use of catecholamines is viewed critically and only seen as a last resort [46, 56].

In one study, the extended prehospital treatment time due to carrying out volume replacement is given as 12-13 minutes [83]. The authors interpret this time loss partly as of little relevance [83] and partly as a major negative factor for mortality [73]. However, it is unclear whether this statement from North America can be transferred to the conditions of the German emergency physician-supported system.

Table 3: Prehospital volume replacement - mortality

Study	**LoE**	**Patient collective**	**Mortality with volume replacement**	**Mortality without volume replacement**
Turner et al. 2000 [83]	1b	Multiply injured patients (n = 1,309)	10.4%	9.8%
Bickell et al. 1994 [11]	2a	Patients with penetrating chest injury (n = 1,069)	38%	30%

Crystalloids versus colloids

Key recommendations:

Crystalloids should be used for volume replacement in trauma patients.	**GoR B**
Isotonic saline solution should not be used; preference should be given to Ringer's malate, or alternatively Ringer's acetate or lactated Ringer's solution.	**GoR B**
Human albumin must not be used in prehospital volume replacement.	**GoR A**
If colloidal solutions are used in hypotensive trauma patients, preference should be given to HES 130/0.4.	**GoR B**

Explanation:

There is still controversy surrounding the choice of infusion solution to be used. The majority of data is taken from animal experiments or from operations and is limited in its evidential value. Different results are produced from the meta-analyses carried out. In 1989, Velanovich et al. showed a reduction of 12.3% in mortality of trauma patients when crystalloid volume replacement was given [85]. In 1999, Choi et al. confirmed this result and hypothesized a lower mortality after trauma when crystalloids were used [23]. A Cochrane analysis of 2008 yielded no difference between colloids and crystalloids after trauma [19, 20, 21]. The authors concluded from this that colloids could be dispensed with as a volume replacement drug as there was no evidence of an advantage from colloids, and crystalloids were cheaper. A proviso should be mentioned here that old, very large-molecule solutions were used in these reviews and the informative value of these reviews is limited. According to the available studies, the newer colloid hydroxy ethyl starch (HES) 1301/0.4 no longer seems to have the disadvantages of older starch solutions [39, 53]. However, a marked deterioration in coagulation was observed in one in-vitro study even for more modern volume solutions including hypertonic saline solution. This effect was not observed when using lactated Ringer's solution or 0.9% saline solution [14].

Lactated Ringer's solution is the preferred choice of crystalloid over isotonic saline solution [30, 41, 43, 78]. Experimental papers showed evidence of dilutional acidosis occurring after infusion of large amounts of isotonic saline solution [62, 63]. The addition of lactate to a Ringer's balanced electrolyte solution prevents dilutional acidosis through the metabolization of the lactate to bicarbonate and water, thus buffering the bicarbonate pool. More recent experimental papers have found evidence of disadvantages in lactated Ringer's solution. According to these papers, lactated Ringer's solution triggers the activation of neutrophil granulocytes, thus causing more lung damage [4, 5, 6, 66]. The rate of granulocyte apoptosis is also apparently increased [32]. There is no evidence of this in clinical studies.

Plasma lactate is used as a shock parameter in diagnosis. Lactated Ringer's solution leads to an iatrogenic increase in plasma lactate level and can thus interfere with the diagnosis [64, 65]. Ringer’s malate or Ringer’s acetate can be used instead. In animal experiments there was evidence of lower mortality with Ringer’s malate. In conclusion, the use of lactated Ringer's solution no longer appears to be worthy of recommendation.

A Cochrane Review did not identify any evidence that one colloid is significantly superior to the other in the choice of colloid to be used [18]. The risk of an anaphylactic reaction to a colloid can be classified as minimal. In 1997, Ring [68] published his findings in The Lancet on the probability of an immune reaction to HES as 0.006%, to dextran as 0.0008% and to gelatine as 0.038%. Individual research papers seem to want to see an advantage of HES over the other colloids [1, 54, 74]. In a large series in France, the tolerance of different colloids was studied in 19,593 patients. 48.1% received gelatine solutions, 27.6% starch solutions, 15.7% albumin, and 9.5% dextrans. Overall, 43 anaphylactic reactions were observed (0.219%). The distribution between the different volume solutions was as follows: 0.345% for gelatine, 0.273% for dextrans, 0.099% for albumin, and 0.058% for starch. 20% of all allergic reactions were serious to very serious (grade III and IV). In a multivariate analysis, independent risk factors were identified as the administration of gelatine (OR 4.81), dextran (OR 3.83), a medical history of allergy to drugs (OR 3.16), and male sex (OR 1.98). Thus, a 6-fold smaller risk of anaphylaxis was observed for starch solutions compared to gelatine and a 4.7 times lower risk for dextran [54].

In 1990, Hankeln et al. tested HES 200/0.6 compared to human albumin in a randomized study of 40 patients with vascular interventions and were able to establish an optimum volume effect for HES 200/0.6 [41]. According to other studies as well, human albumin as a colloid seems to be associated with increased mortality and is not to be recommended [41]. The influence of colloids on coagulation seems negligible [53]. Albumin does not appear to play a role in volume replacement [37].

Hypertonic solutions

Key recommendation:

Hypertonic solutions can be used in multiply injured patients with hypotensive circulation after blunt trauma.	**GoR 0**
Hypertonic solutions should be used in penetrating trauma if prehospital volume replacement is carried out.	**GoR B**
A hypertonic solution can be used in hypotensive patients with severe traumatic brain injury.	**GoR 0**

Explanation:

In recent years, the hypertonic 7.5% saline solution has increasingly gained in importance, especially in prehospital volume replacement. As already described above, the microcirculatory disturbance is the harmful factor in hemorrhagic-traumatic shock.

The mechanism of action of the hypertonic solution is based on mobilizing intracellular and interstitial fluid into the intravasal space and thus on improving microcirculation and total rheology.

The dosage of hypertonic solution is limited in order to counteract harmful hypernatremia. Based mainly on experimental papers, the optimum dosage has been established at 4 ml/kg body weight (BW). A single administration is prescribed.

Microcirculatory disturbance during hemorrhaging is the main factor for late complications occurring. Hypertonic saline solution leads to interstitial and intracellular volume rapidly mobilizing into the intravasal space and thus to consecutively improving rheology and thereby the microcirculatory system [49]. No significant advantages of hypertonic solution have been found in controlled studies. Bunn et al. (2004) studied hypertonic versus isotonic solutions in a Cochrane Review [20]. The authors came to the conclusion that the available data was still insufficient to make a final judgment on hypertonic solution. In two controlled randomized trials, Mattox et al. (1991) and Vassar et al. (1991) argued an advantage of hypertonic solution for survival especially after traumatic brain injury [59, 84]. A paper by Alpar et al. (2004) follows the same line where an improvement in outcome is described in 180 patients especially after traumatic brain injury [2]. However, another controlled study from 2004 revealed that there was no significant difference to be observed in 229 patients in the long-term outcome after traumatic brain injury [29]. Moreover, Vassar et al. (1993) reported that the addition of dextrans did not bring any benefit for survival after trauma and bleeding [84]. This finding is contradicted by several papers which found a clear benefit from the addition of dextran [28, 49, 86, 87].

A positive effect on the clinical treatment of traumatic brain injury has been found in other studies. Wade (1997) and Vassar (1993) showed an effect on mortality after traumatic brain injury and initial treatment with hypertonic solution [84, 90]. Vassar found that the mortality rate dropped from 49 to 60% and Wade's mortality rate from 26.9 to 37.0% with hypertonic solution. In the follow-up treatment for increased intracranial pressure, a lowering effect is described particularly for the combination of hypertonic solution/HES [42, 47, 75, 91, 92, 93]. However, this effect could not be confirmed in a controlled clinical trial [76]. Nor could any advantage from the hypertonic solution be detected in another current paper by Bulger et al. published in JAMA with the result that the study was discontinued after 1,313 patients [15]. Wade et al. conducted a comparative study in terms of a short meta-analysis of 14 papers on hypertonic saline solution with and without the addition of dextran and found no relevant advantage in hypertonic solutions [90]. In a paper from 2003, the same author describes a positive effect of hypertonic solutions in penetrating traumas. In a double-blind study with 230 patients, the patients initially received either hypertonic sodium chloride (NaCl) or isotonic solution. The mortality of the patients who were treated with hypertonic NaCl solution was 82.5% versus 75.5%, which was a significant improvement. The surgery rate and bleeding rate were equal. The authors thus concluded that hypertonic solutions improve the survival rate in penetrating traumas without increasing bleeding [89].

In a current study by Bulger et al. [17], lactated Ringer's solution was compared to hypertonic NaCl solution with dextran in a group of 209 multiply injured patients with blunt trauma. The endpoint of this study was ARDS-free survival. As there were no differences, the study was discontinued after an intention-to-treat analysis. In a subgroup analysis, an advantage for hypertonic NaCl solution with dextran was only found after massive transfusion. Even the most recent publication from this working group did not show any advantages for hypertonic solutions after hemorrhagic shock [16]. In fact, a higher mortality rate was observed in patients not requiring transfusion after being given hypertonic solution [28-day mortality-- hypertonic solution with dextrans: 10%; hypertonic solution: 12.2% and 0.9% saline solution: 4.8%, $p < 0.01$) [16].

Immunologic effects are likewise ascribed to the hypertonic solution. Thus, experimental papers describe a reduction in neutrophil activation and in the pro-inflammatory cascade [4, 5, 6, 7, 26, 27, 31, 33, 66, 81]. No evidence has yet been found on the clinical importance of these effects.

Hypertonic solutions lead to a rapid rise in blood pressure and a reduction in volume requirement [3, 13, 22, 24, 38, 50, 57, 58, 93]. How far this influences the treatment outcome cannot be found in the literature.

With regard to the dosage, Rocha and Silva (1990) showed in dogs that a 7.5% solution with 4 ml/kg BW corresponds to the optimum dosage [70]; this was confirmed again by Wade et al. (2003) [88].

Anti-shock trousers

Key recommendation:

Anti-shock trousers must not be used for circulatory support in multiply	**GoR A**

injured patients.	

Explanation:

The anti-shock trousers (pneumatic anti-shock garment [PASG]) were promoted particularly in the 1980s and were often used in the military sector. Soft tissue damage and compartment syndromes brought their use into question. The current Cochrane Review from the year 2000 no longer recommends the use of anti-shock trousers. There are indications that the PASG increases mortality and extends the period of intensive treatment and hospital treatment [34]. Relevant complications after using anti-shock trousers have been described in several reviews and original papers [25, 80]. According to the literature available, the PASG should no longer be recommended.

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1.4 Thorax

Diagnostic tests

The decision whether to carry out drainage or decompression of the pleural space is based on examination, assessment of findings (diagnosis), and benefit-risk evaluation (diagnosis certainty with limited diagnostic options, time factor, concomitant circumstances, and risks attached to the method itself).

Examination

Key recommendation:

A clinical examination of the thorax and respiratory function must be carried out.	**GoR A**
The examination should include as a minimum the measurement of the respiratory rate and auscultation of the lungs. The examination should be repeated.	**GoR B**
The following can be helpful: inspection (bilaterally unequal in respiratory excursion, unilateral bulging, paradoxical respiration), palpation (pain, crepitations, subcutaneous emphysema, instability) and percussion (hyper-resonant percussion) of the thorax together with pulse oxymetry and, in ventilated patients, monitoring ventilation pressure.	**GoR 0**

Explanation:

Initial examination

The physical examination of the patient is required for establishing a diagnosis, which in turn is a prerequisite for treatment interventions. An acute life-threatening disorder can only be recognized by examination. Even without scientific proof, it appears to be absolutely essential [89].

Scientific studies on the type and scope of physical examination are mainly only on auscultation, measuring respiratory rate and on clarifying spontaneous pain and tenderness. Thus, only experience can define the required scope of the physical examination in the prehospital emergency examination.

In the emergency situation at the accident scene, the initial examination of the thorax should include (after checking and securing the vital functions) checking the respiratory rate and auscultation (presence of breath sounds, bilaterally equal breath sounds) [14, 36, 39, 40]. All these signs are correlated to significant pathologies or have a direct influence on medical decisions. Other useful examinations can be inspection (for signs of injury, symmetry of the thorax, symmetry of respiratory excursion, paradoxical respiration, dyspnea, distended neck veins) and palpation (subcutaneous emphysema, pain points, crepitations, instabilities in the bony structure of the thorax). Monitoring ventilation pressure and pulse oxymetry can be added in the course of further management [55].

All the above-mentioned examinations are used to detect relevant, threatening or potentially threatening disorders and injuries, which altogether can make it necessary to administer immediate and specific treatment or make a logistical decision on the spot. All diagnostic procedures that can be introduced prehospital are without specific risk, the only disadvantage being the loss of time, which is usually minimal.

The different findings are to some extent greatly dependent on the examiner, the patient and the environment. For instance, noise can make auscultation more difficult or impossible. Such circumstances must be taken into account when selecting and interpreting the primary diagnostic study [36, 40, 80, 135].

Several researchers showed that, under in-hospital conditions, ultrasound examination (lung sliding, lung point, comet tail, etc.) allows good and accurate detection of pneumothorax and hemothorax (review in [87]). However, there is no experience in prehospital application so a general recommendation cannot be made.

Patient monitoring

The respiratory rate and, if applicable, ventilation pressure should be checked and auscultation and pulse oxymetry performed during the course since a disorder in the respiratory system, a misplacement of the tube, tension pneumothorax or acute respiratory insufficiency can develop dynamically. The follow-up examination can serve as a performance check of the treatment administered.

Diagnosing pneumothorax

Key recommendations:

A suspected diagnosis of pneumothorax and/or hemothorax must be made if breath sounds are weaker or absent on one side (after checking correct placement of the tube). Absence of such auscultation findings largely rules out a larger pneumothorax, especially if the patient is normopneic and has no chest pain.	**GoR A**
The potential progression of a small pneumothorax which cannot initially be diagnosed in the prehospital phase should be taken into consideration.	**GoR B**

Explanation:

There are currently no methods available for definite prehospital detection or exclusion of pneumothorax. This is only clinically possible by computed tomography (exclusion).

Auscultation

The studies on diagnostic accuracy of auscultation are summarized in

Table 4. The specificity of a unilateral weakened or absent breath sound for the presence of pneumothorax is very high at 93-98%. The positive predictive value, i.e. the probability of there actually being a pneumothorax in the presence of a weakened breath sound, is also very high at 86-97% [35, 135]. Pneumothoraces not detected by auscultation had a mean volume of 378 ml (max. 800 ml), non-detected hemothoraces had a mean volume of 277 ml (max. 600 ml). No large, acutely threatening lesions were missed [36, 80]. In another prospective series, auscultation was the most reliable method of detecting a pneumohemothorax compared to evidence of pain or tachypnea [24]. Conversely, a hemo-/pneumothorax was virtually excluded in the presence of normopnea and normal auscultation and palpation findings [24].

The prerequisite is the correct placement of the endotracheal tube (as available), which must be ensured beforehand if possible. A proviso must be given here that the cited studies were not conducted at the emergency site but on emergency admission in the hospital. However, they appear to be easily transferable as numerous confounders (e.g., high noise level, disturbance) can also predominate in a comparable manner in emergency admission. False positive findings can occasionally be present (4.5% of cases in [88]) in tube misplacements, diaphragmatic rupture [1, 4] or ventilation disorders (large atelectases, shifting of deeper respiratory tracts).

If there are severe bilateral chest injuries, the presence of a bilateral pneumothorax should be considered. Atypical examination findings may occur in this case.

Data for differentiating between a pneumothorax and a hemothorax or mixed types are unavailable. Percussion can be helpful here but in the prehospital setting seems to be only of subordinate relevance as the differentiation between pneumo- and hemothorax has no provable effects on treatment requirements (see below).

Table 4: Diagnostic valency of a pathologic auscultation finding with regard to a hemo/pneumothorax

Study	LoE	Patient collective	Sensitivity	Specificity
Hirshberg et al. 1988 [80]	1	Sharp trauma (n = 51)	96%	93%
Wormland et al. 1989 [143]	3	Sharp trauma (n = 200)	73.3%	98.6%
Thomson et al. 1990 [135]	1	Sharp trauma (n = 102)	96%	94%
Chen et al. 1997 [36]	3	Sharp trauma (n = 118)	58%	98%
Chen et al. 1998 [35]	1	Mainly blunt trauma (n = 148)	84%	97%
Bokhari et al. 2002 [24]	2	Blunt trauma (n = 523)	100%	99.8%
Bokhari et al. 2002 [24]	2	Sharp trauma (n = 153)	50%	100%

Dyspnea

Even if the symptoms of dyspnea and tachypnea are difficult to quantify in consciousness-clouded patients, evidence of normopnea (respiratory rate between 10-20/min) can be put to good use in clinical practice. Several studies revealed that normopnea is a very reliable sign that a larger hemo/pneumothorax can be excluded after blunt trauma (high specificity). In contrast, the presence of dyspnea in no way indicates the reverse, that pneumothorax is present (low sensitivity).

Table 5: Diagnostic valency of dyspnea and tachypnea with regard to hemo/pneumothorax

Study	LoE	Patient collective	Sensitivity	Specificity
Wormland et al. 1989 [143]	3	Sharp trauma (n = 200 patients)	75.6%	84.1%
Hing et al. 2001 [79]	4	Sharp trauma (n = 153 patients)	72.7%	95.5%
Bokhari et al. 2002 [24]	2	Blunt trauma (n = 523 patients)	42.8%	99.6%
Bokhari et al. 2002 [24]	2	Sharp trauma (n = 153 patients)	31.8%	99.2%

Thoracic pain and pneumothorax

Fully conscious patients can be asked if they have chest pains. In addition, the clinical examination provides indications of tenderness in the thoracic region. There is only one clinical study that ranks absence of pain, and it reveals good specificity particularly for sharp trauma [24]. On the other hand, this finding only has adequate diagnostic accuracy in the overall picture with other findings.

Table 6: Diagnostic valency of thoracic pain with regard to hemo/pneumothorax

Study	LoE	Patient collective	Sensitivity	Specificity
Bokhari et al., 2002 [24]	2	Blunt trauma (n = 523 patients)	57.1%	78.6%
Bokhari et al., 2002 [24]	2	Sharp trauma (n = 153 patients)	25.0%	91.5%

Synopsis of thoracic pain, dyspnea, auscultation

Table 7 presents the diagnostic accuracy for the presence of pneumothorax after blunt trauma in relation to the presence of thoracic pain, dyspnea, and unilateral weakened breath sounds detected by auscultation.

Table 7: Statistical probabilities for the presence of a clinically relevant hemopneumothorax in various combinations of findings after blunt chest injury (basic assumption: 10% prevalence as pretest probability and independence of test)

Thoracic pain (sensitivity 57%, specificity 79%)	Dyspnea (sensitivity 43%, specificity 98%)	Auscultation (sensitivity 90%, specificity 98%)	Probability for hemo/ pneumothorax
+	+	+	> 99%
+	+	-	40%
+	-	+	89%
+	-	-	2%
-	+	+	98%
-	+	-	12%
-	-	+	61%
-	-	-	< 1%

Chest injury and pneumothorax

If a chest injury is present, it is not unusual to conclude an increased risk of pneumothorax being present and from this the indication for pleural drainage. Two issues must be considered here:

the success rate of emergency physicians for diagnosing chest injury and the correlation between a chest injury and a concomitant pneumothorax.

However, the diagnostic accuracy of the emergency physician is greatly limited. An analysis of data from the DGU Trauma Registry showed that the emergency physician had grossly overestimated the chest injury in 18% of cases, i.e. the emergency physician assumed a severe chest injury which was not actually there [7].

In 9-50% of patients with confirmed chest injury, there was also a pneumothorax. It should be noted with these figures that the diagnosis of chest injury in all these studies had been made after a full set of diagnostic tests including imaging.

In the majority of studies, between 37 and 59% of patients with a relevant chest injury diagnosed in hospital had a pneumothorax [23, 55, 66, 137]. If occult pneumothoraces - in other words, those which can only be detected in CT but not clinically and not in standard radiography - are not included, then the proportion of patients with chest injury who have a relevant pneumothorax is actually only 17-25% [23, 137]. However, the incidence of pneumothorax secondary to chest injury was markedly lower at 8.9% in individual studies [52].

Table 8: Incidence of pneumothorax in the presence of chest injury

Study	**Incidence of pneumothorax (radiologic diagnostic test without CT)**
Blostein et al. 1997 [23]	25% of chest injuries
Demartines et al. 1990 [52]	8.9% of chest injuries
Di Bartolomeo et al. 2001 [55]	21% of all critically injured
Gaillard et al. 1990 [66]	41% of chest injuries
Trupka et al. 1997 [137]	17% of chest injuries

Other examinations and pneumothorax

Evidence of subcutaneous emphysema is viewed as an indication of the presence of pneumothorax. However, there are no good diagnostic studies to support this. The specificity and positive predictive value are not known. However, the sensitivity is low and is between 12 and 25% [47, 126]. In a 30-year old study, it was reported that subcutaneous emphysema in intensive care patients had 100% sensitivity for the presence of tension pneumothorax. However, these data are possibly not transferable to acutely ill trauma patients in the prehospital phase [130].

Taking into account the relatively high rate of false findings, the findings of an unstable thorax and of crepitations are indications of the presence of a chest injury but not of pneumothorax.

Pneumothorax and progression

The potential progression of an initially asymptomatic pneumothorax is important, particularly in air rescue as well. The progression of pneumothoraces can vary considerably among individuals, and basically the full range from in-hospital finding to rapid progression is possible. The observation of small pneumothoraces can provide certain clues. In a small retrospective series, 13 patients with occult pneumothorax were conservatively treated, 6 of whom were being mechanically ventilated. It was subsequently necessary in 2 cases to insert a chest drain due to a progressive pneumothorax on the second and third day, respectively, after admission [38]. In a prospective randomized study, 8 out of 21 patients with an occult pneumothorax which was under observation developed progressive pneumothorax and, in 3 cases, tension pneumothorax. All these patients were ventilated [60]. The 3 tension pneumothoraces occurred in the operating room, post-operative after admission to the intensive care unit, and during a prolonged stabilization phase; exact times in hours after trauma are not available. A period of at least 30-60 minutes after hospital admission can at least be assumed. In another prospective randomized study of the treatment of occult pneumothoraces, the progression of pneumothorax in the group of conservatively treated patients (12.5%) was not greater than those on a pleural drain (21%) [25]. Details concerning the duration of pneumothorax progression were not recorded. In a series of 44 newborn, mostly intubated children, the time between the probable start of pneumothorax and the clinical diagnosis being made was on average 127 minutes with a scatter between 45 and 660 minutes [99].

In 3 studies, the maximum size of pneumothorax was indicated as 5 x 80 ml (400 ml), beyond which pleural drainage was indicated [25, 60, 70]. However, as pneumothoraces of this size can usually already be clinically diagnosed by auscultation (see above), it can be assumed that the progression of pneumothoraces with normal auscultation finding meets the above-mentioned conditions.

Most experts believe that the progression of pneumothorax to tension pneumothorax is greater in patients who are on positive pressure ventilation [13] but this cannot be quantified.

To summarize, the data suggest that small, clinically non-diagnosable pneumothoraces generally progress relatively slowly and thus do not require any emergency decompression in the prehospital phase.

Diagnosing tension pneumothorax

Key recommendation:

A suspected diagnosis of tension pneumothorax should be made if auscultation of the lung reveals no breath sounds unilaterally (after checking correct placement of the tube) and, in addition, typical symptoms are present, particularly severe respiratory disorder or upper inflow congestion combined with arterial hypotension.	**GoR B**

Explanation:

Good scientific data on diagnostic accuracy of examination findings for tension pneumothorax are few and far between. Practically all conclusions are based on case reports, animal experiments or expert opinion. There is no uniform definition on exactly what tension pneumothorax means. The definitions range from pneumothorax with threatening disorders to vital functions, hiss of escaping air during needle decompression, mediastinal shift on the chest X-ray, raised ipsilateral intrapleural pressure, and hemodynamic compromise [91]. For obvious reasons, the ad-hoc diagnosis in the prehospital phase can only be made on the basis of clinical examination findings.

The vast majority of experts consider the diagnosis of tension pneumothorax as given if life-threatening hemodynamic or respiratory disorders are present. Cyanosis, breathlessness, tachypnea, contralateral tracheal deviation, and a drop in oxygen saturation, elevated respiratory excursion and bulging hemithorax with hyper-resonant percussion on the diseased side are possible respiratory signs. Hemodynamic indicators can include distended neck veins, tachycardia, and ultimately a drop in blood pressure through to cardiac arrest (pulseless electrical activity). However, many of these signs can only be detected on closer examination and have not been systematically examined to date. There are few data on trauma patients; most information has been gained from observing tension pneumothoraces in intensive care medicine [90].

Experimental examinations show that, in the alert patient, respiratory impairment and paralysis of the respiratory center secondary to hypoxia precede cardiac arrest, and hypotension, the endpoint of which is cardiac arrest, is a late sign of tension pneumothorax [13, 124]. These experimental findings were recently confirmed by a patient with accidental tension pneumothorax, who became dyspneic, cyanotic and finally unconscious before respiratory arrest occurred. However, the carotid pulse could be felt throughout [131]. The patient’s condition normalized rapidly after decompressing the elevated intrapleural pressure. A tension pneumothorax in the radiograph (mediastinal shift to the contralateral side) without signs of impaired circulation has been described in another case report [101]. This patient’s circulation remained stable in the 30-minute period between making the diagnosis and inserting the chest drain. In another case report, the tension pneumothorax manifested itself clinically by cyanosis, an increase in respiratory and heart rate and impaired consciousness (GCS 10) while other signs were absent. However, a careful inspection revealed ipsilateral overextension and hypomobility in the chest wall. In a review article from 2005, the two symptoms, breathlessness and tachycardia, were presented as the typical and most frequent signs of tension pneumothorax in the alert patient [91].

However, the same authors also showed that in ventilated patients the cardio-circulatory symptoms of tension pneumothorax occurred earlier and the respiratory symptoms and fall in blood pressure often manifested themselves simultaneously. In the ventilated patient, very elevated or rising airway pressures are an important additional symptom that can be found in approximately 20% of patients with hemo/pneumothorax [14, 40]. However, systematically collected data concerning diagnostic accuracy are not available. According to expert opinion, the combination of (unilaterally) absent breath sound (with tube placement monitored) and life-threatening respiratory and circulatory function disorders makes the presence of tension pneumothorax so probable that the diagnosis should be made and the necessary therapeutic consequences followed. The consequences of a false diagnosis of tension pneumothorax appear to be subordinate compared to failing to carry out necessary decompression.

Indications for pleural decompression

Key recommendations:

Clinically suspected tension pneumothorax must be decompressed immediately.	**GoR A**
Pneumothorax diagnosed on the basis of an auscultation finding in a patient on positive pressure ventilation should be decompressed.	**GoR B**
Pneumothorax diagnosed on the basis of an auscultation finding in patients not on ventilation should usually be managed by close clinical observation.	**GoR B**

Explanation:

Comparative studies between conservative and interventional treatment are not available. The treatment recommendations are based on expert opinion and consideration of the probabilities.

Tension pneumothorax

Tension pneumothorax is an acute life-threatening situation and, if untreated, generally leads to death. Death can occur within a few minutes of the onset of signs of restricted pulmonary and circulatory function. There is no alternative to decompression. The experts are of the opinion that immediate emergency decompression should be carried out particularly on onset of circulatory or respiratory impairment and that the time lost through transferring the patient to a hospital, even one situated in the immediate vicinity, represents an unjustifiable delay. In a study of 3,500 autopsies, there were 39 cases of tension pneumothorax (incidence 1.1%), half of whom had not been diagnosed while still alive. Among soldiers from the Vietnam war, 3.9% of all patients with chest injuries and 33% of all soldiers with fatal chest injury had tension pneumothorax [100]. An analysis of 20 patients who had been categorized as unexpected survivors based on the TRISS prognosis showed that tension pneumothorax had been treated by decompression in 7 of them in the prehospital phase [29].

Diagnosed pneumothorax

A large pneumothorax, which can be assumed if a typical auscultation finding is collected, essentially presents an indication to evacuate the pleural cavity. Whether this has to take place in the prehospital phase or once admitted to hospital is difficult to decide in the individual case as the risk of progression from simple pneumothorax to tension pneumothorax and the amount of time that such a development can take are variable and difficult to estimate. The literature contains neither general data nor risk factors on this topic. There are indications that intubated patients with a chest injury when admitted to hospital are more likely to have tension pneumothorax than non-intubated patients. Overall, it still appears plausible to the experts that a pneumothorax diagnosed by auscultation in a ventilated patient has a markedly higher risk of developing into tension pneumothorax; thus, prehospital decompression is indicated.

If a patient with pneumothorax diagnosed by auscultation is not ventilated, then the risk of progression to tension pneumothorax appears to be markedly lower. In a series of 54 pneumothoraces after trauma, 29 were treated conservatively, i.e. without inserting a pleural drain. These were non-ventilated patients, mostly without concomitant injuries. A pleural drain was inserted in only 2 cases 6 hours after admission to hospital because of radiologic progressive pneumothorax [85]. Prehospital decompression does not appear to be necessary here and close clinical observation should be carried out. If appropriate clinical monitoring is an issue, e.g., during helicopter transfer, then there is a certain, unquantifiable risk that tension pneumothorax will develop which will not be recognized in time and/or which cannot be adequately treated due to space limitations. In such situations, if relevant clinical signs are present and after individual assessment, decompression of the pneumothorax can be carried out before transfer even in non-intubated patients.

Chest injury without direct pneumothorax diagnosis

If no pneumothorax is diagnosed (i.e. if the auscultation finding shows no lateral difference), then there is also essentially no indication for prehospital decompression or pleural evacuation.

The presence of clear signs of severe chest injury means that between 10 and 50% of these patients may have a pneumothorax (see above) and thus pleural drainage could be indicated in every second to tenth patient. Conversely, this means that at least every second patient and up to 9 out of every 10 patients would, under these conditions, receive unnecessary invasive treatment. This also coincides with the findings that air released from the pleural space was observed in only 32-50% of cases of prehospital decompression [14, 125], and decompression was not indicated in 9-25% of cases of pleural drains inserted in the prehospital phase as there was no pneumothorax or chest injury [7, 8, 125].

In addition, it should be considered that the radiologic findings have not been correlated to the clinical findings in the studies on pneumothorax incidence in chest injury. It can be assumed that numerous radiologically detectable pneumothoraces could also have been diagnosed by auscultation. The rate of pneumothoraces which cannot be diagnosed clinically but are present in chest injury can thus be assumed to be much lower [38]. As occult pneumothoraces were also included in a series of these studies, i.e. pneumothoraces which were first detectable at least 30 minutes after hospital admission only by computed tomography but not by standard radiography [23, 137], the proportion of prehospital relevant pneumothoraces falls even further. The risk of a pneumothorax, which at the time of primary survey was small and yielded a normal auscultation finding, progressing to tension pneumothorax has already been discussed above and should be viewed as minor in the prehospital timeframe.

Thus, in a justified individual case, decompression can be carried out in ventilated patients with clear signs of chest injury but normal auscultation finding prior to long road or helicopter transfer with limited clinical monitoring or treatment options. The high rate of false positive diagnoses of chest injury by the emergency physician must be taken into consideration.

Under these conditions, decompression is not indicated in non-ventilated patients.

Other indications

Pneumothorax and hemothorax represent the only typical indications for pleural decompression or pleural drainage in prehospital acute medicine. The therapeutic management of pneumothorax has already been presented above. Although hemothorax is essentially an indication for evacuating the blood located in the pleural space, there is generally no direct danger of compression from the blood and there is no indication for evacuation of the blood to the outside in the prehospital phase. Emergency decompression can only be indicated in cases of massive bleeding, possibly with problems developing in terms of tension hemothorax. However, this situation is generally associated with a pathologic auscultation finding and will thus make it necessary to proceed as per the situation with a pneumothorax, especially as it is generally always difficult to differentiate between a hemothorax and a hemopneumothorax in the prehospital phase.

Treatment

Methods

The aim of the treatment is decompression of positive pressure in tension pneumothorax or tension hemothorax. The second treatment goal to be considered is the prevention of a simple pneumothorax developing into a tension pneumothorax. The permanent and, if possible, complete evacuation of air and blood is of no importance in the prehospital emergency.

Key recommendations:

Tension pneumothorax should be decompressed by needle decompression, followed by surgery to open the pleural space with or without a chest drain.	**GoR B**

Pneumothorax should be treated with a chest drain provided the indication exists.	**GoR B**

Explanation:

As there are no suitable comparative data on the 3 methods, no recommendation for a method of choice can be made based on the data. (Predominantly retrospective) data, case series and case histories are available for all 3 methods and they demonstrate that successful decompression of tension pneumothorax is possible by each of these methods.

In view of the low evidence level on choice of method and benefit-risk profile in the direct comparison of methods, the individual ability of the treating emergency physician should be considered for reasons of practicability and risk potential. In one study, a significant difference in complication rate for insertion of a chest drain was observed between emergency admission physicians and surgeons [62]. In a more recent study, a lower complication rate associated with insertion by surgical compared to non-surgical residents was also observed in North America [11]. Due to a lack of reliable data, the extent to which these results are transferable to the German emergency physician system cannot be evaluated.

Chest drain: Efficacy and complications

Insertion of a chest drain is a highly effective, suitable but not complication-free procedure for decompressing a tension pneumothorax, which must be used particularly when the alternative interventions have failed or are insufficiently effective. Generally, it also represents the definitive treatment and has the highest success rate. In 79-95% of cases, pleural drains inserted in the prehospital phase were the successful, definitive treatment intervention [10, 52, 117, 125].

On the other hand, pleural drainage has a failure rate of 5.4-21% (mean of 11.2%) due to misplacements or insufficient efficacy. With this frequency, it was necessary to insert an additional pleural drain [10, 34, 45, 52, 62, 75, 117, 125]. This involved retained pneumothoraces and hemothoraces to more or less the same extent. Individual cases of persistent tension pneumothoraces were also observed with pleural drains inserted in the prehospital phase [10, 31, 98].

The pooled complication rates for pleural drainage are shown in

Table 9 and in Table 10 (see appendix). There do not appear to be any relevant differences between pleural drains inserted in the prehospital and in-hospital phases. However, there are only 2 studies in which the complication rates for prehospital and in-hospital treatment were directly compared within the same establishment [128, 144]. They revealed comparable infection rates (9.4 versus 11.7%) and misplacements (0 versus 1.2%). The number of days in situ was comparable in both groups in each study.

Table 9: Complication rates for pleural drains inserted in the prehospital versus in-hospital phase

Complication	Only prehospital pleural drains *	Only in-hospital pleural drains *
Subcutaneous misplacements	2.53% (1.55–3.33%) n = 730, 9 studies [10, 14, 47, 52, 88, 117, 125, 126, 144]	0.39% (0.08–1.13%) n = 772, 6 studies [9, 19, 45, 46, 77, 144]
Intra-pulmonary misplacements	1.37% (0.63–2.58%) n = 657, 7 studies [10, 14, 47, 52, 88, 125, 126]	0.63% (0.27-1.23%) n = 1,275, 7 studies [9, 19, 45, 46, 54, 77, 107]
Intraabdominal misplacements	0.87% (0.32–1.88%) n = 690, 8 studies [10, 14, 47, 52, 88, 117, 125, 126]	0.73% (0.29-1.50%) n = 956, 5 studies [9, 45, 46, 77, 107]
Infections (pleural empyema)	0.55% (0.11–1.59%) n = 550, 5 studies [10, 14, 52, 125, 144]	1.74% (1.47-2.05%) n = 8,102, 13 studies [9, 19, 34, 46, 54, 62, 107, 144] [59, 76, 77, 94, 129]

* Mean values obtained from simply adding together the complications given in studies (confidence interval in brackets)

The case histories for the puncture site of the anterior to midaxillary line also report on injury to the intercostal arteries [32], lung perforations [65], perforations of the right atrium [33, 104, 127], the right ventricle [118] and the left ventricle [49], subclavian artery stenosis due to pressure from drain tip from inside [109], Horner syndrome due to pressure on the stellate ganglion from the drain lying in the apex [21, 31], an intraabdominal placement [64], a liver puncture [47], a perforation of the stomach [4] and of the colon [1] due to diaphragmatic hernia, a lesion in the subclavian vein, perforation of the inferior vena cava [61], and triggering of atrial fibrillation [12].

An arteriovenous fistula [43] as well as perforation of the cardiac wall [56] and perforation of the right atrium [104] were reported when the puncture was performed in the mid-clavicular line.

In addition, other known complications are perforations of the esophagus, of the mediastinum triggering a contralateral pneumothorax, an injury to the phrenic nerve among others.

Simple surgical opening: efficacy and complications

The simple surgical opening of the pleural space is a suitable, effective and relatively simple intervention to decompress a tension pneumothorax. However, it is only suitable for patients on positive pressure ventilation as only they have constant positive intrapleural pressure. Negative intrapleural pressure develops in a spontaneously breathing patient and can cause air to be sucked in through the thoracotomy into the thorax.

Clinical experience shows that air is released out when the pleural space is opened in a mini-thoracotomy to insert a pleural drain for a pneumothorax or tension pneumothorax. This release of air can be sufficient to critically improve the clinical symptoms in the case of a hemodynamically active tension pneumothorax. This technique was examined in a case series of 45 patients in prehospital use and proved itself to be effective without any major complications [50]. In a prospective observational study of a helicopter emergency rescue service over a 2-year period, 55 patients with 59 suspected pneumothoraces underwent a simple surgical opening. As a result of the procedure, arterial oxygen saturation increased on average from 86.4% to 98.5%. A pneumothorax or a hemopneumothorax was found in 91.5% of the cases. No cases of recurrent pneumothorax were observed by the authors, likewise no serious complications (major bleeding, pulmonary laceration, pleural empyema) [97].

However, in another series, relevant complications were observed in 9% of patients involving non-decompressed tension pneumothoraces in just under half the cases [8].

The insertion of a pleural drain via the existing mini-thoracotomy is then indicated in hospital.

Needle decompression: efficacy and complications

Needle decompression is a drainage procedure which is frequently effective, suitable and simple but not complication-free. Surgical decompression and the insertion of a drain must be carried out immediately if efficacy is lacking or insufficient.

In a prehospital study, 47% of needle decompressions discharged air. A clinical improvement was observed in 32% of patients who underwent needle decompression[14]. In a similar study [48] , a release of air was observed during needle decompression in 32% of 89 patients with no difference between pulseless patients and those with maintained circulation. However, the release of air in ventilated patients was more frequently documented than in non-ventilated patients (34.9 versus 25.0%). However, the total rate of 60% clinical improvements remains unexplained as it is unclear how needle decompression is supposed to lead to an improvement in vital functions if no tension pneumothorax has been decompressed (i.e. no release of air). In another prospective series of 114 needle decompressions [58], there was an improvement in vital parameters or in dyspnea in 12% of patients.

In contrast, in a prospective series of 14 patients (a further 5 patients died in the emergency room and were not suitable for analysis) who underwent needle decompression, in 8 patients there was no indication of there having been a pneumothorax, in 2 patients there was an occult pneumothorax, in 2 patients a persistent pneumothorax, only in one case a successfully decompressed tension pneumothorax, and in one patient a persistent tension pneumothorax [44] with the result that only one out of 14 patients had unequivocally gained from needle decompression.

In the study by Barton [14], needle decompression had to be supplemented by a drain in 40% of the cases (32 out of 123) due to insufficient efficacy. In other prehospital studies [37, 48], a chest drain was additionally inserted in the prehospital phase in 53–67% of all patients undergoing needle decompression.

In 4.1% of cases of detected pneumothorax, needle decompression did not work at all as the needle could not be placed far enough in. In 2.4% of cases there was a secondary dislocation of the needle and in 4.1% of punctures the needle was difficult to position. No injuries to organs were observed [14]. In another study, needle decompression was unsuccessful in 2% of patients as the puncture was not deep enough. It was not indicated in a further 2% and an iatrogenic pneumothorax was the result. Infections and vessel injuries were not observed [58]. However, other researchers report on individual cases of lung injury [48] or cardiac tamponade [30]. In the latter case, breath sounds were absent in an unrecognized intubation of the right main bronchus. Another group reported on 3 patients with severe bleeding which necessitated a thoracotomy [119]. In addition, several case histories and case series reported a failure of needle decompression [28, 84, 110]. The most probable reason is that the needle was too short. In individual cases, a unilateral or bilateral tension pneumothorax was not identified in patients with chronic obstructive pulmonary disease (COPD) or asthma where the entire lung was not deflated [81, 108].

A known problem is the length of the needle used in relation to the chest wall thickness (for details, see II.2.2.1). A commonly used 4.5 cm long cannula is not sufficient in at least a quarter of patients for reaching the pleural fissure and is therefore unsuitable for decompressing a tension pneumothorax. It is not known by how much success rates could be increased if longer cannulas were used and to what extent the complication rate might increase through the longer cannula length. Thus, the use of longer needles cannot be recommended.

Needle decompression versus pleural drain

In 2 studies, needle decompression required a significantly shorter treatment time (about 5 minutes less) at the scene compared to a pleural drain (20.3 versus 25.7 min) [14, 48].

Air evacuation was achieved with needle decompression in 47% of cases, but after insertion of a pleural drain it was achieved in 53.7% of patients [14].

However, in a randomized study of patients with spontaneous pneumothorax (traumatic pneumothoraces were excluded here), drainage by means of a pleural drain showed a significantly higher success rate with 93% compared to simple needle aspiration (68.5%) [5]. In another prospective randomized study [112] on the same research question, 59.3% of needle aspirations and 84.9% of pleural drains were immediately successful. In 33% of patients with needle aspiration, another puncture or insertion of a pleural drain was necessary. The transferability of these data to the traumatic pneumothorax is open.

Some experts do not consider needle decompression an indication unless as a last resort [63].

If puncture by means of a needle is ineffective, surgical opening of the pleural space, if necessary with insertion of a drain, should be undertaken without delay or, in the case of obese patients, should be the first-line choice.

Conduct

Puncture site

Some authors recommend needle decompression in the 2nd-3rd intercostal space in the midclavicular line [14, 40, 44, 58], whereas others recommend the anterior to midaxillary line at the level of the 5th intercostal space [22, 39, 119]. It is postulated that the thickness of the ventral chest wall is greater than at the axillary line but this could not be confirmed in a study of cadavers (chest wall thickness in the midclavicular line [MCL]: 3.0 cm, in the midaxillary line [MAL]: 3.2 cm) [26].

On the other hand, the danger of a lung injury due to adhesions is considered greater in lateral access, and air in the pleural space would more likely be found in the apex. However, there are no study results on the practical importance of the cited arguments. One study showed that there is a strong trend to puncture medial to the midclavicular line with the associated risk of injuring the heart or great vessels [110].

Both the 4th-6th intercostal space in the anterior to midaxillary line [40, 132, 136] and the 2nd-3rd intercostal space in the midclavicular line are recommended as puncture sites for inserting a pleural drain. The nipple can be used as a guide in male patients. Generally, punctures must not be made below this point because the risk of an abdominal misplacement and injury to abdominal organs increases when the puncture is made too low. It should be noted that the puncture site indicated refers to the opening between the ribs. The skin incision can also lie one intercostal space lower (see conduct of puncture).

Deleterious complications for both puncture sites have been published as case histories. One prospective study found that the puncture level (2nd-8th intercostal space) or the lateral position (MCL or MAL) had no effect on the success rate of draining pneumothoraces or hemopneumothoraces following sharp trauma [57]. The complications from drain insertion in the 2nd-3rd intercostal space in the midclavicular line (n = 21) and in the 4th-6th intercostal space in the anterior axillary line (n = 80) were analyzed in a cohort study [82]. Although the rate of interlobal misplacements when using lateral access was significantly higher, functional misplacement was comparably frequent at both puncture sites (6.3% versus 4.5%).

Instruments (needle decompression)

In a study of cadavers, the average chest wall thickness was approximately 3.2 cm with a wide scatter (standard deviation 1.5 cm) [26]. Britten confirmed these results using ultrasound measurements and observed that in 57% of cases the pleural depth exceeded 3 cm and in 4% of subjects exceeded 4.5 cm. He concluded that, for the pleural space to be reached at all, the minimum length of needle required in the vast majority of cases is 4.5 cm [27]. Even a 4.5 cm long needle can be too short to reach the pleural space [28]. In a more recent study [72], an average chest wall thickness at the midclavicular line of 4.16 cm in men and 4.9 cm in women was determined in trauma patients using computed tomography. A quarter of the patients had a chest wall thickness exceeding 5 cm. Marinaro et al. [95] found a chest wall thickness exceeding 5 cm in 33% of their patients and even exceeding 6 cm in 10% of the injured. In a Netherlands study, the mean chest wall thickness at the midaxillary line was 3.9 cm in women and 3.4 cm in men. A needle with a length of 4.5 cm would not have reached the pleural space in 10-19% of men (under versus over 40 years) and 24-35% of women (under versus over 40 years) [145]. In a comparable study design, the average chest wall thickness in military personnel was 5.4 cm [74].

Some experts recommend the use of longer needles (exceeding 4.5 cm) to increase the chance of the pleural space being reached. Others fear that using longer cannulas carries a greater risk of injuring great vessels or the heart (see also [110]). There are no studies available on the actual benefit-risk evaluation of using longer versus normal length cannulas. Many experts therefore advise using the standard cannula (4.5 cm) and, if unsuccessful, surgically opening the pleural space (mini-thoracotomy).

There are no data available on the cannula diameter or type of cannulas to be used. In general, the largest possible cannula diameter is recommended to allow the maximum amount of air to be released.

Instruments (surgical decompression)

A thin drain should also suffice for decompressing a pneumothorax. In the case of non-traumatic pneumothoraces, 75-87% of patients were successfully treated with size 8-14 French (Fr) pleural catheters [41, 96] A study of patients with pneumothorax secondary to isolated thoracic trauma showed a success rate of 75% with thin catheters (8 Fr). The remaining 25% required a chest drain [51]. One case history reports on the progression of a pneumothorax into a tension situation despite an indwelling 8-Fr drain. This was a ventilated patient with a ruptured air cyst [17].

However, as at least 30% of cases after trauma are combined pneumo-/hemothoraces, it is feared that the drain may block quickly if too narrow. For these reasons, the use of 24-32-Fr drains are recommended in adults [16, 83, 132, 136].

Discharge systems

There are no reliable data on the question of whether and when a chest drain can be left open to the outside and, if so, which discharge system is to be used. A consensus expert recommendation also cannot be given.

No closure

Theoretically, the chest drain to the outside can be left open in a patient who is on positive pressure ventilation. There is a potentially increased risk of transferring infectious diseases to staff and there is contamination from the unprotected discharge of blood via the drain. On the other hand, there is only a minor risk of the discharge becoming obstructed and a recurrence of the (tension) pneumothorax.

However, if the patient is spontaneously breathing, there is a danger during inspiration that air from outside can be sucked into the pleural space, leading to total collapse of the pulmonary lobe. In this situation it is necessary to insert a valve device.

Heimlich valve

One such commercially available valve device is the Heimlich valve. It was originally used for decompressing spontaneous pneumothoraces [20]. In one out of 18 cases, the valve stuck and there was a resulting loss of function. In a retrospective comparison, 19 patients with a Heimlich valve had a shorter drainage time and length of stay in hospital compared to 57 patients with a standard drainage system (1/3 of patients with traumatic pneumothorax). However, patients with hemothorax were excluded and 4 patients with a Heimlich valve had to change to the standard drainage group [111]. Thus, it is unclear whether these experiences can be transferred to the prehospital situation. Further case reports show that the valve can get stuck causing the outflow to be diverted and a recurrent tension pneumothorax occurred [78, 93]. Heimlich valves were routinely used during the Falklands war, where it was reported that they frequently got stuck due to blood coagulation and that the valve had to be repeatedly replaced; the problem was not quantified [142]. It was shown in experimental studies that 2 out of 8 valves had a loss of function and in 7 out of 8 cases where the Heimlich valve was past its expiry date it was defective [78]. In addition to material fatigue, coagulated blood can also cause a loss of function. This uncertainty regarding the functionality of the Heimlich valve creates an incalculable risk potential and close monitoring is necessary during use. These considerations essentially apply to all other valves with the exception of multi-bottle systems. The Heimlich valve also does not offer protection against contamination and dirt.

Closed bag or chamber systems

Although the attachment of a closed collection bag can reduce the danger of dirt and infection, it can rapidly fill up with air or blood if there is a relatively large air fistula and so may lead to positive pressure with tension developing again in the pleural space.

Under in-patient conditions, a discharge via a 2- or 3-chamber system is generally used, these being predominantly closed commercial discharge systems. Advantages are their good functionality and protection against the surroundings being contaminated with blood. They would also be the definitive discharge system for ongoing treatment in hospital. In prehospital use, problems arise because they are awkward to handle when repositioning and during transportation and there is a resulting risk of tilting. If the chambers are overturned and there is uncontrollable displacement of the fill fluids between the chambers, their functional reliability is at risk [73].

In a prospective randomized study of patients following thoracotomy, a commercially available discharge system, consisting of a safety valve, a bag and an air outlet, was as successful as a multi-chamber system with underwater seal. Blockages were not observed here although the drains also conveyed blood and bloody secretion. There are no field reports on its use in the prehospital phase for traumatic hemothoraces or for pneumothoraces.

The use of a simple bag without valve (e.g., colostomy bag) [138] is not an option for trauma patients and pneumothoraces.

The Xpand Drain is a new development which has a collection reservoir attached via a valve to the pleural drain. A suction unit can be attached to the collection reservoir and larger amounts of fluid can be evacuated via a separate discharge. In a randomized but not blinded study, this collection reservoir (n = 34) was compared in a hospital setting with a conventional underwater seal (n = 33) in patients with pneumo- or hemopneumothorax after penetrating trauma [42]. The Xpand Drain was shown to be operationally comparable to the underwater seal. In principle, this system has potential advantages (small, easily transportable, transient overturning appears non-critical, clean) but to date there is no published experience on its use in the prehospital phase. A recommendation, therefore, should not be made until this is available.

Conduct (needle decompression)

The best technique has never been examined in controlled trials so these are expert opinions. Care must be taken to select the puncture site correctly as there is a tendency to puncture medial to the midclavicular line [110]. The puncture should follow a straight path using a permanent venous cannula attached to a syringe aspirating for air, continuing until air is aspirated [40]. After the pleural space has been punctured, the steel stylet should be left in situ to prevent the unprotected plastic cannula from kinking [44, 114]. Other authors hold the view that the steel stylet should be removed after puncture and only the plastic cannula left in situ[58, 110]. However, kinks have been documented (1 out of 18 punctures) [110].

Conduct (surgical decompression)

Key recommendation:

The pleural space should be opened by mini-thoracotomy. The chest drain should be inserted without using a trocar.	**GoR B**

Explanation:

The best technique has never been examined in controlled trials. Most experts recommend a standardized technique: a pleural drain must be inserted using a sterile technique. After the skin has been disinfected, a local anesthetic is administered to the not fully unconscious patient down to the pleural wall. A horizontal (transverse) skin incision approximately 4-5 cm in length is made with a scalpel along the upper border of the rib below the intercostal space to be punctured, or one rib lower (for cosmetic reasons this is done at the appropriate level in the sub-mammary fold in women). The subcutaneous layer and the intercostal musculature on the upper edge of the rib are opened up by blunt dissection or a clamp. The pleura can be separated by blunt dissection or by a small cut with the scissors. Then a finger (sterile glove) is inserted into the pleural space in order to verify correct access to the pleural space and ensure that there are no adhesions or, if applicable, to release them [16, 50, 107, 123, 132, 133, 136, 139]. If the ribcage is only to have a simple opening, the wound is covered with a sterile dressing, which is not taped on one side (for venting).

If a chest drain is to be inserted, the intervention is continued: a subcutaneous tunnel is not considered necessary by all experts [133]. A trocar should never be used for blind preparation of the passage. Serious complications have occurred through its use such as the perforation to the right atrium in a patient with kyphoscoliosis [104] or perforations to the lung [65]. The complication rates in studies on the trocar technique are much higher than in the studies on the surgical technique (11.0% versus 1.6%) (Appendix). In a prospective cohort study (on intensive care patients), it was shown that the use of a trocar was associated with a significantly higher rate of misplacements [120]. At the moment of transsectioning the pleura and inserting the drain, some experts recommend ventilated patients have a short ventilation break to reduce the risk of injury to the lung parenchyma when the lung is expanded [65, 115, 116].

The chest drain is then inserted through the prepared passage. The finger inserted in parallel can be used as a guide. The tip of the drain can also be held in a clamp and guided using this more rigid guiding option. Alternatively, a trocar can be used to guide the drain (not for preparing or perforating the chest wall!). It must be ensured that the tip of the trocar never protrudes beyond the tip of the drain and that no force is applied in advancing the drain [136].

The drain must be prevented from dislocating by fixing steristrips or a suture. A self-locking plastic tie can also be used for fixation [105].

Alternative techniques for insertion

A series of alternative techniques and modifications to the mini-thoracotomy for evacuating the pleural space have been published. They have usually been published simply as a description of the technique or examined in small case series or studies. There is usually no description of prehospital use or use in trauma patients. For these reasons, there are no perspectives that appear to justify use of these techniques as an equivalent alternative to the standard mini-thoracotomy described for trauma patients in the prehospital phase. Although there are no scientific proofs of the superiority of the standard technique either, it is the unanimous opinion of the experts that empirical experiences justify the recommendation of the standard technique as long as the alternative procedures have not supplied evidence of equivalence or superiority under the above-mentioned conditions.

Altman [3] modified the standard technique using mini-thoracotomy such that a Tiemann catheter consistent with the Seldinger technique is first inserted with a clamp into the pleural space and then serves as a guide bar for the actual drain. This enables a smaller skin incision compared to the standard technique.

The use of a laparoscopic trocar catheter is a technique that has been well-studied compared to numerous other alternative guide techniques but not in direct comparison with the standard technique [18, 67, 86, 92, 140]. Technique and complications were described in a prospective cohort study in which 112 patients were included, 39 of them after trauma [140]. The only complication (0.89%) described was an injury to the lung.

In 1988 Thal and Quick described a technique involving the insertion of a guidewire after direct puncture and expansion of the puncture passage using increasingly larger dilators and insertion of the drain (up to 32 Fr) over the guidewire [113, 134]. The technique led to an initial success in 24 pediatric patients (14 pneumothoraces, 3 hemothoraces, 7 others). In 5 cases (approx. 20%) there were complications due to kinking in the 10-20 Fr catheters [2]. In a systematic review, no advantages in the Seldinger technique could be confirmed compared to other techniques [6].

A frequent alternative, used particularly in pediatrics, is pigtail catheters with narrow lumen (7-8 Fr) inserted by direct puncture (with or without the Seldinger technique). Gammie et al. [68, 69] used an 8.3 Fr pigtail catheter in 109 partially-ventilated patients (10 trauma patients). The success rate was 86% for pleural effusions (no hemothorax) and 81% for pneumothoraces (predominantly not traumatic). Roberts reports a complication rate of 11% insufficient drainage, 2% each hemo- and pneumothoraces, 1% liver perforation and 2% kinking or compression through the chest wall. The drainage success was insufficient particularly in pneumothoraces

(25%) and hemothoraces (15%) [121]. There was a failure rate of 25% with 8-Fr catheters which were inserted using guidewire in 16 adult patients with traumatic pneumothorax [51]. Transferability to acute trauma patients remains unclear.

Other techniques have been suggested such as inserting a guidewire, subsequent dilation using a Howard Kelly clamp and then inserting the drain via the dilated passage [106].

In a small prospective randomized study, Röggla et al. [122] compared the standard pleural drain (14 Fr trocar, 13 patients) with the Tru-Close® Thoracic Vent catheter with valve and integrated collection chamber (17 patients) in spontaneous or iatrogenic pneumothorax. With a comparable success rate for re-expansion, the patients with the Thoracic Vent had less need of analgesics and could be treated more frequently as outpatients. As hemothoraces and ventilated patients were excluded, it is not possible to transfer these results to prehospital trauma patients.

At the end of the 1970s, McSwain developed a system for a prehospital chest drain (15 Fr), called the McSwain Dart® [102, 103], which most closely resembles a basket catheter, which is inserted via a puncture using a cannula. In a case series of 40 patients [141], the McSwain Dart revealed good effectiveness with 2 (5%) complications (diaphragm injury and intercostal artery lesion). The authors explained that some of the catheters were later blocked by blood and had to be replaced. The device was not considered suitable for draining a hemothorax. In a study of dogs, the McSwain Dart frequently caused injuries to the lung parenchyma if no pneumothorax was present [15].

Gill et al. [71] developed a 5 cm long, conical, expandable, puncture cannula with a 10 mm diameter, which was pushed through the pleural drain and studied in 22 patients.

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Appendix

Table 10: Complications when inserting a pleural drain

Author	N	SC	IP	IA	PE	MF	PS	Technique	Site	QF	Comments
Baldt et al. [10]	77	2.6%	6.4%	0	3.9	21%*	no data	trocar and blunt	PRE	EP	Misplacements: trocar technique 29%; blunt technique: 19%
Barton et al. [14]	207	1.2%	0	1.2%§	0	14.2%	MAL	no data	PRE	Flight nurse	
Bailey et al. [9]	57	0	0	0	1.8%	no data	MAL	blunt	ED ICU	EDP	
Bergaminelli et al. [19]	191	1.0%	0.6%	no data	2.6%	no data	no data	no data	no data	no data	
Chan et al. [34]	373	no data	no data	no data	1.1%	15%*	no data	no data	ED, OR, ward	SURG EDP	Complications: ED: 14% OP: 9% Ward: 25%
Curtin [45]	66	0	1.5%	4.5%	no data	18%*	no data	no data	ED	SURG	
Daly et al. [46]	164	0.6%	0.6%	0.6%	1.2%	no data	MAL	blunt	ED, ICU, OR	SURG	
David et al. [47]	52	4%	2%	2%	no data	no data	MAL	trocar	PRE	EP	

(continued)

Table 10: Complications when inserting a pleural drain - contd.

Author	N	SC	IP	IA	PE	MF	PS	Technique	Site	QF	Comments
Demartines et al. [53]	90	5.4%	0	0	0	18.9%*	no data	no data	PRE	EP	
Eddy et al. [59]	117	no data	no data	no data	5%	no data	no data	no data	ED	SURG	
Etoch et al. [62]	599	no data	no data	no data	1.8%	9.8%*	no data	no data	ED, ICU etc.	SURG EDP	Complications: Surgeons: 6% ED physicians 13%
Heim et al. [75]	40	0	5%	0	no data	45%*	no data	no data	PRE, ED	NA, SURG	
Helling et al. [76]	216	no data	no data	no data	3%	no data	MAL	blunt	ER, OP, ICU	no data	Complications: ED: 37% OP/ICU: 34%
Lechleutner et al. [88]	44	4.5%	4.5%	2.3%§	no data	no data	MAL	trocar	PRE	EP	
Mandal et al. [94]	5.474	no data	no data	no data	1.6%	no data	no data	no data	hospital	no data	
Millikan et al. [107]	447	no data	0.25%	0.75%	2.4%	no data	MAL	blunt	ED	SURG, EDP	
Peters et al. [117]	33	9%	21%#	3%	no data	12%*	no data	no data	PRE	EP	

(continued)

Table 10: Complications when inserting a pleural drain - contd.

Author	N	SC	IP	IA	PE	MF	PS	Technique	Site	QF	Comments
Schmidt et al. [125]	76	1.3%	0	0	0	5.2%*	MAL	blunt	PRE	NA (SURG)	
Schöchl et al. [126]	111	2.7%	1%	1%	no data	no data	MAL	trocar	PRE	EP	
Sriussadaporn et al. [129]	42	no data	no data	no data	3%	no data	no data	no data	hospital	no data	

* Additional pleural drain necessary; # possibly false CT interpretation; § in diaphragmatic rupture

SC, subcutaneous misplacement; IP, intrapulmonary misplacement; IA, intraabdominal misplacement; PE, pleural empyema; MF, malfunction; PS, puncture site; QF, qualification of medical staff; PTX, pneumothorax; HTX, hemothorax; PRE, prehospital; ED, emergency department; ICU, intensive care unit; OP, operating room; EP, emergency physician; SURG, surgeon; EDP, emergency department physicians; MAL, mid to anterior axillary line; MCL, midclavicular line

1.5 Traumatic brain injury

Interventions at the accident scene

Vital functions

Key recommendation:

The goal in adults should be arterial normotension with a systolic blood pressure not below 90 mmHg.	**GoR B**
A fall in arterial oxygen saturation below 90% should be avoided.	**GoR B**

Explanation:

Prospective randomized controlled trials, which examine the effect of hypertension and/or hypoxia on the treatment outcome, are certainly indefensible on ethical grounds. However, there are many retrospective studies [8, 25] which provide evidence of a markedly worse treatment outcome if hypotension or hypoxia is present. The absolute priority of diagnostic and treatment interventions at the accident scene is therefore to recognize and if possible immediately eliminate all conditions associated with a fall in blood pressure or reduction of oxygen saturation in the blood. Due to side effects, however, aggressive treatment to raise blood pressure and oxygen saturation has not always proved successful. The goals are normoxia, normocapnia, and normotension.

Intubation is always considered for insufficient spontaneous breathing. However, it can also be considered in cases of unconsciousness with adequate spontaneous breathing. Unfortunately, the literature does not contain any high quality evidence on this to prove a clear benefit for the intervention. The main argument in favor of intubation is the efficient prevention of hypoxia. This is a threat in unconscious persons even with sufficient spontaneous breathing as the impaired protective reflexes can cause aspiration. The main argument against intubation is the hypoxic damage that can occur through misplaced intubation. During the development of the DGNC Guideline “Traumatic brain injury in adulthood” [6], which served as a model, there was consensus that there was overall benefit, and an A recommendation was thus given in this guideline. It was not possible to reach this consensus for the current polytrauma guideline.

Interventions to ensure cardiovascular functions in multiply injured patients are described elsewhere in this guideline (see Chapter 1.3). Specific recommendations cannot be made for the infusion solution to be used in volume replacement in multiple injuries with concomitant traumatic brain injury [8].

Neurologic examination

Key recommendation:

Full consciousness, clouded consciousness or unconsciousness with pupil function and Glasgow Coma Scale must be recorded and documented at repeated intervals.	**GoR A**

Explanation:

In the literature, the only clinical findings with a prognostic informative value are the presence of wide, fixed pupils [8, 23, 26] and a deterioration in the GCS score [8, 17, 23], both of which correlate with a poor treatment outcome. There are no prospective randomized controlled trials on using the clinical findings to guide the treatment. As such studies are definitely not ethically justifiable, the importance of the clinical examination was upgraded to a Grade of Recommendation A during the development of the guideline on the assumption, which cannot be confirmed at present, that the outcome can be improved by the earliest possible detection of life-threatening conditions with corresponding therapeutic consequences.

Despite various difficulties [2], the Glasgow coma scale (GCS) has established itself internationally as the assessment of the recorded severity at a given point in time of a brain function impairment. It enables the standardized assessment of the following aspects: eye opening, verbal response and motor response. The neurologic findings documented with time of day in the file are vital for the sequence of future treatment. Frequent checks of the neurologic finding must be carried out to detect any deterioration [8, 10].

However, the use of the GCS on its own carries the risk of a diagnostic gap, particularly if only cumulative values are considered. This applies to the initial onset of apallic syndrome, which can become noticeable through spontaneous decerebrate rigidity which is not recorded on the GCS, and to concomitant injuries to the spinal cord. Motor functions of the extremities must therefore be recorded with separate lateral differentiation in arm and leg as to whether there is incomplete, complete or no paralysis. Attention should be paid here to the presence of decorticate or decerebrate rigidity. Providing no voluntary movements are possible, reaction to painful stimulus must be recorded on all extremities.

If the patient is not unconscious, then orientation, cranial nerve function, coordination, and speech function must also be recorded.

Cerebral protection treatment

Key recommendation:

Glucocorticoids must not be administered.	**GoR A**

Explanation:

According to the latest scientific knowledge, the goal of interventions to be taken at the accident scene is to achieve homeostasis (normoxia, normotension, prevention of hyperthermia) and prevention of threatening complications. The intention is to limit the extent of secondary brain damage and to provide those brain cells with functional impairment but which have not been destroyed with the best conditions for functional regeneration. This applies equally if multiple injuries are present.

Up till now, there is no evidence from the data in the scientific literature of benefit being derived from more extensive treatment regimens viewed as specifically cerebral-protective. At present, no recommendation can be given on the prehospital administration of 21-aminosteroids, calcium antagonists, glutamate receptor antagonists or tris-(tris[hydroxy methyl]aminomethane) buffer [8, 11, 18, 29].

Antiepileptic treatment prevents the incidence of epileptic seizures in the first week after trauma. However, the incidence of a seizure in the early phase does not lead to a worse clinical outcome [20, 25].

The administration of glucocorticoids is no longer indicated due to a significantly increased 14-day case fatality rate [1, 4] with no improvement in clinical outcome [5].

Treatment for suspected severely elevated intracranial pressure

Key recommendation:

If severely elevated intracranial pressure is suspected, particularly with signs of transtentorial herniation (pupil widening, decerebrate rigidity, extensor reaction to painful stimulus, progressive clouded consciousness), the following treatments can be given: ▪ **Hyperventilation** ▪ **Mannitol** ▪ **Hypertonic saline solution**	**GoR 0**

Explanation:

In cases of suspected transtentorial herniation and signs of apallic syndrome syndrome (pupil widening, decerebrate rigidity, extensor reaction to painful stimulus, progressive clouded consciousness), hyperventilation can be introduced as a treatment option in the early phase after trauma [8, 25]. The guide values are 20 breaths/min in adults. However, hyperventilation, which used to be used because of its often impressive effect in reducing intracranial pressure, also causes reduced cerebral perfusion because of the induced vasoconstriction. With aggressive hyperventilation, this involves the risk of cerebral ischemia and thus deterioration in clinical outcome [25].

The administration of mannitol can lower intracranial pressure [ICP] for a short time (up to 1 hour) [25]. It can also be given without measuring ICP if transtentorial herniation is suspected.

Up till now, there has been only scant evidence of the cerebral-protective effect of hypertonic saline solutions. Mortality appears to be somewhat less compared to mannitol. However, this conclusion is based on a small number of cases and is statistically not significant [28].

There is insufficient evidence [19] for the administration of barbiturates, which was recommended in previous guidelines for intracranial pressure crises not controllable by other means [23]. When administering barbiturates, attention must be paid to the negative inotropic effect, possible fall in blood pressure, and impaired neurologic assessment.

Transport

Key recommendation:

In the case of penetrating injuries, the penetrating object should be left in situ; in certain circumstances it must be detached.	**GoR B**

Explanation:

It is essential that multiply injured persons with symptoms of concomitant traumatic brain injury are admitted to a hospital with adequate treatment facilities. In the case of a traumatic brain injury with sustained unconsciousness (GCS ≤ 8), increasing cloudiness (deterioration in individual GCS scores), pupillary disorder, paralysis or seizures, the hospital should definitely have provision for neurosurgical management of intracranial injuries [8].

No clear recommendation can be given on analgesic sedation and relaxants for transportation as there is a lack of studies with evidence of a positive effect on traumatic brain injury. With these interventions, cardiopulmonary management is definitely easier to guarantee so that the decision on this must be left to the judgment of the treating emergency physician. The disadvantage of these interventions is a more or less severe limitation on the ability to make a neurologic assessment [23].

In the case of penetrating injuries, the penetrating object should be left in situ; in certain circumstances it must be detached. Injured intracranial vessels are often compressed by the foreign body so that removing it encourages the development of intracranial bleeding. Removal must therefore be carried out under surgical conditions with the possibility of hemostasis in the injured brain tissue. Even if there are no prospective randomized controlled trials on the optimum procedure for penetrating injuries, this procedure makes sense from a pathophysiologic viewpoint.

The possibility of a concomitant unstable spine fracture should be considered during transportation, and the patient should be appropriately positioned (see Chapter 1.6).

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1.6 Spine

When should a spinal injury be assumed?

What diagnostic procedures are required?

Key recommendation:

A thorough physical examination including the spine and the functions associated with it must be carried out.	**GoR A**

Explanation:

A physical examination of the patient is the basic requirement for making a diagnosis which, in turn, is the prerequisite for subsequent treatment interventions.

After the vital functions have been monitored and secured, the initial examination of a responsive patient's spine in the emergency situation at the accident scene involves the exploratory neurologic assessment of sensitivity and motor functions. A segmental neurologic deficit indicates the presence of a spinal cord injury. The level and complete/incomplete lesions can be measured to a limited extent. An absence of back pain is not a definite sign that there can be no relevant injury to the thoracic or lumbar spine [28].

To complete the initial examination, the cervical spine and the entire back are inspected (for signs of injury, deformities) and felt (tenderness, percussion tenderness, steps, displacements, palpable gaps between spinous processes).

Assessing the mechanism of injury can provide clues on the probability of a spinal injury [20].

Even if there are no scientific studies on the importance and the necessary scope of the physical examination in the prehospital emergency examination, it is still an indispensable requirement for detecting symptoms and making (suspected) diagnoses. All the above-mentioned examinations are used to detect relevant, threatening or potentially threatening disorders and injuries, which altogether can make it necessary to administer immediate and specific treatment or make a logistic decision on the spot [2, 17].

The circulation parameters, blood pressure and pulse, should be measured more than once at least during the course (depending on finding, overall situation and timeframe). These are dynamic values, which are indicators for the occurrence of neurogenic shock.

Various scoring systems do not permit a clear statement but combining several scores increases the probability of success [63].

Which concomitant injuries make the presence of spinal injury likely?

Key recommendation:

The presence of a spinal injury must be assumed in unconscious patients until evidence to the contrary is found.	**GoR A**

Explanation:

The coincidence of spinal injuries and certain other injury patterns is increased. These are purely statistical probabilities.

How is the diagnosis for unstable spinal injury made and how definite is it?

Key recommendation:

If the following 5 criteria are absent, it can be assumed that no unstable spinal injury is present: ▪ **impaired consciousness** ▪ **neurologic deficit** ▪ **spinal pain or myogelosis** ▪ **intoxication** ▪ **trauma in the extremities**	**GoR A**

Explanation:

Several groups have developed clinical decision rules to simplify prehospital patient transportation and to set sensible limits to the radiologic primary diagnostic study after blunt trauma to the spine. Some of these decision rules relate to the prehospital situation [23, 24, 45] whereas others relate to the emergency department [9, 33, 35, 36, 56]. Whereas some studies examine the whole spine, others limit themselves to the cervical (C) or thoracic/lumbar spine (T/L).

The results of these studies correspond [9] to the maximum extent so that we can primarily rely hereinafter on the prospectively validated criteria of Domeier et al. and Muhr et al. [24, 25]. Smaller studies have concentrated solely on multiply injured patients [53] but find similar predictors so that it appears justified to generalize the results. On other hand, Muhr et al. and Holmes et al. regarded the presence of other relevant injuries as a criterion that made the definite exclusion of a spinal injury more difficult or impossible. A retrospective study of patients with thoracolumbar spinal injuries found that the presence of concomitant injuries lowered the frequency of (pressure) pain in the back from over 90% to 64% [43]. However, one can assume from this that multiply injured patients have either an extremity fracture or impaired consciousness so that, depending on the decision rules, a suspected spinal injury cannot be ruled out.

Taking into consideration the 5 criteria of impaired consciousness, neurologic deficit, spinal pain or myogelosis, intoxication, and trauma in the extremities, Domeier et al. missed only 2 relevant spinal injuries [24]. In addition, there were 13 stable spinal injuries that did not require osteosynthesis thus yielding a sensitivity of 95% with a negative predictor value of 99.5%. The study related to the whole spine and found approximately 100 fractures each in the cervical, thoracic, and lumbar spine.

Rotation injuries (type C according to AO) are relatively unstable and have an increased risk of further neurologic deterioration [32]. If a rotation injury is suspected on the basis of the mechanism of injury, immobilization should be carried out carefully and without delay on account of the instability.

How is the diagnosis for spinal injury without spinal cord involvement made and how definite is it?

Key recommendation:

Acute pain in the spinal region after trauma should be assessed as an indication of a spinal injury.	**GoR B**

Explanation:

The cited injury signs may be present both in a bony spinal injury and in a solely soft tissue injury surrounding the bone. There are no prehospital findings that can be collected which can prove or exclude a spinal injury with certainty. External injury signs - deformations, tenderness, percussion tenderness, steps, lateral displacements, palpable gaps between spinous processes - are indirect clues to the presence of an injury to the spine. An evaluation of the (positioning) stability of the injury cannot be made in the prehospital phase.

How is the diagnosis for spinal injury with spinal cord involvement made and how definite is it?

Explanation:

The neurologic deficit in sensitivity and/or motor functions is definitive in the diagnosis of damage to the spinal cord. It is highly probable that a bony injury to the spine is also present in adults. Neurologic deficits without bony involvement can occur more frequently in children (SCIWORA [Spinal Cord Injury Without Radiographic Abnormality] syndrome) [7].

The level and complete/incomplete lesions can only be measured to a limited extent. It is therefore not possible to make a conclusive statement on the prognosis of the injury at the accident scene.

On the other hand, a normal neurology finding does not exclude a spinal injury with spinal cord involvement.

How is a spinal injury treated in the prehospital phase?

What is the technical rescue procedure for a person with a spinal injury?

Key recommendations:

In the event of acute threat to life (e.g., fire/danger of explosion), which can only be eliminated by immediate rescue from the danger zone, immediate, direct rescue from the danger zone must be effected even if a spinal injury is suspected, if necessary even disregarding precautionary measures for the injured person.	**GoR A**
The cervical spine must be immobilized before technical rescue.	**GoR A**

Explanation:

The first prehospital procedure for a casualty is to immobilize the cervical spine using a cervical collar. To date, however, we are not aware of any literature that confirms this procedure in preventing secondary damage during the technical rescue. No differences in the use of different immobilization collars have been found [18, 51].

During the rescue of an injured person, all non-physiologic spine movements, particularly flexion, segmental rotation and lateral inclination, must be avoided. The spine must be moved into its neutral position, i.e. flat supine position, in a coordinated way with enough assistants [6]. With due consideration of the time required, a more extended technical rescue - e.g., involving removal of a car roof - should be considered. Aids such as the scoop stretcher or spine boards make it easier to rescue a person with a spinal injury in the above-mentioned neutral position from a difficult accident scene.

How is a person with a spinal injury positioned/immobilized?

Explanation:

Up till now, the first prehospital procedure for a casualty is the immobilization of the cervical spine using a cervical collar, even if the evidence level for this is not high. The cervical spine is thereby put into the neutral position. If this causes pain or an increase in neurologic deficit, do not reposition in the neutral position.

In a prospective study, Bandiera and Stiell found evidence that clinically significant injuries could be detected with a sensitivity of 100% using the Canadian C-spine rule [56]. However, a proviso should be added here that this study was conducted in hospital on fully conscious patients [5]. Thus, a relatively long period of time has already elapsed since the accident and, at this later point in time, the symptoms of milder acceleration injuries to the cervical spine also manifest themselves for the first time; these may not occur at the accident scene due to the psychologic impairment.

When there is a traumatic brain injury and a suspected cervical spine injury, it should be weighed up whether to fit a rigid cervical collar or whether another type of immobilization (e.g., only a vacuum mattress) is possible in order to prevent a potential increase in ICP [21, 22, 37, 38, 39, 50]. In another clinical study, there was no evidence of an increase in ICP if the rigid cervical collar was fitted correctly [39]. So, when a rigid cervical collar is being fitted on a patient with a TBI, care should be taken that it is the correct size and not too tightly fastened so that the possibility of any venous outflow obstruction is excluded. In addition, the upper part of the body should be elevated if possible in this situation.

The above-mentioned position can also be immobilized on the vacuum mattress. This achieves the currently most effective immobilization of the whole spine as well. If the head is also enclosed with high cushions or belts, this further restricts possible residual movement of the cervical spine. To date, there is no randomized study that provides evidence of a positive effect from immobilizing the spine [40].

A patient carry sheet on the vacuum mattress makes subsequent re-positioning in hospital easier [8]. Other aids such as the scoop stretcher or spine boards can only immobilize the spine to a limited extent.

How is a person with a spinal injury transported?

Key recommendation:

Transport should be as gentle as possible and free of pain.	**GoR B**

Explanation:

A patient with a spinal injury should be transported as gently as possible, i.e. without further external force to avoid pain and possible secondary damage. After positioning and strapping in, analgesics are administered during transportation. A helicopter offers the smoothest form of transport. In addition, it might offer a time advantage when a patient with a spinal injury and neurologic deficits has to be transported to a center.

Is there a specific treatment for spinal injury in the prehospital phase?

Explanation:

The benefit of a high dose of cortisone treatment being administered prehospital (or subsequently) for spinal injuries with neurologic deficit is controversial [65]. Following the successful administration of corticosteroids for spinal trauma in many animal experiments [1, 25, 26, 58, 59, 66], it has not been possible to confirm the results in all clinical studies. Criticism has been leveled at the NASCIS (National Acute Spinal Cord Injury Studies) several times [19], for instance, the lack of effect in the NASCIS I study (there was no control group here but low-dose cortisone was compared with too little high-dose cortisone) and the lack of placebo group in the NASCIS III study as well [19]. The positive effects in the NASCIS II study were only minor, of limited clinical relevance, and less marked after 1 year than after 6 months.

Here is a summary of the advantages and disadvantages of giving methylprednisolone according to current literature:

Reasons for cortisone treatment:

1. The NASCIS II study showed an improvement in motor outcome providing methyl prednisolone treatment was started within 8 hours [11, 12]. However, this outcome was only unilaterally verified and dependent on the researcher.
2. Other studies of worse methodological quality have also found a benefit from cortisone treatment but in this case the start of treatment was predominantly evaluated after admission to hospital.
3. The NASCIS III study showed a greater effect in treatment duration of 48 hours providing treatment commenced between 3 and 8 hours after trauma [14, 15].
4. Relevant side effects such as abdominal bleeding are not increased [27] and there has been no evidence of accumulation of femoral head necroses following high-dose cortisone treatment [64].

5. There is no other definitive pharmacologic treatment for spinal cord injury.

Reasons against cortisone treatment:

1. No relevant benefit could be found in the NASCIS I study [13].
2. The proven benefit was only found in patients who had received treatment within 8 hours.
3. The proven benefit was small, of unconfirmed clinical significance, and even smaller after 1 year than after 6 months [10, 12].
4. There was no placebo control group in the NASCIS III study [14, 15].
5. Further studies showed a higher complication rate in the patients treated with cortisone (increase in lung complications [29, 31], particularly in elderly patients [42], and gastrointestinal bleeding [48]).
6. Lack of neurologic benefit in other studies with frequently unclear injury pattern [30, 42, 48, 49].

Infusion treatment to stabilize the circulation is necessary in neurogenic shock with due consideration being paid to other possible sources of bleeding caused by injury. The infusion volume to be administered and the target mean arterial pressure is also disputed by expert opinion. Adequate analgesic treatment is necessary to prevent shock.

Extreme pulling forces on the cervical spine, e.g., when removing a motorbike helmet, and segmental torsions on unstable C injuries (cervical vertebrae) of the spine can lead to deterioriation in the neurologic deficit by directly affecting the spinal cord. It should be noted here that there are no references to secondary damage in the literature on this either.

Are there advantages for the patient with spinal injury in being transported primarily to a trauma center with a spine surgery facility?

Key recommendation:

Patients with neurologic deficits and suspected spinal injury should be transported primarily and as a minimum to a regional trauma center with a spine surgery facility.	**GoR B**

Explanation:

Early surgery on spinal injuries with spinal cord involvement can improve the neurologic outcome [44, 52].

Early surgery (within 72 hours) on cervical spine injuries with neurologic deficits does not conceal an increased risk of additional complications [44].

For this reason, particularly in the case of isolated spinal trauma and a non-acute threat to life, management should, if possible, be in a spinal center [60]. Patients with a spinal canal constriction, particularly in the cervical region, appear to gain from early surgery [4]. Even if there is only little evidence, it should still be assumed that patients with incomplete neurology and partial displacement of the spinal canal could gain from early reduction and, if necessary, surgical debridement.

Summary:

The vast majority of the screened literature relates mainly to the hospital situation, in other words, to studies which were conducted after admission to hospital. Provided they are relevant, these data must be extrapolated to the prehospital situation. There is a relatively large number of studies which were conducted in the USA and thus in the paramedic system. This initial management at the accident scene is only partially comparable with the German rescue and emergency physician system.

These two points must be taken into account as this means that conclusions (in terms of a guideline) have only restricted validity on applicability to the prehospital emergency physician situation in Germany.

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1.7 Extremities

Priority

Key recommendations:

Heavily bleeding extremity injuries, which can impair the vital function, must be given first priority.	**GoR A**
The management of extremity injuries must avoid further damage and not delay the total rescue time if there are additional threatening injuries present.	**GoR A**

Explanation:

Securing the vital functions and examining the head and trunk should precede the examination of the extremities. Specifics can occur in extremity injuries with severe blood loss [21, 27].

Severe and immediate life-threatening bleeding must be treated immediately even ignoring the ABCDE protocol (see page 133).

Confirmation of more major, external bleeding which is not directly life-threatening is important and is usually carried out under “C” (circulation) whereas more minor bleeding comes under the “secondary survey” [21].

The first rule is to avoid further damage, restore and maintain vital functions and transport to a suitable hospital [11, 25].

The management of extremity injuries (irrigation/wound management/splinting) should not delay the rescue time if there are additional threatening injuries present [23].

Diagnostic study

Medical history

A very detailed medical history (firsthand/third party) of the circumstances of the accident can be gathered to obtain sufficient information on the impacting force and, if applicable, the degree of contamination of open wounds [2, 27].

If possible, information (allergies, medication, previous diseases and fasting state) should be collected in addition to the accident history and the time of the accident. In addition, details of tetanus immunization status should be obtained [21, 34].

Examination

Key recommendation:

All extremities of a casualty should undergo an exploratory assessment in the prehospital phase.	**GoR B**

Explanation:

Alert patients should be asked first whether they have any pain and where it is. If there is pain, adequate analgesics can be administered early on [21]. A prehospital examination should be carried out [11]. The examination at the accident scene should assess to an appropriate extent the severity of the injury without delaying the total rescue time too much [2]. The examination should be an exploratory survey from head to toe and not last longer than 5 minutes [34].

The examination should be carried in the following order: inspection (malposition/wounds/swelling/circulation), stability test (crepitation, abnormal mobility, stable and unstable fracture signs), assessment of circulation, motor functions and sensitivity. Soft tissue findings should also be assessed (closed versus open fracture, compartment syndrome) [11, 21, 27].

Leather clothing such as motorbike apparel, for example, should be left on if possible as this serves as a splint with compression effect particularly for the pelvis and the lower extremity [14, 21].

Capillary reperfusion can be tested by comparing with the uninjured limb [21].

Treatment

General

Key recommendation:

Even if an extremity injury is only suspected, it should be immobilized against rough movement and before transporting the patient.	**GoR B**

Explanation:

Immobilizing an injured extremity is an important procedure in prehospital management. An extremity injury should be immobilized against rough movement and before transporting the patient. Reasons for this are to alleviate pain, prevent further soft tissue damage/bleeding and reduce the risk of a fat embolism and neurologic damage [21, 34].

Even a suspected injury should be immobilized [10, 34].

The joints proximal and distal to the injury should be included in the immobilization [10, 11, 24, 34]. The injured extremity should be supported flat [4]. Particularly in shortened femoral fractures, traction/immobilization under traction should be carried out to minimize bleeding [2, 21]. Vacuum splints are suitable for immobilizing an abnormal position. Vacuum splints are rigid and can adapt to the shape of the extremity [21]. Air chamber splints are suitable for splinting upper extremity injuries with the exclusion of injuries in the proximity of the shoulder joint. In the lower extremity, they are suitable for immobilizing knee, lower leg, and foot injuries. On their attachment, the pressure in the air chamber splints and the peripheral blood supply must be regularly checked [4]. The advantage of the air chamber splint is its low weight; the disadvantage is the compression of soft tissue which can cause secondary damage. Vacuum splints are therefore preferred. Air chamber and vacuum splints are unsuitable for immobilizing femoral fractures and those in the proximity of the shoulder joint [5]. Cooling can reduce swellings and help to alleviate pain [10]. Femur injuries can be adequately immobilized without complications with a spine board or rigid splinting. It is not absolutely necessary for traction splints to be carried in the emergency medical service.

In a retrospective study with 4,513 callouts made by emergency paramedics in an American emergency medical system (EMS), 16 patients (0.35%) with injuries to the mid-femur were singled out. While 11 of these patients had only minor injuries, 5 of these patients (0.11% of all patients) were treated under a femoral fracture diagnosis. Three of these 5 patients received a traction splint. In one of the cases, the traction splint had to be removed again due to severe pain and a rigid immobilization device was attached. One patient could not have a traction splint because of simultaneous hip trauma. Another patient who was free of pain was transported in a comfortable position. The authors conclude that femur injuries and/or a suspected fracture are rare and can be well managed with a backboard or rigid immobilization. For this reason, it is not absolutely necessary for traction splints to be carried in the emergency medical service [1]. Traction splints should not be used particularly on multiply injured patients as there are many contraindications for their use in these patients (pelvic fracture/knee/lower leg/ankle joint injury) [33]. They are only rarely used due to the existing contraindications on the use of a traction splint, particularly in critically injured patients. Dislocated proximal femoral fractures are also contraindications for the use of a traction splint [7].

Traction splints are useful and, depending on the model, easy to use for immobilizing femoral fractures, even dislocated proximal femoral fractures. Further studies are necessary [8]. Traction splints reduce muscle spasms and thus alleviate pain. Traction helps to restore the femur shape and by reducing volume leads to a decrease in bleeding [8, 30, 31]. Oxygen can be given via a non-rebreather mask (15 l/min) [2, 21]. Jewelry (rings/chains) must be removed from the injured extremity [2, 10].

Photos of wounds/open fractures can be taken for documentation (polaroid/digital). Photographic documentation of wounds, open fractures or discovered malpositions appears expedient as it can, under circumstances, avoid immobilized extremities or wounds already dressed in the prehospital phase from being exposed again in the hospital until they are definitively treated. Photographic documentation can assist the subsequent treating physician in assessing the injury. Photographic documentation must not extend the management/rescue time [2, 21].

The severity and extent of the injuries must be documented in the emergency physician logbook and the local finding must be described to the subsequent treating surgeon, if possible in person [3].

Fractures

Key recommendation:

If possible, and particularly with concomitant ischemia in the extremity concerned/with a long rescue time, grossly dislocated fractures and dislocations should be approximately reduced in the prehospital phase.	**GoR B**

Explanation:

The primary goal is to secure the local and peripheral blood supply. The primary goal is not an exact anatomic reduction. What is more important is correct axial positioning and the restoration of an adequate local and peripheral blood supply [3, 5]. If the neurovascular supply to the extremity distal to the injury is not compromised, reduction can be ignored in principle [2]. If possible, and particularly with concomitant ischemia in the extremity concerned/with a long rescue time, grossly dislocated fractures and dislocations should be reduced in the prehospital phase by axial traction and manual correction into the neutral position or into a position that is nearest to the neutral position. It is important to check the peripheral blood supply and motor functions and sensitivity (where possible) before and after reduction [3, 4, 5, 11, 21, 25]. Too much longitudinal traction must be avoided as this increases compartmental pressure and worsens the blood supply in the soft tissue [3, 5].

A neurologic or vascular deficit distal to the fracture requires an immediate reduction attempt. The same applies if the soft tissue sheath/skin is compromised [21]. After successful immobilization, circulation, sensitivity, and peripheral motor functions should be checked again [2, 21]. If neurovascular circulation deteriorates after a reduction attempt, the extremity must be immediately placed back in the initial position and stabilized as well as possible [21].

Reduction of ankle fractures/ankle dislocation fractures should only be carried out by those experienced in this procedure. Otherwise, the goal is immobilization in the position found [21]. In the case of commonly dislocated ankle joint fractures with obvious malposition, reduction can be carried out at the accident scene. With adequate analgesia, an approximately correct axial position can be achieved by controlled, continuous longitudinal traction with both hands on the calcaneus and heel of the foot; this position can then be immobilized. After this, the blood supply and neurologic situation should be recorded again.

Obvious long bone fractures in the shaft area should also be treated in this way. Fractures in proximity to joints are difficult to assess in their extent and, after being immobilized in the pain-free position found, can be transferred as rapidly as possible for further hospital diagnosis [2, 34].

Stronger longitudinal traction should be avoided in distal femoral fractures as this can compromise the popliteal vessels. The knee joint can be supported in a slightly bent position (30-50 degrees) [4].

Open fractures

Key recommendation:

Each open fracture should be cleaned of coarse contamination and covered with a sterile dressing.	**GoR B**

Explanation:

Each open fracture should be identified and coarse contamination immediately removed [21]. Open fractures should be irrigated with physiologic saline solution [2, 21, 23, 26]. All open wounds should be covered with a sterile dressing [3, 4, 11, 21, 26, 34]. Without further cleansing or disinfection measures, open wounds must be covered with a large sterile dressing. Coarse contamination is removed [3, 4, 5]. Thereafter, they should be immobilized as for closed injuries [26, 34]. It is best if the dressings are not removed until in the operating room [21, 26].

Antibiosis should be carried out at the earliest possible time. The risk of infection increases dramatically after 5 hours [26]. If available, intravenous antibiosis can be administered in the prehospital phase, usually with a 2nd generation cephalosporin which is easily distributed in the bone [4]. Prehospital antibiosis should be carried out if the rescue time is extended [23].

Key recommendations:

Active bleeding should be treated according to the following stepwise approach: ▪ **manual pressure/pressure dressing** ▪ **(elevation)** ▪ **tourniquet**	**GoR B**
Indications for immediate use of a tourniquet/arrest of blood supply can be: ▪ **life-threatening bleeding/multiple sources of bleeding in an extremity** ▪ **inability to reach the actual injury** ▪ **several injured persons with bleeding**	**GoR 0**

Explanation:

The measures for arresting bleeding should follow a stepwise approach. A primary attempt should be made to arrest active bleeding by manual pressure and elevation of the extremity. Then a pressure dressing should be applied. If this is not adequate, a second pressure dressing should be applied over the first one. A sterile pad can be used to help to focus pressure. If bleeding persists, pressure should be applied to an artery proximal to the injury. In addition, if possible, a tourniquet should be applied. As an exception, the vessel can be clamped (amputation, longer transportation time, neck vessel, anatomic position makes the use of a tourniquet impossible) [3, 4, 11, 21, 32].

In regions where tourniquets cannot be applied (proximal extremities), hemostatic dressings can be used [13]. Applying a tourniquet requires appropriate analgesia [21]. A blood pressure cuff with 250 mmHg can be applied to the upper arm and one with 400 mmHg to the femur [3, 5]. The time at which the tourniquet was applied should be noted [21, 22, 28]. The tourniquet must interrupt the arterial blood flow completely. An incorrectly applied tourniquet can intensify bleeding (only compromises low pressure system) [22]. Effectiveness is monitored by an arrest in bleeding rather than the disappearance of the distal pulse. In the case of a fracture, bleeding can also come from the bone marrow [22].

Indications for immediate use of a tourniquet can be [22]:

- Extreme bleeding/multiple sources of bleeding in an extremity necessitating parallel securing of vital functions
- Inability to reach the actual injury (e.g., trapped person)
- Mass casualty incident

The following points should be borne in mind when applying a tourniquet:

- Apply as far distally as possible, approx. 5 cm proximal to the injury
- Apply directly on the skin to prevent it slipping [22, 28].

If ineffective, re-apply with more pressure and only after that consider applying a second tourniquet directly proximal to the first [22]. Cooling an extremity that has a tourniquet applied can increase ischemic tolerance during long rescue times [15].

There is only insufficient data on the safe application time for a tourniquet. The general recommendation is 2 hours but this has emerged from data obtained from normovolemic patients with a pneumatic tourniquet [22]. If the transportation time until surgery is less than 1 hour, the tourniquet can remain in situ. For longer rescue times (> 1 hour), attempts should be made to release the tourniquet in a stabilized patient. If bleeding should start again, the newly applied tourniquet should then remain in situ until it is managed in the operating room [22]. After 30 minutes, the tourniquet should be checked to see if it is still necessary. This is not indicated if the patient is in shock or the attendant circumstances (personnel) are adverse [12].

In a retrospective case series on war injured from the database of the British military, tourniquets were applied to 70 patients out of 1,375 patients who had been treated during the period in English field hospitals (5.1%). A total of 107 tourniquets were applied (17 of the treated [24%] had 2 or more tourniquets applied). Of this number, 5 had a double tourniquet applied for the same injury and 12 of the injured had bilateral tourniquets (maximum number per injured 4 - 2 each on both lower extremities). A hundred and six tourniquets were applied prior to arrival at the field hospital. Sixty-one of these 70 patients (87.1%) survived. Mean value of the survivors: ISS = 16, mean value of fatalities (only 6 could be autopsied): ISS = 50.

Whereas prior to the introduction of tourniquets as standard (February 2003 to April 2006) only 9% (6 injured persons) were treated with a tourniquet, following introduction (April 2006 through February 2007) it was 64 (91%). Without details of the total number of injured persons during this period, the authors indicate a 20-fold increase in the use of tourniquets. Three complications directly caused by the tourniquets were observed. There were 2 cases of compartment syndromes (one each in the femur and lower leg, one of which was due to incorrect application of the tourniquet) and one case of damage to the ulnar nerve (with no further details on the course). The use of tourniquets was assessed as life-saving in 4 cases of patients with isolated extremity injuries, hypovolemic shock and massive transfusion (and factor VIIa administration) [9].

In a retrospective study of 165 patients (inclusion criteria: traumatic amputation or severe vessel injury in extremities), Beekley et al. showed that the prehospital use of tourniquets led to improved control of bleeding; this relates particularly to multiply injured patients (ISS > 15). Forty percent of soldiers (n = 67) had a tourniquet. Reduced mortality could not be observed. The average tourniquet time was 70 minutes (min.: 5 minutes; max.: 210 minutes); damage due to use was not observed [6].

In a prospective cohort study of 232 patients who had 428 tourniquets applied, Kragh et al. showed that there was no link between tourniquet time (average 1.3 hours) and morbidity (thromboses, number of fasciotomies, pareses, amputations). With tourniquet times over 2 hours, there is a trend towards increased morbidity with respect to amputations and fasciotomies.

The tourniquet should be applied as early as possible. If a tourniquet does not lead to the disappearance of the distal pulse, a second should be applied directly proximal to the first one to increase effectiveness. There should be no materials underneath the tourniquet as they can lead to the tourniquet loosening. Tourniquets should be applied directly proximal to the wound. The effectiveness of tourniquets should be re-evaluated during the course [17]. The use of tourniquets is linked to a higher survival probability. The use of tourniquets before the occurrence of shock is linked to a higher survival probability, likewise when it is applied in the prehospital phase. No amputation has been require as a result of the use of a tourniquet.

In a study of the US army in Baghdad with 2,838 injured persons with severe extremity injury, 232 (8.2%) of those treated had 428 tourniquets applied (to 309 injured extremities). Of these, 13% died. In a matched pair analysis (Abbreviated Injury Scale [AIS], Injury Severity Score [ISS], all male, age) of 13 injured persons with tourniquet applied (survival rate 77% [10 out of 13]) and 5 (more were not identified in the time span) without tourniquet (but where there was an indication for tourniquet use and who all died in the prehospital phase [usually only 10-15 minutes!]), it was shown that early use of tourniquets significantly increased the survival probability in severe extremity injuries ($p < 0007$). Ten of the injured only received the tourniquet in a manifest state of shock, and 9 (90%) died. Two hundred and twenty-two received the tourniquet before the onset of shock and only 22 died (10%, $p < 0001$). Twenty-two of the 194 patients who already received the tourniquet in the prehospital phase (11%) and 9 of the 38 (24%) who only received the tourniquet in the hospital’s emergency department died ($p = 0.05$). Ten cases of transient nerve paralysis occurred without any correlation to the length of time the tourniquet was applied [18].

The use of tourniquets is an effective, simple (for medical and non-medical personnel) method to prevent exsanguination in the military prehospital setting [20]. The use of tourniquets is a safe, rapid and effective method to control bleeding from an open extremity injury and should be used routinely and not only as a last resort (civil study) [16]. Tourniquets can contribute towards a reduction in mortality of those injured in battle and show only low complication rates (nerve paralysis, compartment syndrome). The loss of an extremity due to the use of a tourniquet is a rarity [13].

Amputations

Key recommendation:

The amputated part should be cleaned of coarse contamination and wrapped in sterile, damp compresses. It should be indirectly chilled while being transported.	**GoR B**

Explanation:

In addition to arresting bleeding, the amputation stump should be splinted and a sterile dressing applied. Only coarse contamination should be removed [3, 4]. The amputated part must be preserved. Bony parts or amputated digits should be taken from the accident scene or, if necessary, brought on afterwards.

Wrap the amputated part in sterile, damp compresses and transport chilled, if possible packed using the “double bag method”. Here, the amputated part is packed in an inner plastic bag with sterile, damp compresses. This bag is placed in a bag with iced water (1/3 ice cubes, 2/3 water) and sealed. This avoids secondary cold damage (no direct contact between ice or cool pack and the tissue) [2–4, 19].

Amputations influence the choice of designated hospital and advance warning should be given [2, 3].

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1.8 Genitourinary tract

Key recommendation:

In the case of a suspected urethral injury, prehospital bladder catheterization should not be carried out.	**GoR B**

Explanation:

Genitourinary tract injuries can occur in approximately 5-10% of cases of multiply injured persons and are thus relatively frequent. In numbers, kidney injuries are at the forefront, followed by bladder and urethra. In contrast, about half of all urologic trauma are associated with further injuries consistent with multiple injuries [1, 7]. Relatively severe and combined genitourinary injuries typically occur only with multiple injuries [4, 7]. Due to their relative frequency and clinical importance, recommendations shall be given below for injuries to the kidney, ureters, bladder, and urethra. In contrast, injuries to the external genital organs are not discussed as they are relatively rare and are usually treated in a similar way in polytrauma as in monotrauma.

In contrast to other injuries, injuries to the ureter, bladder, and urethra do not represent a direct threat to life (evidence level [EL] 4 [2]). Although kidney ruptures are potentially life-threatening, they cannot be treated in the prehospital phase. Accordingly, there are scarcely any specific prehospital procedures for diagnosis and treatment of urological injuries. A diagnosis time advantage is assumed only for the transurethral catheterization of the bladder because the presence and severity grade of hematuria can be important both in the choice of designated hospital and for its management upon arrival in hospital. As time losses represent a relevant risk *quoad vitam* to multiply injured patients particularly in prehospital care, prehospital catheterization may be advantageous if longer rescue/transport times are predicted providing it in turn does not lead to delays. Internationally, the transurethral bladder catheter is a quite common procedure in the prehospital treatment of multiply injured patients.

There is a slight risk that an additional injury is caused through bladder catheterization (EL 4 [3]) by turning an incomplete urethral rupture into a complete rupture. In addition, the transurethral catheter can cause a *via falsa* in a complete urethral rupture (EL 5 [5, 6]). Based on these considerations, it seems advisable to dispense with transurethral catheterization in patients with clinical signs of a urethral injury until the diagnostic study has been completed. Hematuria and/or blood leakage from the meatus urethra are the main clinical criteria for a urethral injury. In addition, dysuria, suspected pelvic fracture, local hematoma development, and the general mechanism of injury can provide diagnostic clues.

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1.9 Transport and designated hospital

Key recommendation:

Primary air rescue can be used for the prehospital management of severely injured persons as it can result in a survival advantage particularly for medium to high injury severity.	**GoR 0**

Explanation:

For years, air rescue has been a permanent component in the care provided by the emergency services not only in Germany but also internationally. In most European countries, a comprehensive network of air rescue bases has been built up over recent decades covering the primary and secondary management sectors. Numerous studies to date have tried to prove the effectiveness of air rescue. Thus, a possibly shorter prehospital period (time of accident until hospital admission) and more aggressive prehospital treatment have been referred to as potential grounds for an improved outcome in multiply injured patients. For a long time, however, it remained controversial whether the use of air rescue actually led to a reduction in mortality. A lack of medical effectiveness together with high contingency costs has thus put a question mark over air rescue for primary use.

The necessity of the partly enormous logistic contingency costs in trauma centers has also come under question. In addition to expensive technology, staff resources in particular have been held in readiness, necessary for the optimum logistic management of multiply injured patients. Up till now, there has also been a lack of justifiable study conclusions on the rationale of high contingency costs.

The results of the prehospital management of multiply injured patients by air rescue were compared in 19 studies (evidence Level 2b [2–6, 8, 11, 14, 16, 17, 18, 20, 21, 28, 29, 32] with those of land-based rescue. The case fatality rate was the primary endpoint here in all cases. Nine studies were designed as prospective, 8 studies as retrospective, and 6 studies were multicenter. In 16 studies, the primary designated hospital was exclusively a Level 1 trauma center [1], and in one study [20] Level 2/3 hospitals were also involved.

Case fatality rate

In 11 studies there was evidence of a statistically significant reduction in case fatality rate (between -8.2 and -52%) through the use of air rescue. Six studies show no advantage in outcome for patients transported by air rescue but reveal the following abnormalities:

Phillips et al. 1999 [21]: With identical case fatality rates in both patient groups, the injury severity of the rescue helicopter (RTH) group was increased highly significantly ($p < 0001$); an adjusted case fatality rate comparison was not carried out. Schiller et al. 1988 [28]: The patients in the rescue helicopter group had both a significantly increased case fatality rate and a significantly higher injury severity; an adjusted case fatality rate comparison was not carried out. Nicholl et al. 1995 [20]: The patients in both treatment groups were also treated in Level 2 and 3 hospitals as well as trauma centers. Cunningham et al. 1997 [11]: Patients in the rescue helicopter group with mean injury severity (ISS = 21–30) had a significantly reduced case fatality rate; but this result was not confirmed in the logistic regression. Bartolomeo et al. 2001 [12]: Only patients with severe head injuries (AIS ≥ 4) were studied. The land-based emergency physician team also carried out invasive prehospital treatment interventions comparatively frequently so that the "gap" between their treatment level and that of the rescue helicopter group was only very slight. In Biewener et al. (2004) [5]: In their own paper it is also noticeable that a comparatively high level of invasive prehospital treatment is carried out by the land-based emergency physician team.

Comparability and transferability of study results

As a result of very different country-specific emergency service structures, the comparability of the studies must be questioned. For instance, a rescue system based on paramedics is found particularly in the North American region, whose structure cannot be compared with the German rescue service. The studies also differ noticeably in the injury pattern. For instance, blunt injuries in particular are predominant in European countries whereas penetrating trauma are predominant in North America. The studies also differ enormously in the transport distances to be covered and the aggressiveness of the prehospital management. The majority of the studies (11/17) show a statistically significant reduction in case fatality rate of multiply injured patients - particularly with average injury severity - through the use of air rescue. The 6 studies without evidence of a direct treatment advantage nevertheless reveal a trend towards better results with helicopter patients through increased injury severity with identical case fatality rate.

Furthermore, all studies show a marked extension to the prehospital period. This is firstly because of a partly markedly longer transport distance, and secondly because of a markedly more aggressive prehospital management strategy. However, further evidence on the effectiveness of aggressive prehospital treatment is incomplete.

In summary, these papers show a trend towards a fall in the case fatality rate of multiply injured patients through the use of air rescue compared with the land-based emergency service. This is particularly relevant to patients with average injury severity whose survival is particularly strongly dependent on treatment effects. The reasons are considered to be a better clinical diagnostic study and treatment due to the rescue helicopter team's training and experience advantages. This conclusion is limited in its general validity and transferability by the listed systematic error sources of the cited papers and by the heterogeneity of the regional emergency service and hospital structures and of the types of injury.

Comparison of trauma center versus hospital level II and III

The importance of the duration of prehospital management of multiply injured patients has been proven in numerous studies and the term "golden hour" has been coined. The goal must be to transport the patient to a hospital which has at its disposal a 24-hour acute diagnostic and acute treatment unit in terms of prompt availability of all medical and surgical disciplines and the provision of corresponding capacities for acute treatment. Furthermore, it was shown that hospitals with a high footfall of critically injured patients had a clearly better outcome than facilities with markedly less annual revenue.

Key recommendation:

Severely injured patients should be primarily transferred to a trauma center.	**GoR B**

Explanation:

Hospital level:

In the analysis of the studies, the term hospital levels 1-3 and partly also 1-4 are used. In this context, a Level 1 hospital equates to a maximum care hospital, which normally represents a trauma center, a term which does not have an internationally consistent definition.

A care Level 2 hospital equates to a specialist hospital, and a care level 3 hospital equates to a basic, general hospital.

Through the development of DGU trauma networks, 3 new categories of trauma care have been defined [24, 31]: “transboundary trauma center”, “regional trauma center”, and “basic care facilities”.

Each care level is clearly defined using a certification procedure and is obliged to maintain the required performance. In addition to the previous structures, these facilities are linked to each other via “network development”. This enables shared resources and integrated patient care. Based on those trauma networks which are being developed and the corresponding lack of studies, the existing hospital grades (Level 1-3) have to be used to define the designated hospital recommendations. However, it might be possible to assume from an interlinking of various care centers that even the care quality of regional trauma centers legitimizes polytrauma care.

The German Trauma Society (DGU) has developed the White Paper in association with the development of the trauma network [31]. It summarizes inter alia data of relevant international and national care studies, prospective data in the trauma registry of the German Trauma Society, and data and literature analyses of the interdisciplinary working group “S3 Guideline of the DGU on the treatment of seriously and multiply injured patients” in order to give recommendations on the structure, organization, and equipment for the care of the severely injured.

The authors of the White Paper recommend that a severely injured patient is transferred to the nearest regional or transboundary trauma center if there is an indication for emergency room management based on mechanism of injury, injury pattern, and vital parameters and if the trauma center can be reached within 30 minutes’ drive time. If it cannot be reached in that time, the patient must be transported to an adequately equipped smaller hospital (currently called a basic care facility). If a criterion exists for onward transfer, secondary transfer to a regional or transboundary trauma center is carried out from there after the vital parameters have been stabilized.

Comparison of Level 1-trauma center versus Level 2/3 hospitals

The research yielded 7 studies from the USA (n = 3), Canada (n = 2), Australia (n = 1), and Germany (n = 1), which directly compare the results of trauma centers (maximum care hospital) with Level 2/3 hospitals (specialist/basic and general care) [5, 9, 10, 15, 23, 26, 27].

All papers come to the conclusion that the case fatality rate is lowered if the primary treatment of patients with serious blunt and penetrating injuries is carried out in the trauma center. This result is statistically significant in 5 studies. The significance level falls just short ($p = 0.055$) in one study [27]. Differences in prehospital management (prehospital interval, amount of treatment) which could have contributed to the difference in the case fatality rate were documented only in their own paper. The interpretation of the study results is simplified in that all papers come to a comparable, statistically confirmed result: the case fatality rate of multiply injured patients is lowered through direct admission to a trauma center or a hospital with a comparable quality of care.

However, due to the considerable, not fully controlled sources of bias and the heterogeneity of the care systems studied, this conclusion cannot equate to definitive scientific evidence. Some authors pointed out that stabilization in a regional hospital followed by transfer to a trauma center, did not negatively influence the case fatality rate compared to patients directly admitted to the trauma center [7, 13, 19, 22, 30, 31, 33]. Patients who died before a possible transfer are not included in these papers. The “transfer” patient cohort is thus positively selected. This should be taken into consideration in the final analysis. It is thus not possible to conclude whether this care pathway actually does represent an equivalent alternative to direct admission to a trauma center or a hospital of comparable quality of care.

Furthermore, a fresh analysis of the treatment results at all care levels must be conducted after the trauma networks are implemented to provide scientific proof of potential positive effects on the outcome from networking.

Conclusion

The analyzed papers on comparing air rescue with the land-based emergency service reveal a trend towards a fall in the case fatality rate through the use of air rescue. If available, primary air rescue *can* be used for the prehospital care of severely injured persons as it *can* result in a survival advantage particularly for medium to high injury severity. Severely injured patients should undergo primary transfer to a trauma center as this procedure leads to a lowering of the case fatality rate. If a regional or transboundary trauma center cannot be reached within a reasonable time (White Paper recommendation: 30 minutes), then the patient should be taken to a closer hospital which is able to carry out primary stabilization and life-saving first aid measures. During the further course, if circulation is stable and specific criteria are present, secondary transfer to a regional or transboundary trauma center can be carried out if necessary.

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1.10 Mass casualty incident (MCI)

The mass casualty incident represents a big challenge for the medical team management. Screening and triage of emergency patients must utilize the available personnel and material resources as efficiently as possible in the prehospital individual management of the injured. Following the attacks inter alia in Madrid and London and the Football World Cup in Germany in 2006, for example, the extreme topicality of this problem should not be in dispute.

The major catastrophic event must be differentiated from a disaster. A strategy for controlling a major catastrophic event with a mass casualty incident was drawn up here according to methodological criteria; its transferability and application in a disaster scenario is only possible to a limited extent at this juncture.

Results

The literature screening revealed that there is no literature of Evidence Level 1 according to the current state of knowledge. The major literature citations for Level 2 and 3 are: [4, 6, 10, 11, 12, 15, 16, 20, 22, 23, 27, 37, 41, 43, 44, 50, 56, 57, 63, 64, 74]. Case histories are difficult to extract from literature citations for Evidence Level 3 as they are generally the only authentic and practically utilizable experience reports of major catastrophic events. For this reason, these publications are also classified in our guideline under Evidence Levels 4 and 5: [1, 3, 5, 8, 9, 13, 14, 17, 18, 21, 23, 30–33, 36, 38–40, 42, 45, 47, 49, 51–53, 55, 58–62, 67, 69–71, 73, 75, 76]. Computer simulations were also applied; their quality is also up for discussion [29, 65].

Status of discussion

Due to the present data status, the evidence-based development of a strategy for the mass casualty incident is currently not possible. As no evidence could be found for individual steps and individual research questions, the authors initially developed a proposal from the synopsis of literature and their own experiences to illustrate the process management in a mass casualty incident. While assessing available study results, the appointed experts group therefore carried out a formal consensus process to draw up the treatment strategy. Within the framework of the nominal group process, the individual opinions could be modified, thus enabling the requirements for a democratic consensus to be fulfilled with appropriate legitimization [35, 54]. The relevant decision criteria and intervention options were defined accordingly and assessed in order of priority with regard to presenting them using an algorithm. To present the results, a modified flow diagram was selected which gives sufficient clarity despite the complexity of the task [34]. The final approval was obtained in a Delphi conference [24]: the anonymized opinions of the experts were gathered by interview and listed. Several survey rounds followed and after each round the responses received were summarized and submitted again for appraisal by those surveyed. This led to systematic modification and criticism of the summarized responses. A group response was achieved by summarizing the individual opinions in a final round, after which it was possible to produce a convergence of opinions.

The algorithm developed for the prehospital processing of a major catastrophic event with a mass casualty incident defines as a treatment strategy both the entire process and the major decision points and management steps. It consists of 2 parts: action instructions for the ambulance team management (SanEL, consisting of the lead emergency physician, LEP, and the organizational leader of the emergency service (OrgL) and part 2, the triage of the injured. The essential prerequisite for processing it is to ensure the accident scene is safe so that the personnel involved are not exposed to any unnecessary hazard.

Discussion

At a mass casualty incident, it is generally not possible for time reasons for the lead emergency physician to carry out prehospital individual triage of all patients. Although there is a good half dozen published triage instructions in the literature, these are neither applicable to the individual medical care systems in equal measure nor do they reveal any type of relatively high evidence [19]. Thus, our own triage algorithm, which can be well and easily applied to the German emergency services conditions, had to be developed from the data in the literature and from the experiences of the members of the consensus conference. The START (Simple Triage and Rapid Treatment) algorithm commonly used in North America, which enables a targeted sorting of the injured by the emergency services personnel first on the scene, serves as an important basis for the algorithm developed for prehospital triage. The START strategy was initially developed for the Californian fire department [10] and is superior to other triage algorithms in the recognition of critical injuries [28]. Besides the priorities according to the ATLS® specifications [2], the algorithm developed for prehospital triage also takes account of the specific requirements of the German emergency system [68], both with regard to the tasks and activity of the lead emergency physician or of the ambulance team management and to the appropriate screening categories.

Triage is generally made more difficult in that the severely injured must be rapidly and definitely identified from among a large number of casualties with minor injuries. Usually, the problem is less one of undertriage, in other words, of not recognizing critically at-risk patients, and far more one of overtriage, of the incorrect assessment of the non-critically injured. The rate of overtriage correlates linearly with the mortality of the critically injured [25] as prehospital and hospital resources are used up in the initially non-urgent treatment of those with minor injuries when these resources are urgently required for the treatment of the critically injured.

After triage has commenced, all the walking wounded are first of all sent to a collection point for those with minor injuries. Patients whose vital functions are acutely threatened are identified according to the ABCD priorities (Airway, Breathing, Circulation, Disability) and dispatched for treatment as rapidly as possible. If there is an acute surgical indication such as thoracotomy/laparotomy to arrest bleeding or decompression in the case of traumatic brain injury, the patient is transported without delay to the nearest suitable hospital after a second screening and approval given by the lead emergency physician (or the SanEL).

The algorithm particularly takes account of the problem that among the large number of injured only a small proportion of the patients have acutely threatened vital functions and require immediate treatment. Besides the life-saving interventions that can be carried out at the scene, it also includes the rapid, resource-dependent transportation to acute surgical care.

An additional fifth screening category for dead persons accommodates the requirement of the European Consensus Conference [68] to assign dead persons and still alive patients who nevertheless have no hope of survival due to their injuries to their own group instead of the hitherto usual 4 groups.

The strategy introduced for the mass casualty incident is essentially based on the results of the consensus conference where there is insufficient data available. Studies of Evidence Level 2 use simulation models for the major catastrophic situation using analysis of carefully documented populations of trauma patients [28] or of events such as the Munich Oktoberfest with a pile-up of many casualties [63]. Although the partial issue of screening and triage can be researched in this way, the operational logistics cannot be recorded with such studies.

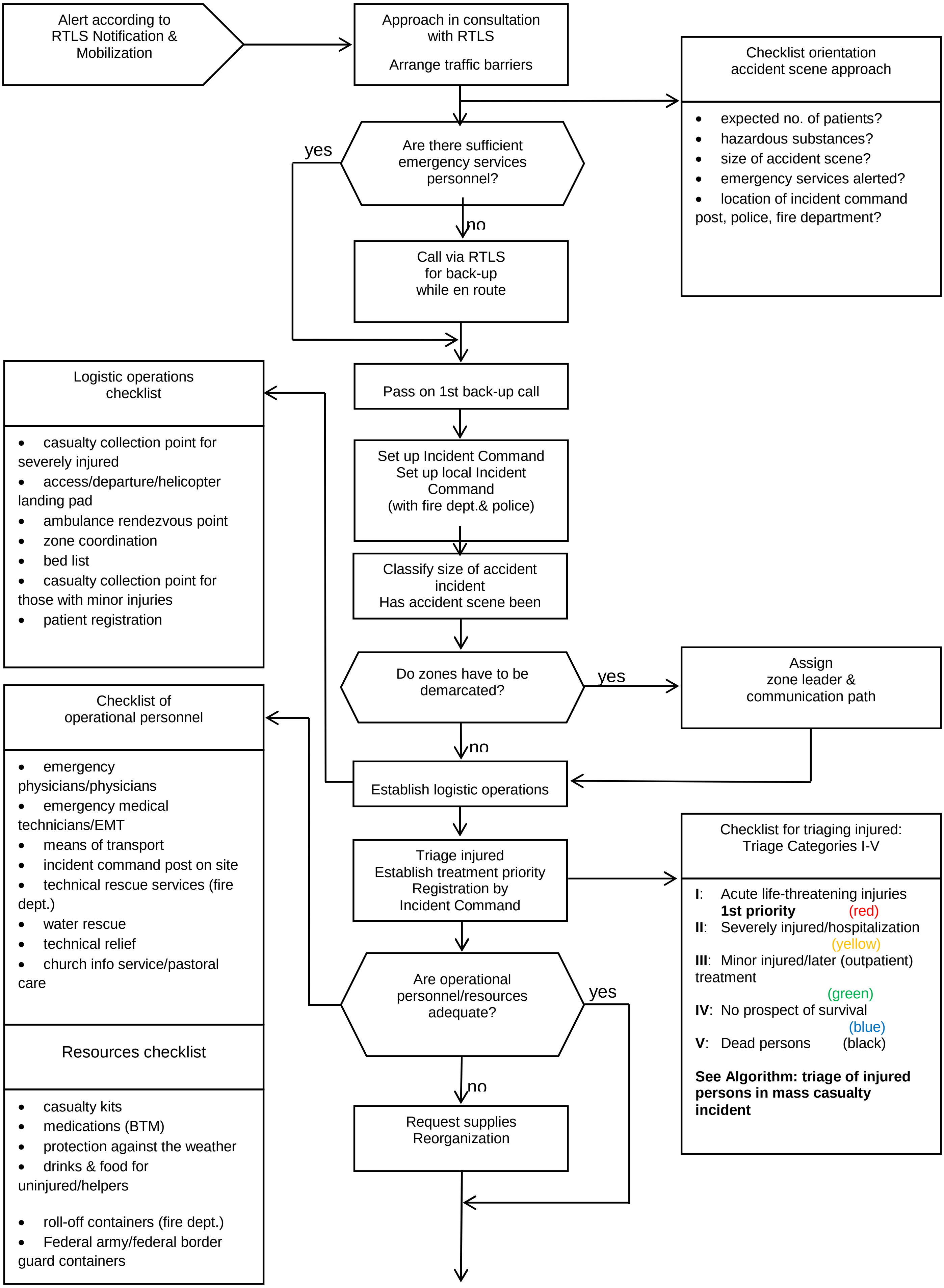
The following problems relating to process quality are identified both in the literature [6, 32, 46] and by the members of the working group:

- Lack of communication at the scene and with the competent superordinate locations (hospitals, emergency control center, etc.)
- Persons in charge at the scene are not clearly identified
- Lack of documentation of the incident
- Lack of identification of the injured

Summary:

Finally, the following conclusion should be drawn: contingencies cannot be predicted or practiced in advance in the context of a major catastrophic event and definitely not in a disaster. In such situations, it has been proven of more advantage to build up available structures as required (regular emergency services, fire department, ambulance service, disaster protection, etc.) rather than create new structures for major catastrophic events. But one thing still stands: good preparation and good training [26] are the best basic prerequisites for dealing with such a situation despite all contingencies [33, 48]. This means the sensible overhaul and improvement in process quality by all local committees involved. Simulation games are a suitable means for evaluation. The algorithm specified by us for processing a major catastrophic event must be included in the local considerations which relate (according to Stratmann) to the medical care principles and to coordinating the cooperation of the emergency services with other organizations (e.g., fire department, police, ambulance service, disaster protection, German army) [72]. The algorithm should be adapted as required to local circumstances, and existing disaster protection plans or similar should also be adapted to it.

Figure 1: Operational algorithm for mass casualty incident (MCI) [7]



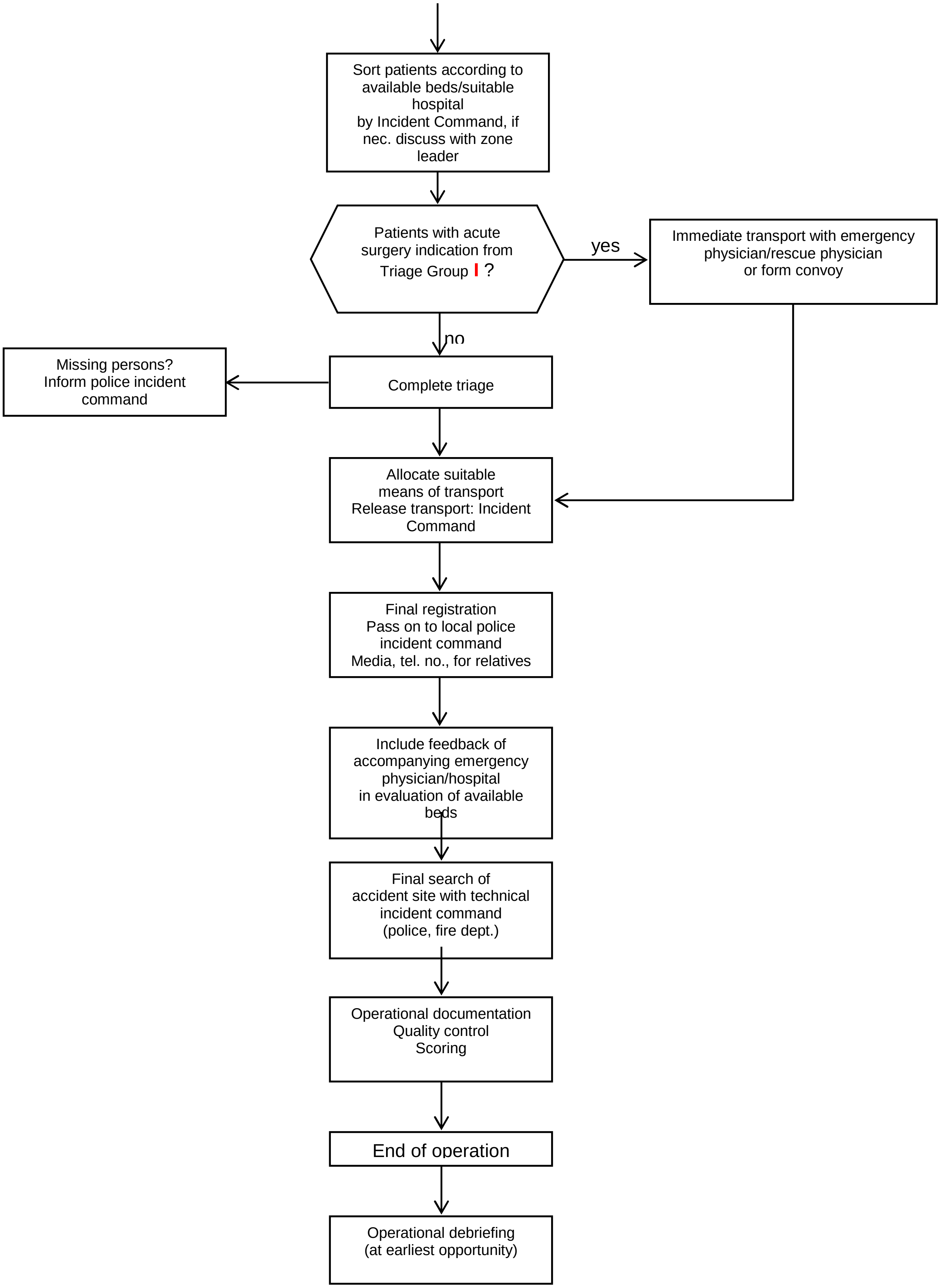
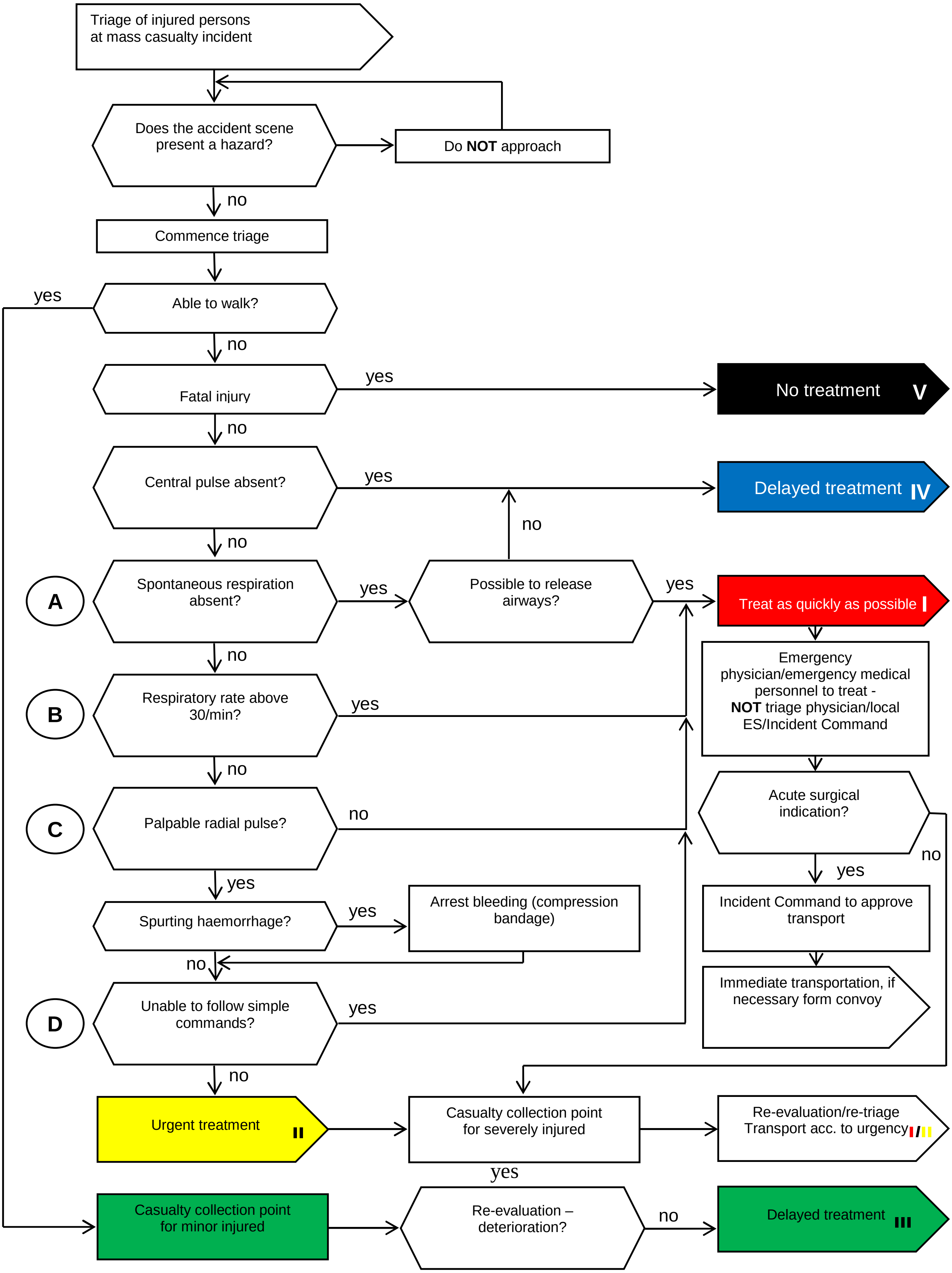

Sort patients according to available beds/suitable hospital by Incident Command, if nec. discuss with zone leader
Patients with acute surgery indication from Triage Group I ?
yes
Immediate transport with emergency physician/rescue physician or form convoy
no
Missing persons? Inform police incident command
Complete triage
Allocate suitable means of transport Release transport: Incident Command
Final registration Pass on to local police incident command Media, tel. no., for relatives
Include feedback of accompanying emergency physician/hospital in evaluation of available beds
Final search of accident site with technical incident command (police, fire dept.)
Operational documentation Quality control Scoring
End of operation
Operational debriefing (at earliest opportunity)

Figure 2: Triage of injured persons at mass casualty incident [7]



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2 Emergency room

2.1 Introduction

How would you treat?

You are called to the emergency room one winter's night. As this is your first shift in trauma surgery, you're feeling quite nervous when you enter the casualty department. You reach the preheated emergency room and shortly afterwards receive a handover from the emergency physician. He reports that a 42-year-old patient has had a motorbike accident. The initial GCS at the accident scene was 13, the right chest wall has marked crepitations, peripheral saturation is 85% during spontaneous breathing and, in addition, the patient is complaining of an intense tenderness in the right upper abdomen. The pelvis is stable and he has not noticed any extremity injuries. After prehospital anesthesia induction and oral intubation, peripheral saturation has risen to over 95%. Due to adequate oxygenation and normal capnometry, the insertion of a chest drain was dispensed with for the short transport journey. The patient is now intubated and ventilated and has stable circulation (110/80 mmHg, pulse 85). However, measurement of peripheral saturation yields a value of 90%. The patient is not fully undressed. A cervical collar has been applied. You look up at the wall in your emergency room and recognize an algorithm there which you are familiar with, which you recently learnt on a polytrauma course:

A Airway with immobilization of the cervical spine

B Breathing/Ventilation

C Circulation

D Disability/Neurology

E Expose – Environment/Undress - Keep Warm

Your confidence grows and you immediately start with the "primary survey and treatment" in the emergency room. You note that the cervical collar is sitting in the correct place. Under "B", the on-duty anesthesiologist notices a weakened breath sound in the right chest, and peripheral saturation is now 83%. You have a brief discussion with him and decide to insert a chest drain via a mini-thoracotomy. Air is released and approximately 400 ml of blood. You check the success of your intervention and notice an increase in saturation to 99%. You are still nervous but know what you have to do next under "C". Meanwhile, a central venous catheter and arterial access have been placed. Blood pressure is 110/80 mmHg, heart rate 85/min. Ultrasonography of the abdomen (FAST) detects free fluid in the Douglas cavity and around the liver, the on-duty radiologist estimates the volume to be approximately 500 ml. You do not detect any relevant bleeding to the outside. After alerting the visceral surgeon, the neurosurgeon has meanwhile checked the pupils under point "D". After he has established that they are narrow but light-reactive, you start "E" and examine the now fully-undressed patient. A full-body CT scan is conducted because of the mechanism of injury. The laboratory values show a hemoglobin value of 11.5 g/dl, INR of 90%, and a base excess of -1.5 mmol/l. The patient has received a total of 1,500 ml fluid.

The visceral surgeon who has meanwhile arrived confirms the ultrasonography finding. The full-body CT scan shows a severe pulmonary contusion on the right and a liver laceration without active bleeding. You come to a consensual decision to proceed as follows: conservative treatment of the abdominal injury and direct transfer of the patient to an intensive care unit.

The aim of this “emergency room” guideline section

The case presented at the start shows the importance of a logical and clear algorithm in an extreme situation. The sequence of actions in the emergency room must be checked against the evidence from as complete a literature base as possible. An expert committee examines the evidence levels, resulting in the grades of recommendation, which can strongly influence the sequence of actions. Thus, the aim of this guideline section is, on the one hand, to create clear, sustainable process sequences which, on the other hand, must contribute towards further improving care of the critically injured. For it is precisely the scientific reproducibility of the clinician’s actions in the emergency room that form the basis of reproducible, valid treatment and, in collaboration with the various medical disciplines, effectuate the parallelizing of processes and thus an improvement in the treatment.

Special notes:

A guideline does not claim to be able to treat every situation conclusively; this also applies to the emergency room. Not infrequently, the generation of clear recommendations is hampered by the lack of studies with a high evidence level. Clear views are expressed on this issue in the corresponding background texts to each chapter. In addition, various statements are subject to a time dynamic. This is accommodated by conducting a re-evaluation after 2 years. Nevertheless, there is a need to describe important correlations in detail.

Managing a multiply injured patient in the emergency room places a great demand on the treatment process because of the acuteness of the events and the large number of treating physicians from different specialties. As with all complex sequences of actions, errors do occur. But not every error need have a negative influence on the quality of treatment [1]. However, an accumulation of errors can occasionally have fatal consequences for the patient. For this reason, the basis of rational quality management lies in calmly working through the complications, and this approach should be firmly established within a quality circle in hospitals which are involved in the care of the critically injured [5]. Care in the emergency room should be quite rigorously characterized here by prescribed sequences and a common language with prehospital and emergency room care merging together seamlessly. Course strategies, such as depicted by Prehospital Trauma Life Support® (PHTLS®) for prehospital care and Advanced Trauma Life Support® (ATLS®) or European Trauma Course® (ETC®) for clinical care, can automate and thus improve this process through a clear hierarchy of treatment sequences and a common language [3, 4]. It is important that every hospital has an emergency room algorithm and that all those potentially involved are familiar with it.

Working groups and quality circles have been successfully introduced in many hospitals and they regularly evaluate and improve their own emergency room strategy based on actual cases. Both the leadership of such quality circles and the question of responsibility in the emergency room are issues that are the subject of heated debate in professional associations. Because severe injury is part of the core competence in trauma surgery, it may be legitimate for physicians qualified in this discipline to be in charge of both the quality circles and treatment in the emergency room [5]. However, it must not be forgotten that there are also other operational strategies in emergency room care [6, 7, 9]. For this reason, during the development of the guideline, this sensitive topic has been accommodated in various places in the background text as even strategies without a team leader are feasible involving just a multidisciplinary team working together. However, it should be discussed upfront who takes over responsibility in which situation in order to be prepared especially for medico-legal questions [8].

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2.2 The emergency room - personnel and equipment resources

The annual number of multiply injured patients in Germany is approximately 32,000-38,000 [13, 30, 39, 53]. In the Federal Republic of Germany, there are currently approximately 700-800 hospitals available for the initial treatment of these patients (emergency room treatment). Although this figure would seem to indicate demand is adequately covered, it should be emphasized that a) not all hospitals have sufficient personnel or structural requirements or the specialist competence to care for these patients, b) there are still regions in Germany without sufficient provision of hospitals for polytrauma treatment, and c) fully equipped hospitals cannot always be reached within acceptable time periods, particularly at night if rescue helicopters are not allowed to take off due to the existing nighttime flying ban or because of capacity problems.

The introduction of regionalized trauma centers with defined standards in the management of trauma patients resulted in a reduction in the rate of avoidable deaths in the United States [8, 54].

To further improve polytrauma management in Germany, and make it more consistent across the whole country, it seems logical to define the requirements for the care of severely injured patients in terms of structure and personnel, and to standardize them to the maximum possible extent.

The DGU Trauma Network Project[D] has been initiated to implement this requirement. In the participating hospitals, which already number approximately 800 (as at April 2010), the DGU Trauma Network[D] is coordinating the implementation of the written contents of the DGU's White Paper on the management of the severely injured [8, 54].

Emergency room team

Key recommendation:

In polytrauma management, fixed teams (known as emergency room teams) must work according to pre-structured plans and/or have completed special training.	**GoR A**

Explanation:

To achieve coordinated, balanced cooperation among various staff in polytrauma management, it is internationally commonplace to put together fixed teams for emergency room care, which work according to pre-structured plans and/or have completed special training (particularly ATLS®, ETC, Definitive Surgical Trauma Care [DSTC™]) [14a] [4, 47, 49, 51, 56]. Various studies have found that this emergency room strategy has clinical advantages [13, 30, 39, 53]. Ruchholtz et al. showed, for example, that an interdisciplinary team, integrated into a quality management (QM) system and acting on the basis of internal hospital guidelines and discussions, works very efficiently under joint surgical and anesthesiologic management [8, 54].

Key recommendation:

The basic emergency room team must consist of at least 3 physicians (2 surgeons, 1 anesthesiologist), with at least 1 anesthesiologist and 1 surgeon having attained specialist grade.	GoR A

Explanation:

There are no validated studies on the composition of the emergency room team so that statements on team composition can only relate to how these are predominantly formed internationally. So, the question as to which specialties should be primarily represented in the emergency room team often depends on local conditions [6, 9, 11, 12, 14, 20–25, 27, 31–33, 38, 41, 45, 50]. On the other hand, individual studies from other countries show that a large proportion of multiply injured patients can be effectively managed even with only 2 physicians [3, 7, 12]. Depending on the injury pattern/severity, however, the team initially comprising at least 2-3 persons will then have to be supplemented with more colleagues [29, 40, 46]. In screening the international literature, it emerged that almost all teams worldwide had either special trauma surgeons of different training levels or general surgeons with (many years') trauma experience, also with different training levels.

Accordingly, the cited team composition of at least 3 physicians can only serve as a minimum number and the team should be enlarged by one or two other 1-2 physicians (e.g., radiologist, neurosurgeon) depending on the size and care level of the hospital and the severely injured workload. In any event, the management of the severely injured must be undertaken by a qualified surgeon whose minimum qualification must be at the level of a specialist in general/visceral surgery or a specialist in orthopedics and trauma surgery (regional medical association (*Landesärztekammer*) [LÄK], Rules for Specialist Training for Physicians, as at 07/2009). The treating anesthesiologist must have the minimum qualification of specialist.

The function of and necessity for a "trauma leader" in the emergency room is a matter of much controversy in the literature. Even in the consensus conferences during the development of the S3 guideline, there was intense, heated debate about the necessity for a "team leader" and about what his duties should be and to which specific specialist area he should be assigned. A structured literature search was conducted on these issues during the guideline development. In terms of patient survival, no credible evidence was identified for the superiority of one particular management structure in the emergency room ("trauma leader" versus "interdisciplinary management group") or for the assignment of a "trauma leader" to one particular specialist area (trauma surgery, surgery versus anesthesia).

Hoff et al. [21] showed that bringing in a team leader (known as a command physician) improved the care and treatment pathway [21]. Alberts et al. also found evidence of improved treatment pathways and treatment results after the strategy of "trauma leader" had been introduced [1]. Depending on the tasks - including patient handover, examining the patient, carrying out and monitoring therapeutic and diagnostic measures, consulting with other specialist disciplines, coordinating all medical and technical team members, preparing examinations following on from emergency room care, contacting relatives after completion - that the "trauma leader" needs to be able to take on in principle, this task must either be carried out on an interdisciplinary basis or by a “team leader” experienced in the management of multiply injured patients. In an interdisciplinary process even closer attention should be paid that the treatment pathways are agreed and consensual to avoid any time delays [18, 21, 37, 50].

According to the recommendations of the American College of Surgeons Committee on Trauma (ACS COT), a qualified surgeon must take over the team leadership [8, 54]. In a large comparative study of over 1,000 patients, there were almost identical case fatality rates and length-of-hospital-stays irrespective of whether 1 out of 4 trauma surgeons or 1 out of 12 general surgeons, albeit with trauma surgery knowledge, were responsible for the emergency room [41]. In a comparison between “trauma surgeons” and “emergency physicians”, Khetarpal showed that under traumatologic leadership the management times and the start of surgery were shorter, but without this apparently having had an effect on the treatment outcome [8, 54]. In a study by Sugrue et al. it is confirmed that no serious implications arise from who leads the ER team so long as he has adequate experience, expertise, and training [8, 54]. In many places, trauma teams have also been led very effectively, cooperatively, and successfully by anesthesiologists for many years.

High specialization in the individual specialist disciplines is particularly taken into account in interdisciplinary leadership models. Here, each specialist discipline has predefined tasks and is in charge of the devolved tasks at defined points in time within emergency room management. The leadership group, comprising anesthesiology, radiology, surgery, and trauma surgery (in alphabetical order), confers at fixed times and in addition to these if the situations in question demand it [57].

Notwithstanding, the experts argue for clear rules on responsibilities aligned to local conditions, agreements, and competences. Team leadership should be encouraged, irrespective of which specialist discipline it originates from or whether consisting of one person or a leadership group. The task of the team leadership is to collect and inquire about the findings of the individual specialized team members and to effectuate decision-making. The team leadership heads communication and establishes further diagnostic and treatment steps in agreement with the team. Within the quality circles of the establishment, the functions and qualifications of the “team leader” and of the “interdisciplinary leadership group” should be established in the emergency room. Ideally, after agreement, the “best” (one or more persons) must take on the task of “trauma leader” and “interdisciplinary leadership group”. In particular, rules must be made for the following points, which must stand up to a “best practice jurisdiction” inspection.

- Responsibility
- Leadership structure for coordination, communication and decision-making within the context of emergency room management

- Monitoring and ensuring quality (implementing quality circles; identifying quality and patient safety indicators; continuous monitoring of structures, processes, and results)

Key recommendation:

Trauma centers must have provision for enlarging emergency room teams	**GoR A**

Explanation:

The size and composition of the enlarged emergency room team is determined by the care level of the hospital concerned and the corresponding injury severity to be expected there as well as by the maximum number of surgical interventions that can be performed there if necessary (White Paper). Accordingly, transboundary trauma centers, being the highest care level, should contain all specialist disciplines which perform emergency care. Table 11 gives an overview. A qualified specialist (specialist physician) from the department concerned must be able to get there within 20-30 minutes (see below).

Key recommendation:

Attending physicians necessary for subsequent care must be present within 20-30 minutes of being alerted.	**GoR A**

Explanation:

A comparative study of hospitals found that it was not absolutely necessary for the *trauma surgeon* to be available in the hospital all hours provided the distance to the hospital was not greater than 15 minutes and a resident was already in the hospital [11]. Allen et al. and Helling et al. give 20 minutes as the limit here [3, 19]. In contrast, Luchette et al. and also Cornwell et al. found “in-house” readiness to be an advantage [9, 33] although Luchette showed that only the diagnosis and start of surgery was speeded up if an attending physician was initially present, both the period of intensive care and mortality of patients with severe thoraco-abdominal or head injuries remaining unaffected [13, 30, 39, 53].

In a comparison over several years, figures from the Trauma Audit and Research Network (TARN) (England & Wales) confirm that the increased presence of a qualified specialist/attending physician (60% versus 32%) contributes to significant reductions in mortality [28]. Wyatt et al. also found evidence that severely injured patients in Scotland (n = 1,427; ISS > 15) were treated faster and were more likely to survive if they were treated by an experienced attending physician/consultant instead of a resident [58]. In the ACS COT recommendations, the presence of an attending surgeon is not mandatory, provided a senior surgical resident is directly involved in the management of the severely injured [8, 54]. In a retrospective analysis over a period of 10 years, Helling et al. showed that no relevant improvement in treatment outcomes are achieved by the initial presence of an attending physician [35, 39, 52]. For patients with penetrating injuries, in shock, with a GCS < 9 or ISS ≥ 26, there was no difference in the care quality with regard to mortality, start of surgery, complications or length of treatment in the intensive care unit if the on-duty physician participated in the subsequent care within 20 minutes (“on call”). Only the initial care period and the total length of stay in hospital were less for blunt trauma if the attending physician could be in the emergency room (“in-house”) immediately. These results are confirmed to a large extent by Porter et al., Demarest et al., and Fulda et al. [11, 16, 43].

Overall, it can be concluded from these results that an attending physician does not have to be present immediately at the start of emergency room care if a surgeon qualified in the care of the severely injured (specialist grade and if applicable ATLS® and ETC certified) initially carries out the care of the injured. However, it should be ensured that an attending physician can be reached quickly.

A thoracic surgeon, ophthalmologist, maxillofacial surgeon and otolaryngologist (ENT) should be reachable within 20 minutes [18, 27, 34, 42]. According to Albrink et al. [2], the thoracic surgeon should be brought in as early as possible particularly in the case of aortic lesions.

It seems that a pediatric surgeon is also not necessary in the basic ER team. The studies of Knudson et al. [26], Fortune et al. [15], Nakayama et al. [36], Rhodes et al. [44], Bensard et al. [5], D'Amelio et al. [10], Stauffer [48] and Hall et al. [17] were unable to find evidence of any improvement in treatment outcome through the involvement of special pediatric surgeons.

An anesthesiologist necessary for the subsequent care of the multiply injured patient must also be present within 20–30 minutes of being alerted.

Key recommendation:

The size of the emergency room should be 25-50 m^2 (per patient to be treated).	**GoR B**

Explanation:

The information given is based on a) the recommendations for initial management of the patient with traumatic brain injury and multiple injuries of the individual working group and circles of the German Society of Anesthesiology and Intensive Care Medicine (DGAI), the German Society for Neurosurgery (DGNC), and the German Interdisciplinary Association of Intensive Care and Emergency Medicine (DIVI). They recommend a minimum size per treatment unit of 25 m^2 [55].

In addition, the room size can also be calculated b) using the specifications of the Technical Rules for Workplaces (*Arbeitsstätten-Richtlinie*) (ASR), the Workplaces Ordinance (*Arbeitsstättenverordnung*) (ArbStättV, 2nd section; room dimensions, air space), the German X-ray Ordinance (*Röntgenverordnung*) (RöV), and the Technical Rules for Hazardous Substances (*Technische Regeln für Gefahrenstoffe*) (TRGS). It specifies that 18 m^3 of breathable air per person carrying out heavy physical activity and 15 m^3 for average physical activity must be ensured in rooms with natural ventilation or air conditioning; 10 m^3 is estimated for every additional person who is only temporarily there. Thus, a room volume of about 75-135 m^3 would be required if there were 5-9 persons present (3-5 physicians, 1 medical radiologic technologist, 1-2 trauma surgery nurses, anesthesiology nurses) and the assumption of average physical work (lead aprons worn during care). With a ceiling height of 3.2 m, this corresponds to a room size of approximately 23-42 m^2. Not included in the calculation is the loss of space through anesthesia and ultrasonography equipment, work surfaces, patient stretcher, cupboards and similar so that a total of 25-50 m^2 per unit should be the starting point. If it is possible to treat a maximum of 2 severely injured patients simultaneously, the area is enlarged accordingly. Section 38 (2) of the German Workplaces Ordinance of 1986 specifies a clear door width of at least 1.2 m with a door height of 2 m for paramedic and first aid rooms.

Key recommendation:

The emergency room, ambulance entrance, radiology department, and surgery department should be in the same building. The helicopter landing pad should be located in the hospital grounds.	**GoR B**

Explanation:

All screening tests necessary for emergency surgery (laparotomy, thoracotomy, external fixator/pelvic C-clamp) must be kept in readiness.

Table 11: Composition and presence of specialist grade physicians in the enlarged emergency room team in relation to the care level

Specialist Department	**Transboundary TC**	**Regional TC**	**Local TC**
Trauma surgery	**X**	**X**	**X**
General or visceral surgery	**X**	**X**	**X**
Anesthesia	**X**	**X**	**X**
Radiology	**X**	**X**	**X**
Vascular surgery	**X**	*	–
Neurosurgery	**X**	*	–
Cardiac or thoracic surgery	*	*	–
Plastic surgery	*	*	–
Ophthalmology	*	*	–
ENT	*	*	–
OMFS	*	*	–
Pediatrics or pediatric surgery	*	*	–
Gynecology	*	*	–
Urology	*	*	–
X: required –: not required *: optional			

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2.3 Criteria for emergency room activation

Efficiently working trauma score systems or parameters should select and identify patients so precisely that the necessary treatment is allotted to each casualty according to his injury severity. The difficulty lies in being able to assess injury severity adequately. Ideally, trauma/emergency room activation criteria should minimize as much as possible the rate of undertriage as well as that of overtriage of severely injured patients. Undertriage describes the proportion of patients who, despite a relevant severe injury requiring emergency room treatment, for example, are not identified as such. In contrast, overtriage describes the proportion of patients with a minor injury or none at all who nevertheless are classified as severely injured and, for example, are delivered to an emergency room. An advantage of overtriage - besides the optimum treatment of each patient - can be team training as the interplay and sequences can be practiced in “quasi-serious situations” even with non-severely injured persons. However, overtriage is associated with considerable costs and an often considerable disruption to routine sequences. The effectiveness of individual, different trauma score systems/trauma criteria can be described by parameters such as sensitivity, specificity, positive predictive value, and the calculation of overtriage and undertriage. The American College of Surgeons Committee on Trauma [25] gives an undertriage rate of 5-10% with simultaneous 30-50% overtriage as necessary in order to carry out efficient emergency room care. In a paper by Kane et al., the authors describe how, in order to attain a sensitivity of more than 80%, the rate of overtriage could not be brought below 70%.

The primary goal of trauma/emergency room activation criteria is therefore to keep undertriage low and at the same time not increase overtriage to an unacceptable level.

Activation criteria

Key recommendation:

The trauma/emergency room team should be activated for the following injuries: ▪ **Systolic blood pressure below 90 mmHg after trauma** ▪ **Penetrating injuries to the neck and torso regions** ▪ **Gunshot wounds to the neck and torso regions** ▪ **GCS below 9 after trauma** ▪ **Respiratory impairment/requirement for intubation after trauma** ▪ **Fracture of more than 2 proximal bones** ▪ **Unstable chest** ▪ **Pelvic fractures** ▪ **Amputation injury proximal to hands/feet** ▪ **Spinal cord injury** ▪ **Open head wounds** ▪ **Burns > 20% and degree ≥2b**	**GoR A**

Explanation:

Blood pressure/respiratory rate

Individual studies have shown that hypotension following trauma with a systolic blood pressure below 90 mmHg is a good predictor/good criterion for activating the emergency room team. Thus, Franklin et al. [1] showed that 50% of trauma patients with prehospital hypotension or hypotension at admission were sent for immediate surgery or transferred to an intensive care unit. A total of 75% of patients with hypotension were operated on during the course of the hospital stay.

Tinkoff et al. [2] found a 24-fold increased mortality, a 7-fold increased admission to the intensive care unit, and a 1.6-fold increased emergency surgery rate where hypotension was present after trauma as an expression of existing shock. In the recommendations of the American College of Surgeons Committee of Trauma [25], hypotension is found to be an important criterion for admission to a trauma center. Smith et al. [3] cite hypotension as a consistently used criterion for trauma team activation in all hospitals in the state of New South Wales in Australia. In a review by Henry et al. [4] of the New York State Trauma Registry, there were mortality rates of 32.9% in trauma patients with an SBP (systolic blood pressure) of < 90 mmHg and 28.8% for trauma patients with a respiratory rate of < 10 or > 29/min.

Gunshot wounds

In a study by Sava et al. [5], the authors ascertained that gunshot wounds to the torso as a single activation criterion had a high informative value similar to the TTAC (Trauma Team Activation Criteria) used up till then. In a subgroup with gunshot wounds to the abdominal/pelvic region, the frequency of severe injuries was equal in the group with and without TTAC (74.1% and 70.8%, p = 0.61). A proviso must be made here that the overwhelming proportion of patients (94.4%) with gunshot wounds had already been identified using the TTAC. Tinkoff et al. [2] also found a significant correlation between gunshot wounds to the neck or torso and the need to admit to an intensive care unit (see below). Furthermore, this criterion was predictive for the existence of severe or fatal injuries and for emergency surgery. In a retrospective analysis, Velmahos et al. [6] report an overall survival rate following penetrating gunshot and stab wounds of over 5.1% in patients without vital signs in the emergency room. In a literature review (25 years, 24 studies), Rhee et al. [7] found a survival rate of 8.8% following emergency thoracotomy due to penetrating trauma.

The American College of Surgeons Committee on Trauma [25] listed various, differently-weighted triage criteria in its last edition (2006). The Step One and Step Two criteria, which necessitate admission to a Level 1 or Level 2 trauma center include: a) GCS below 15 or b) systolic blood pressure (BP) below 90 mmHg or c) respiratory rate below 10/min or above 29/min (Step One). Step Two criteria are a) penetrating injuries to the head, neck, torso, and proximal long bones, b) unstable thorax, c) fracture of 2 or more proximal long bones, d) amputation(s) proximal to the hands/feet, e) unstable pelvic fractures, f) open head fractures, and g) spinal cord injuries. Overall, there is currently rather a lack of evidence for the cited criteria. In a study by Knopp [8] on 1,473 trauma patients, the authors found a positive predictive value (PPV) of 100% for an ISS > 15 for spinal cord injuries and amputation injuries; however, fractures of the long bones only had a PPV of 19.5%.

In their study, Tinkoff et al. [2] examined several of these criteria for their accuracy in identifying severely injured and *high-risk patients.* Trauma patients who fulfilled the criteria of the ACS COT had more severe injuries, higher mortality, and longer stay in intensive care than patients in the control group. Systolic blood pressure below 90 mmHg, endotracheal intubation, and a gunshot wound to the neck/torso were predictive in the study for the necessity of emergency surgery or admission to intensive care. Mortality was markedly increased with systolic blood pressure below 90 mmHg, endotracheal intubation or GCS of less than 9. In their study, Kohn et al. [9] analyzed various trauma team activation criteria (see Table 1a), which are similar to those of the ACS COT. Kohn et al. found the parameter “respiratory rate below 10 or above 29/min” as the most predictive in terms of informative value for the presence of a severe injury. Additional parameters with high prediction were: a) burns with more than 20% body surface (BS), b) spinal cord injury, c) systolic blood pressure below 90 mmHg, d) tachycardia, and e) gunshot wounds to the head, neck or torso.

Open head injuries

With a lack of studies on the relevance of open head injuries, this criterion is regarded by the ACS COT rather as a significant indicator of severe injuries which require a high level of specialist medical competence and should thus be assigned to the *Step One criteria*.

GCS

Kohn et al. [9] regard a GCS of less than 10 as an important predictor of severe trauma. 44.2% of patients, for whom the ER team was activated because they had a low GCS, had confirmed severe injuries. The value of the GCS as a predictor of a severe injury and as an activation criterion for the emergency room team was also confirmed in studies by Tinkoff et al., Norwood et al., and Kühne et al. [2, 10, 11]. In these patients, Norwood as well as Kühne found that even GCS scores of less than 14 indicated pathologic intracerebral findings and the necessity for inpatient admission. However, according to this, the activation of the trauma/emergency room team does not appear to be absolutely necessary with these patients (GCS ≤ 14 and ≥ 11). For a GCS of less than 10, Engum [12] found a sensitivity of 70% for the endpoint OP, intensive care unit (ICU) or death. The odds ratio (OR) was 3.5 (95% CI: 1.6–7.5). The authors found a PPV of 78% for the presence of a severe injury in children with a GCS < 12.

Key recommendation:

The trauma/emergency room team should be activated for the following additional criteria: ▪ **fall from more than 3 meters height** ▪ **road traffic accident (RTA) with** - **frontal collision with intrusion by more than 50-75 cm** - **a change in speed of delta >30 km/h** - **collision involving a pedestrian or two-wheeler** - **death of a driver or passenger** - **ejection of a driver or passenger**	**GoR B**

Explanation:

Accident-related/-dependent criteria

Accident-related/-dependent criteria are evaluated very differently in the literature with regard to their informative value for the presence of severe trauma.

Norcross et al., Bond et al., and Santaniello et al. [13, 14, 15] report on rates of overtriage of up to 92%, sensitivities of 70-50%, and PPV of 16.1% if accident-related mechanisms have been included as the sole criterion for describing the injury severity. If physiologic criteria were also used, a sensitivity of 80% was attained with a specificity of 90% [14].

Knopp et al. found only poor positive predictive values for the parameters road traffic accident (RTA) with ejection or death of a driver or passenger and road traffic accident involving a pedestrian [8]. Engum et al. also found the lowest predictive power for the road traffic accident involving a pedestrian at 20 mph (miles per hour) and the road traffic accident with death of a driver or passenger and trauma from being run over [12]. In the ACS COT recommendations, the trauma from being run over was removed from the criteria in the current version. Frontal collision with intrusion by more than 20-30 inches, death of a driver or passenger, road traffic accident involving pedestrian/two-wheeler collision at ≥ 20 mph, and ejection of a driver or passenger are cited as *Step Three criteria*, i.e. there is no necessity to transport these patients to centers of the maximum care level. Kohn et al. [9] also regard the rollover trauma as lacking in suitability. According to Kohn et al., the same also applies to the criteria/parameters road traffic accident (RTA) with ejection or death of a driver or passenger and road traffic accident involving a pedestrian [9].

Champion et al. [16] regard a vehicle rollover as an important indication of severe injury. The average probability of suffering a fatal injury is markedly greater after a rollover than not after one.

Nevertheless, the ACS COT removed the rollover mechanism from its triage criteria because relevant injuries after such an accident incident would already be included in *Step One* or *Step Two*.

Deformation to vehicle bodywork

In a multivariate analysis of 621 patients, Palanca et al. [17] found no significant relationship between vehicle deformation (intrusion of > 30 cm or > 11.8 inches) and the presence of a relevant severe injury (OR: 1.5; 95% CI: 1.0–2.3; p = 0.05). Henry came to comparable results in the multivariate analysis in his study [4]. Using the data of the National Automotive Sampling System Crashworthiness Data System (NASS CDS), Wang found a PPV of 20% for an ISS > 15 [18].

Death of a driver or passenger

Knopp et al. found an increased risk of surgery or death if a driver or passenger was fatally injured (OR: 39.0; 95% CI: 2.7–569; PPV 21.4%) [8]. Palanca et al. [17] could not confirm any statistically significant relationship between the death of a driver or passenger and the existence of a severe injury even if the simultaneous frequency of a severe injury was 7%.

Fall from a great height

In a prospective study by Kohn et al. [9], 9.4% of patients who had suffered a fall from more than 6 meters height had severe injuries - defined as intensive care admission or immediate surgery. Yagmur et al. [19] found 9 meters to be the average height for patients who died from the consequences of a fall.

Burns

It is essential to distinguish whether a thermal injury is present without additional injuries. In the case of a combination injury where the non-thermal component is predominant, the patient should be brought to a trauma center [25].

Age

Kohn et al. [9] analyzed various trauma team activation criteria which are similar to those of the ACS COT. Of the criteria examined, “age over 65” had the least informative value. The authors therefore recommended that this criterion be removed from the “first-tier activations”. Demetriades et al. [20] found a markedly higher mortality (16%), increased admission to intensive care, and an increased necessity for surgical intervention (19%) in patients over 70 years of age compared to younger patients. However, all patients who could remain outpatients were excluded from the study beforehand so that the cited percentages are probably an overestimation. Kühne et al. [21] found an increase in mortality - irrespective of ISS - with increasing age in a retrospective study of over 5,000 trauma patients in the DGU Trauma Registry. The cut-off value of mortality increase was 56 years. MacKenzie et al. [22] also found a marked increase in (fatal) injuries from > 55 years of age upwards. In a 13-year review, Grossmann et al. [23] found that mortality increased by 6.8% per additional year over 65 years of age. In a study by Morris et al. [24], patients who died from the consequences of an accident had a lower ISS than younger patients in the control group.

Overall, there is variation and controversy over the assessment of the influence of age on the outcome of trauma. The American College of Surgeons COT has classified age as a criterion for triage in a Level 1 or Level 2 trauma center as rather low (Step Four criterion).

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2.4 Thorax

What importance does the previous medical history have?

Key recommendations:

A detailed previous medical history (from third party if necessary) should be taken.	**GoR B**
High energy trauma and road traffic accidents with lateral collision should be interpreted as indications of a chest injury/aortic rupture.	**GoR B**

Explanation:

Even if there are only a few studies on taking the medical history with regard to chest injury, it is still an essential requirement for assessing the injury severity and the injury pattern and is used to establish whether an accident has in fact occurred. Collecting exact details of the circumstances of the accident is important in taking the medical history. The speed of the vehicle at the moment of impact and the direction of the impacting force are particularly important questions in road traffic accidents involving passenger vehicles. For instance, there are marked differences in the occurrence and severity of the chest injury and the overall injury severity depending on whether the impact is lateral or frontal.

Horton et al. [1] demonstrated a sensitivity of 100% and a specificity of 34% for aortic rupture in a lateral collision of the vehicle and/or with a change in velocity (delta V) ≥ 30 km/h. In another study [2], high velocity injuries at speeds of > 100 km/h were graded as suspicious for aortic rupture. Richter et al [3] also found an increased risk of chest injury in lateral collisions. In this study, delta V correlated with the AIS (thorax), ISS, and clinical course. In the study by Ruchholtz et al. [4], chest injury was diagnosed in 8 out of 10 cases of passenger vehicle accidents involving lateral collision. In this study, 72% of patients who had an accidental fall also sustained a chest injury.

In a study of 286 passenger vehicle occupants with an ISS ≥ 16, the probability of an aortic injury after a lateral collision was twice as high as after a frontal collision [5]. An impact in the region of the superior thoracic aperture appears to be particularly important and there appears to be increased incidence of fractures to ribs 1-4 [6].

Children also have a 5-fold higher risk of a severe chest injury (AIS ≥ 3) and a significantly higher overall injury severity when they are passenger vehicle occupants in a lateral collision compared to a frontal collision [7].

The effect of a seatbelt on the presence of a chest injury appears uncertain. Thus, in a retrospective study of 1,124 patients with relatively minor overall injury severity (ISS 11.6), Porter and Zaho [8] did find cumulative incidence of sternum fractures (4% versus 0.7%) in belted patients but the proportion of patients with chest injury was identical in both groups (21.8% versus 19.1%).

What importance do physical examination findings have?

Key recommendations:

A clinical examination of the thorax must be carried out.	**GoR A**
The physical examination should include auscultation.	**GoR B**

Explanation:

Even if there are hardly any scientific studies except for auscultation on the importance and the required scope of the physical examination, it is still an indispensable requirement in identifying symptoms and in making (suspected) diagnoses. The above-mentioned examinations are used to identify relevant, life-threatening or potentially fatal disorders or injuries which require immediate, specific treatment. Even if a physical examination has already been carried out in the prehospital phase and a chest drain has already been inserted, the physical examination must be carried out in the emergency room as a change could have occurred in the constellation of findings.

The initial physical examination should include:

- auscultation (presence of breath sounds and lateral uniformity)
- details of pain
- respiratory rate
- inspection (skin and soft tissue injuries, symmetry of the thorax, symmetry of respiratory excursion, paradoxical respiration, inflow congestion, belt marks)
- palpation (subcutaneous emphysema, crepitation, tenderness points)
- dyspnea

Monitoring ventilation pressure, blood oxygen saturation (pulse oxymetry), and expiratory CO_2concentration can be added during the course.

The auscultation finding is the lead finding for making a diagnosis of chest injury. In addition, subcutaneous emphysema, palpable instabilities, crepitations, pain, dyspnea, and elevated ventilation pressures can be indications of a chest injury.

In a prospective study, Bokhari et al. [9] examined 676 patients with blunt or penetrating chest injury for clinical signs and symptoms of hemopneumothorax. But out of 523 patients with blunt trauma, only 7 had a hemopneumothorax. In this group, auscultation has a sensitivity and negative predictive value of 100%. The specificity was 99.8% and positive predictive value was 87.5%. In penetration injuries, the sensitivity of auscultation is 50%, specificity and positive predictive value 100%, and negative predictive value 91.4%. In both mechanisms of injury, pain and tachypnea are inadequate indications of the presence of a hemopneumothorax.

In a retrospective study of 118 patients with penetrating trauma, Chen et al. [10] also found for auscultation only a sensitivity of 58%, specificity and positive predictive value of 98%, and negative predictive value of 61%. In a prospective study of 51 patients with penetrating trauma, the combination of percussion and auscultation exhibited a sensitivity of 96%, specificity of 93%, and positive predictive value of 83% [11].

These studies show that in penetrating trauma a weakened breath sound generally has an underlying pneumothorax and a chest drain can then be inserted before a radiograph is taken.

In their search for a clinical decision aid to identify children with chest injury, Holmes et al. [12] studied 986 patients, 80 of whom had a chest injury. This yielded an odds ratio of 8.6 for a positive auscultation finding, an odds ratio of 3.6 for an abnormal physical examination (reddening, skin lesions, crepitation, tenderness), and an odds ratio of 2.9 for an elevated respiratory rate.

What importance is attached to the diagnostic equipment (chest radiograph, ultrasound, CT, angiography, ECG, laboratory tests) and when is it indicated?

Key recommendations:

If a chest injury cannot be clinically excluded, a radiologic diagnostic study must be carried out in the emergency room.	**GoR A**
Every patient with clinical and anamnestic indications of a severe chest injury should undergo a helical CT scan of the thorax with contrast agent.	**GoR B**

Explanation:

As given under points 1 and 2, both the mechanism of injury and the findings from the physical examination provide important information on the presence or absence of a chest injury. For this reason, a chest radiograph can be dispensed with if, with respect to the circumstances of the accident, a chest injury can be excluded and at the same time there are no findings from the physical examination that make an intrathoracic injury probable.

On the other hand, a chest radiograph should be taken of all patients with confirmed chest injury. This serves to confirm diagnoses already made and to confirm or exclude further possible diagnoses. The initially taken radiograph is used to diagnose a pneumothorax and/or hemothorax, rib fractures, tracheobronchial injuries, pneumomediastinum, mediastinal hematoma, and pulmonary contusion [13]. The chest radiograph is widely used as the primary diagnostic tool due to its low costs and availability. Nevertheless, there is little evidence on sensitivity and specificity in the diagnosis of pulmonary or thoracic injuries. There are only a few studies that report on a series of major injuries missed in the radiographs.

In a prospective study of 100 patients, there was evidence that the most important chest injuries can be detected by a chest radiograph examination. The sensitivity of images taken upright was 78.7% and that of supine images 58.3% [14]. On the other hand, McLellan et al. [15] found autopsy evidence in a series of 37 patients who died within 24 hours of admission that the chest radiograph did not detect important injuries in 11 cases. Among these were 11 cases of multiple rib fractures, 3 sternum fractures, 2 diaphragmatic ruptures, and 1 aortic intimal tear.

The chest radiograph offers sufficient accuracy for indicating a chest drain, for example. In a prospective study of 400 multiply injured patients, Peytel et al. [16] thus showed that insertion of chest drains (n = 77) based on the radiographic findings was correct in all cases.

Yet, numerous studies have shown that intrathoracic injuries can be revealed with significantly higher frequency by CT scan than by chest radiograph alone. In particular, there is a marked superiority in the detection of pneumothoraces and hemothoraces, pulmonary contusion, and aortic injuries. Here, preference should be given to the helical CT with administration of intravenous (i.v.) contrast agent [17]. By using multi-slice helical CTs, the examination time for a full-body scan can be reduced from an average of 28 to 16 minutes compared to the single-slice helical CT, and initial diagnostic information can even be taken from the realtime images on the monitor [18].

In a series of 103 severely injured patients, Trupka et al. [19] obtained additional information from 65% of patients on the underlying chest injury (pulmonary contusion n = 33, pneumothorax n = 34, hemothorax n = 21) compared to the radiographic examination. In 63% of these patients, direct therapeutic consequences resulted from the additional information, which in the majority of cases consisted of the chest drain being re-inserted or corrected.

In patients with relevant trauma (road traffic accidents with crash speed > 15 km/h, fall from a height of > 1.5 m), Exadaktylos et al. [20] were unable to detect chest injuries in 25 out of 93 patients using the conventional radiograph. In 13 of these 25 patients, however, the CT showed in part substantial chest injuries, including 2 aortic lacerations. In a prospective study of 112 patients with deceleration trauma, Demetriades et al. [21] performed a helical CT scan of the chest, which produced the diagnosis of aortic rupture in 9 patients. Four of these patients exhibited a normal chest radiograph. The aortic rupture was confirmed by CT in 8 patients. In one patient with an injury to the brachiocephalic artery, the CT revealed a local hematoma but the vessel was not visible in the CT slices. Even in patients without clinical signs of chest injury and with a negative radiographic finding, chest injuries showed up in the CT in 39% of patients, and in 5% of cases led to a change in treatment [22].

Blostein et al. [23] come to the conclusion that a routine CT is not to be recommended generally in blunt chest injury as, out of 40 prospectively studied patients with defined chest injuries, 6 patients had a change in treatment (5x chest drains, 1x aortography with negative result). However, the authors also state that, in patients who require intubation and ventilation, the CT produces findings that are not visible on the conventional radiograph. In patients with an oxygenation index (PaO_2/FiO_2) < 300, the CT can help to estimate the extent of the pulmonary contusion and to identify patients at risk of pulmonary failure. Moreover, patients can be identified in whom an incompletely decompressed hemo- and/or pneumothorax could lead to further decompensation. In a retrospective study with 45 children [24] with 1) pathologic radiographic finding (n = 27), 2) abnormal physical examination finding (n = 8), and 3) substantial impact on the chest wall (n = 33), additional injuries were found in the CT in 40%, of which 18% of cases led to a change in treatment.

Although for blunt chest trauma the supplementary diagnostic information from the chest CT is generally accepted in more recent literature [25], there is controversy surrounding the benefit of the effect on the clinical outcome and it is not yet confirmed. In a prospective study by Guerrero-Lopez et al. [26], the chest CT proved to be more sensitive in detecting hemo/pneumothorax, pulmonary contusion, spinal fractures, and chest drain misplacements and led to treatment changes in 29% of cases. In the multivariate analysis, no therapeutic relationship could be ascertained between the CT and ventilation time, intensive care stay or mortality. The authors therefore conclude that a chest CT should only be performed if there are suspected severe injuries that can be confirmed or excluded by the CT.

Current studies showed a clear benefit from multi-slice CTs of the chest if there was a defined indication. Brink et al. [122] studied its routine, selective use in 464 and 164 patients. The indications for a routine CT were: high-energy trauma, vital parameters under threat, and severe injuries such as pelvic or spinal fractures, for example. The indications for a selective CT were: abnormal mediastinum, more than 3 rib fractures, pulmonary shadowing, emphysema, and fractures in the thoracolumbar spine. Injuries which were not visible in the conventional radiograph were found in 43% of patients who underwent routine CT. This led to changes in treatment for 17% of patients. Among the 7.9% of patients with a normal chest radiograph, Salim et al. [121] found pneumothoraces in 3.3%, a suspected aortic rupture in 0.2%, pulmonary contusions in 3.3%, and rib fractures in 3.7%.

If the literature results are summarized, this produces an indication for chest CT in the presence of the following indication criteria:

Indication criteria for chest CT (summarized according to [121, 122]):

- road traffic accident Vmax > 50 km/h
- fall from > 3 m height
- patient ejected from vehicle
- rollover trauma
- substantial vehicle deformation
- pedestrian knocked down at > 10 km/h
- biker knocked down at > 30 km/h
- crush

- pedestrian hit by vehicle and flung > 3 m
- GCS < 12
- Cardio-circulatory abnormalities (respiratory rate > 30/min, pulse > 120/min, systolic blood pressure < 100 mmHg, blood loss > 500 ml; capillary refill > 4 seconds)
- Severe concomitant injuries (pelvic ring fracture, unstable spinal fracture or spinal cord compression)

A retrospective multicenter analysis using the database of the DGU Trauma Registry found evidence of an improvement in survival probability for patients who had initially undergone a full-body CT scan [128]. The use of full-body CT leads to a relative reduction in mortality of 25% in TRISS and of 13% in the RISC score. The CT proved to be an independent predictor for survival in the multivariate analysis.

Key recommendation:

Every patient with clinical signs of chest injury should undergo an initial ultrasound examination (as part of the ultrasound examination of the torso) unless an initial chest helical CT with contrast agent has been carried out.	**GoR B**

Explanation:

In a prospective study of 27 patients, chest X-rays, ultrasound examinations and CT were compared for accuracy in diagnosing a pneumothorax. The ultrasound examination of the thorax showed a sensitivity and a negative predictive value of 100% and a specificity of 94% [27]. In another study, the ultrasound examination compared with the X-ray examination showed a sensitivity and a positive predictive value of 95% and a negative predictive value of 100% for diagnosing a pneumothorax [28]. However, emphysema bullae, pleural adhesions or extensive subcutaneous emphysema can falsify the results of ultrasonography.

As a retrospective study of 240 patients showed, the ultrasound examination ranks equally with the X-ray in diagnosing hemothorax. In 26 of these patients, the hemothorax was confirmed either by a chest drain or by chest CT. Ultrasound and chest X-ray each showed a sensitivity of 96%, a specificity and a negative predictive value of 100%, and a positive predictive value of 99.5% [29].

In a prospective study of 261 patients with penetrating injuries, chest ultrasound had a sensitivity of 100% and specificity of 96.9% for detecting pericardial tamponade [30]. However, false-negative ultrasound results can occur especially in patients with larger hemothoraces which can conceal smaller hematomas in the pericardium [31]. For this reason, sensitivity of the ultrasound was only 56% in this study.

In a retrospective study of 37 patients with a pulmonary contusion confirmed in a CT, ultrasonography revealed a sensitivity of 94.6%, specificity of 96.1%, and a positive and negative predictive value of 94.6% and 96.1%, respectively [127].

A chest helical CT scan with contrast agent excluded aortic injuries in patients without detected mediastinal hematoma, resulting in angiography not being necessary. Due to inadequate sensitivity, conventional CT examinations are less suited for the exclusion of an aortic injury [32, 33, 34].

In the prospective study by Gavant et al. [35], 1,518 patients with blunt trauma underwent helical CT scans with contrast agent. Of this group, 127 patients with abnormalities in the mediastinum or aorta received aortography. An aortic injury was detected in 21 of these patients. Sensitivity for the CT and the aortography was 100 and 94.4%, respectively, whereas specificity was 81.7 and 96.3%, respectively. It was concluded from this that in the absence of a mediastinal hematoma or if the aorta presented normally despite mediastinal hematoma, CT was sufficient for diagnosis and aortography was not necessary.

In a prospective study, Dyer et al. [2] studied 1,346 patients after blunt chest trauma using contrast CT and 19 of the patients exhibited an aortic injury in the CT. All patients with positive CT findings had additional angiography. On the assumption of a periaortal hematoma as indication of an aortic injury, the CT has a sensitivity and a negative predictive value of 100%, a specificity of 95%, and a positive predictive value of 22%. The authors conclude that aortography should only be carried out in patients who have undergone a CT scan that cannot be interpreted or have a periaortal hematoma without direct signs of an aortic injury. Aortography can also prove necessary if the proximal extent of the aortic injury cannot be reliably assessed from the CT scan.

In another prospective study of 494 patients with blunt chest trauma and mediastinal hematoma, the sensitivity for helical CT with contrast agent was 100% compared to 92% for aortography [36]. The specificity for the CT was 83% compared to 99% for aortography. The positive predictive value for the CT was 50% compared to 97% for aortography and the negative predictive value was 100% compared to 97%. In contrast to the above-mentioned study by Dyer et al. [2], Fabian et al. [36] conclude that patients with a mediastinal hematoma but no direct indication of an aortic injury also require no further diagnostic workup.

The prospective study by Parker et al. [37] of 142 patients with radiographically abnormal mediastinum showed that both the helical CT and the aortography produced a sensitivity and a negative predictive value of 100% for aortic injury. In a retrospective study of 74 patients, Tello et al. [38] found normal CT findings in 39 patients. Of these 39 patients, 5 received an angiography which showed all findings normal and 34 patients were asymptomatic at a clinical follow-up examination 12 months later.

There is general consensus now that helical CT with contrast agent is suitable for the exclusion of an aortic rupture [123, 124, 126]. There is a high probability that patients without detectable mediastinal hematoma have no aortic injury. Through the use of computed tomography, a large number of unnecessary aortographs can thus be avoided. However, if a brain CT scan is required, it should be carried out before the chest CT scan as the administration of contrast agent hampers the traumatic brain injury diagnosis.

As comparative studies on angiography have shown, a CT without evidence of a mediastinal hematoma has a negative predictive value of 100% for the injury of large intrathoracic vessels [39]. However, the specificity in the study by Parker et al. [37] is only 89% due to 14 false-positive findings. It is therefore recommended that angiography is performed on patients with a para-aortic hematoma detected by CT or with peribranch vessel hematomas and abnormal aortic contours. A negative contrast agent CT scan definitively excludes an aortic rupture [34, 40, 41].

In an analysis of 54 patients with surgically detected aortic ruptures, Downing et al. [42] showed a sensitivity of 100% and specificity of 96% for helical CT. In a prospective study of 1,104 patients with blunt chest trauma, Mirvis et al. [43] found mediastinal bleeding in 118 cases, of which 25 patients had an aortic rupture. For the aortic rupture, the helical CT showed a sensitivity and a negative predictive value of 100%, a specificity of 99.7%, and a positive predictive value of 89%. In a retrospective study on chest CT, Bruckner et al. found a negative predictive value of 99%, a positive predictive value of 15%, a sensitivity of 95%, and a specificity of 40%.

In another prospective study of 1,009 patients, 10 patients had an aortic injury [44]. For the detection of direct signs of an aortic injury, the helical CT showed a sensitivity and a negative predictive value of 100%, a specificity of 96%, and a positive predictive value of 40%.

In contrast to the above-mentioned prospective studies, Collier et al. [45] found only a sensitivity of 90% and a negative predictive value of 99% in a retrospective study of 242 patients; an aortic injury was found during the autopsy of one patient with a normal CT finding who had subsequently died from the consequences of a traumatic brain injury. In another retrospective study, angiography did not detect any aortic injury in 72 patients with an intrathoracic hematoma detected in a CT scan but no evidence of a direct aortic or other intrathoracic vessel injury [125].

Transesophageal echocardiography (TEE) is a sensitive screening test [46, 47, 48] but angiography was often additionally carried out afterwards [49, 50]. TEE requires an experienced examiner [51] and is generally not so rapidly available as CT or angiography. The benefit of TEE may lie in imaging small intimal tears [47] which might not be visible in angiography or helical CT. However, TEE cannot provide good images of the ascending aorta and the branches of the aorta, which thereby elude diagnosis [52]. To date, there is only one prospective study in which helical CT has been compared to TEE in the diagnosis of aortic injury. CT and TEE showed a sensitivity of 73 and 93%, respectively, and a negative predictive value of 95%.

Key recommendations:

A 3-lead ECG must be carried out to monitor vital functions.	**GoR A**
A 12-lead ECG should be carried out if there is a suspected blunt myocardial injury.	**GoR B**

Explanation:

The initial ECG is essential for every severely injured patient. The ECG is necessary particularly in the absence of palpable pulses in order to differentiate in cardiac arrest between rhythms that can be defibrillated and those that cannot be defibrillated. The ECG can also be used as a screening test for potential cardiac complications from a blunt cardiac injury.

Patients with a normal ECG, normal hemodynamics and no other additional relevant injuries do not require any further diagnostic tests or treatment. Cardiac enzymes are irrelevant in predicting complications from a blunt cardiac injury although raised troponin I levels can predict abnormalities in echocardiography. The echocardiogram should not be used in the emergency room for the diagnosis of blunt cardiac injury as it does not correlate with the occurrence of clinical complications. Echocardiography should be carried out on hemodynamically unstable patients in order to diagnose pericardial tamponade or pericardial rupture. Transthoracic echocardiography should be the method of choice here as to date there have been no clear evidence that transesophageal echocardiography is superior in diagnosing blunt cardiac injury.

The ECG is a rapid, cost-effective, non-invasive examination which is always available in the emergency room. In a meta-analysis of 41 studies, it was shown that the ECG and the creatine kinase MB (CK-MB) levels have a higher importance than radionuclide examinations and the echocardiogram in diagnosing clinically relevant blunt cardiac injury (defined as a complication requiring treatment) [53].

Fides et al. [54] report prospectively on 74 hemodynamically stable patients with normal initial ECG with no existing heart disease or other injuries. None of these patients developed cardiac complications. Another retrospective study of 184 children with blunt cardiac injury showed that patients with a normal ECG in the emergency room did not develop complications [55]. In a meta-analysis of 41 studies, an abnormal admission ECG correlated with the development of complications requiring treatment [53]. In contrast, in a prospective study by Biffl et al. [56], 17 out of 107 patients with a contusion developed complications. Only 2 out of 17 patients initially had an abnormal ECG and 3 had sinus tachycardia. In another retrospective study of 133 patients in 2 establishments with clinical suspicion of a blunt cardiac injury, 13 patients (9.7%) developed complications but no patient with a normal initial ECG showed other abnormalities [57]. In the study by Miller et al. [58], 4 out of 172 patients developed arrhythmias requiring treatment with all 4 patients having an abnormal initial ECG. Wisner et al. [59] studied 95 patients with suspected blunt cardiac injury and discovered that 4 patients developed clinically significant arrhythmias, only 1 of which had a normal admission ECG. In summary, the majority of authors recommend that asymptomatic, patients with stable circulation with a normal ECG do not require any further diagnostic tests or treatment.

Key recommendation:

The measurement of troponin I levels can be undertaken as an additional laboratory test in the diagnosis of blunt myocardial injuries.	**GoR 0**

Explanation:

The studies on creatine kinase MB (CK-MB) in the diagnosis of blunt cardiac injury reveal a major limitation in the lack of a clear definition of blunt cardiac injury and the lack of a gold standard. In a retrospective study of 359 patients, 217 of whom were included to exclude blunt cardiac injury, 107 were diagnosed either because of an abnormal ECG finding or elevated CK-MB level. 16% of patients developed complications requiring treatment (arrhythmias or cardiogenic shock). All of these patients had an abnormal ECG but only 41% of them had elevated CK-MB levels. The course was without complication in patients with normal ECG and elevated CK-MB [56]. In a prospective study of 92 patients who all received an ECG, a CK-MB analysis, and continuous monitoring, 23 patients developed arrhythmias which, however, did not require any specific treatment. This shows that the number of arrhythmias requiring clinical treatment is small. 52% of patients with arrhythmias revealed elevated CK-MB levels whereas 19% of patients without arrhythmias also had elevated CK-MK levels [60]. In addition, other studies showed no correlation between elevated CK-MB levels and cardiac complications [58, 59, 61-65].

Troponin I and T are sensitive markers in the diagnosis of myocardial infarction and considerably more specific than CK-MB as they are not present in skeletal muscle. In a study of 44 patients, the 6 patients with blunt cardiac injury confirmed by echocardiography showed simultaneously elevated CK-MB and troponin I. Of the 37 patients without cardiac injury, 26 had elevated CK-MB levels but no patient had elevated troponin I [66]. In another study of 28 patients, 5 of whom had a blunt cardiac injury detected by echocardiography, troponin I had a specificity and sensitivity of 100% for the contusion. In a study of 29 patients, troponin T showed higher sensitivity (31%) than CK-MB (9%) in diagnosing blunt cardiac injury. Troponin T showed a sensitivity of 27% and a specificity of 91% in 71 patients for predicting clinically significant ECG changes [67].

In a more current prospective study of 94 patients, 26 patients were diagnosed with blunt cardiac injury either by ECG or echocardiography. Troponin I and T showed a sensitivity of 23 and 12%, respectively, sensitivity of 97 and 100%, respectively, and a negative predictive value of 76.5 and 74%, respectively. The authors describe an unsatisfactory correlation between the two enzymes and the occurrence of complications [68]. In another prospective study, sensitivity, specificity, and the positive and negative predictive values of troponin I are given as 63, 98, 40, and 98%, respectively, for detecting blunt cardiac injury [69]. Velmahos et al. carried out ECG tests and troponin I measurements prospectively in 333 patients with blunt chest trauma [70]. In 44 diagnosed cardiac injuries, the ECG and troponin I showed a sensitivity of 89 and 73%, respectively, and a negative predictive value of 98% and 94%, respectively. The combination of ECG and troponin I produced a sensitivity and a negative predictive value of 100% each. Rajan et al. [71] showed that a cTnI level below 1.05 µg/l at admission and after 6 hours excludes myocardial injury.

The results available to date show that troponin I in particular is a more specific indicator than CK-MB for the presence of a blunt cardiac injury. However, the importance of troponin in predicting complications is still the subject of current discussion.

A transthoracic echocardiography (TTE) is often carried out in the diagnosis of blunt cardiac injury but has hardly any importance in patients with stable circulation. In a prospective study, Beggs et al. carried out TTE in 40 patients with suspected blunt chest injury. Half of the patients had at least one pathologic finding either in the ECG, in the cardiac enzymes or in TTE. There was no correlation between TTE, the enzyme or ECG findings, and TTE could not predict the development of complications [72]. In another prospective study of 73 patients who all underwent TTE, CK-MB measurements, and cardiac monitoring, 14 patients presented abnormalities in the echocardiography. However, only 1 patient who initially had a pathologic ECG developed a complication in the form of a ventricular arrhythmia [73]. A prospective study of 172 patients came to the conclusion that only an abnormal ECG or shock has a predictive value with reference to monitoring or to a specific treatment. Patients with abnormalities in TTE or elevated CK-MB levels without a simultaneous pathologic ECG developed no complications requiring treatment [58]. Although there are a number of studies which show the benefit of TTE in the diagnosis of pericardial effusion or of pericardial tamponade in penetrating trauma, the benefit of this study on blunt trauma is debatable [30, 58, 74].

There are a number of studies which show that the accuracy of transesophageal echocardiography (TEE) is greater than that of TTE in the diagnosis of cardiac injuries [75-79]. In addition, other cardiovascular changes such as aortic injuries, for example, can be diagnosed by TEE. Vignon et al. [80] prospectively carried out helical CT and, in the intensive care unit, TEE on 95 patients with risk factors for an aortic injury. The sensitivity of TEE and CT was 93 and 73%, respectively, the negative predictive value was 99% and 95%, respectively, and the specificity and the positive predictive value were 100% for both examination methods. TEE proved to be superior in identifying intimal tears whereas an aortic branch lesion was missed.

In summary, echocardiography should be carried out if a pericardial tamponade or pericardial rupture is suspected.

What additional diagnostic tests exist for emergency room patients?

Fabian et al. [36] state that patients with a mediastinal hematoma and no direct evidence of an aortic injury require no further assessment. This also applies to intimal tears and pseudo-aneurysms. However, patients with changes that cannot be classified in more detail should undergo angiography for further assessment. Gavant et al. [35] also stated that, in the absence of a mediastinal hematoma or if the aorta presented normally despite mediastinal hematoma, helical CT with contrast agent was sufficient for diagnosis and aortography was not necessary.

Mirvis et al. [43] and Dyer et al [44] suggest that an aortic injury detected in a CT or an injury to the main lateral branches and a mediastinal hematoma require either an angiography or direct thoracotomy depending on the experience of the establishment concerned. Angiography is also necessary for a mediastinal hematoma in direct contact with the aorta or with the proximal great vessels without direct evidence of a vessel injury or for abnormal aortic contours [37].

Downing et al. [42] conclude from the results of their study that surgical treatment can be carried out without further diagnostic tests if a helical CT clearly detects an aortic rupture. In contrast to the above-mentioned study by Dyer et al. [2], Fabian et al. [36] conclude that patients with a mediastinal hematoma but no direct evidence of an aortic injury require no further work-up.

To date, there are no comparative studies which investigate the necessity of additional angiography prior to a planned intervention for an aortic injury detected in a CT scan. For this reason, the recommendations are based, on the one hand, on conclusions from studies which evaluated angiography and CT in the diagnosis of aortic injury and, on the other hand, on data from diagnostic tests carried out prior to endovascular treatment.

Thus, Gavant et al. [35], recommend that aortography is carried out prior to surgical or endovascular treatment in order to confirm the injury and define the extent of the damage. Parker et al. [37] also consider angiography necessary for confirming positive CT findings.

In patients with direct indication of an aortic injury and a mediastinal hematoma, Mirvis et al. [43] and Dyer et al [44] suggest either angiography or direct thoracotomy depending on the experience of the establishment concerned.

Downing et al. [42] and Fabian et al. [36] hold the view that a thoracotomy can also be carried out without additional angiography if the CT finding is clear.

In a series of 5 patients with acute traumatic rupture of the thoracic aorta, a CT scan and angiography were carried out on all patients prior to stent implantation [81].

What importance is attached to emergency procedures (chest drain, intubation, pericardiocentesis, thoracotomy)?

Key recommendations:

A clinically relevant or progressive pneumothorax must first be decompressed in the ventilated patient.	**GoR A**
A progressive pneumothorax should be decompressed in the non-ventilated patient.	**GoR B**
A chest drain must be inserted for this purpose.	**GoR A**
Preference should be given to wide lumen chest drains.	**GoR B**

Explanation:

A pneumothorax detected in the radiographic image represents an indication to insert a chest drain particularly if mechanical ventilation is necessary. This represents general clinical practice although there are no comparative studies on this in the literature [12, 82-85]. Due to the underlying pathophysiology, it is upgraded to Grade of Recommendation A. Westaby and Brayley [86] recommend that a chest drain should always be inserted for a pneumothorax which exceeds 1.5 cm in size and is at the level of the 3rd intercostal space. If the size is less than 1.5 cm, a chest drain should only be inserted if ventilation is necessary or if there is bilateral occurrence. The insertion of a chest drain can be omitted only in small ventral pneumothoraces detected by CT although close clinical monitoring is required.

The insertion of a chest drain should be carried out in the emergency room as the risk of a progressive pneumothorax can lead to a tension pneumothorax and the timespan of such a development cannot be estimated. The risk of a tension pneumothorax occurring should be rated markedly higher in ventilated patients than in non-ventilated patients. In non-ventilated patients, small pneumothoraces less than 1-1.5 cm in width can initially be treated conservatively by close clinical monitoring. If this is not possible for logistic reasons, the pneumothorax should also be decompressed in this situation.

The increasing use of abdominal and chest CT in the diagnosis of blunt trauma has led to pneumothoraces being detected in a CT scan which had not been detected previously by conventional supine radiographic images. These so-called occult pneumothoraces, usually lying ventrally, are found in 2-25% of patients after severe multiple injuries [19, 22, 23, 87-89]. Based on the available literature, the initial insertion of a Bülau drain should be omitted in an occult pneumothorax diagnosed by CT if:

- the patients are hemodynamically stable and have a largely normal lung function,
- there are frequent clinical checks with the possibility of radiography in between

and

- a chest drain can be inserted at any time by a qualified physician.

Also in a prospective randomized study, Brasel et al. [91] studied the necessity of inserting a chest drain for an occult traumatic pneumothorax. Chest drains were inserted in 18 patients while 21 patients were clinically observed only. Ventilation was necessary in 9 patients in each group. In the group with chest drains, the pneumothorax increased in 4 patients; in the group without chest drain, a Bülau drain was inserted in 3 patients, of whom 2 patients were then also ventilated.

In a prospective study of 36 patients with 44 occult pneumothoraces, the subdivision was made into minimal (< 1 cm visible on a maximum of 4 CT slices), anterior (> 1 cm but not extending laterally into the dorsal half of the chest), and anterolateral pneumothoraces [92]. Fifteen minimal pneumothoraces were closely clinically monitored irrespective of the necessity for ventilation. The secondary insertion of a chest drain was then required in 2 cases. A drain was always inserted for anterior and anterolateral pneumothoraces if ventilation was required. In a prospective study of children, Holmes et al. identified 11 patients with occult pneumothoraces which were also subdivided according to the above-mentioned plan [93]. In the case of minimal pneumothoraces, the patients were also conservatively treated irrespective of the necessity for ventilation.

In a retrospective study, patients with pneumothorax were treated with (13) and without (13) a chest drain [94]. Out of 10 patients who required mechanical ventilation, 2 patients had to have a secondary chest drain inserted. However, there are no data on the size of the initial pneumothorax. In another retrospective study, the size of the occult pneumothorax was compared against the requirement to insert a chest drain and it was suggested that pneumothoraces less than 5 x 80 mm could be observed irrespective of the necessity for mechanical ventilation [95]. Weißberg et al. [96] stated in their retrospective study of 1,199 patients (of whom 403 patients had traumatic pneumothorax) that management by clinical observation is possible for a pneumothorax volume less than 20% of the pleural space. However, there are no details on the effect of possible mechanical ventilation.

A score was proposed by De Moya for the improved definition of the “small” pneumothorax, which is composed of 2 parts: 1) the largest diameter of the pneumothorax and 2) its relationship to the pulmonary hilus. If the pneumothorax does not exceed the pulmonary hilus, 10 is added to the millimeter figure of the pneumothorax; if the hilus is exceeded, 20 is added. The sum of the individual values for each side gives the score value. The positive predictive value for a chest drain was 78% for a score > 30 and the negative predictive value was 70% for a score < 20 [136]. In a randomized study of 21 ventilated patients, observation of the occult pneumothorax proved to be reliable. In 13 patients initially treated without a chest drain, there was no need for emergency decompression in any case even though pleural effusion had to be decompressed during the course in 2 patients and an increasing pneumothorax had to be decompressed after insertion of a central venous catheter in one patient. It seems justifiable to take a “wait and see” attitude towards inserting a chest drain for an occult pneumothorax both in spontaneously breathing and ventilated patients [129, 130].

Key recommendation:

Pericardial decompression should be carried out if there is evidence of pericardial tamponade and acute deterioration in vital parameters.	**GoR B**

Explanation:

Irrespective of the patient’s condition, the diagnosis of pericardial tamponade should be made rapidly and reliably so that surgery can be performed quickly if required. Although the diagnosis of tamponade can be confirmed by the insertion of a pericardial window, this is an invasive procedure, particularly if there is only slight suspicion of a cardiac injury. Ultrasound examination has been proven to be a sensitive procedure in the diagnosis of pericardial effusion and thus represents the current method of choice. In a prospective multicenter study of 261 patients with penetrating pericardial chest injuries, there was a sensitivity of 100%, a specificity of 96.7%, and an accuracy of 97% [30]. There were no false-negative study results. In another study, fluid was detected by ultrasound scan in the pericardium in 3 cases out of 34 patients. One patient, who was hemodynamically unstable, underwent a thoracotomy and the other two patients had a negative pericardial window [105].

Pericardiocentesis is now of lesser importance in the diagnosis of pericardial tamponade, having been replaced by ultrasound examination [30, 106].

Key recommendation:

A thoracotomy can be performed if there is an initial blood loss of > 1,500 ml from the chest drain or if there is persistent blood loss of > 250 ml/h over more than 4 hours.	**GoR 0**

Explanation:

The indication for thoracotomy depending on the volume of initial or continuous blood loss from the chest drain has been intensely discussed by the guideline group, not least because of the inconsistent volumes described in the literature. These are almost exclusively cohort studies on penetrating trauma; randomized studies are not available on this research question. The available data is considerably less clear for blunt trauma; a thoracotomy is indicated rather less frequently and usually later than for penetrating trauma. Under certain circumstances, with a certain volume of blood loss, the thoracotomy can also be useful in hemodynamically stable patients. There are no data on coagulation status as a decision criterion but body temperature can be taken into account.

In the 1970s, based on the experiences of penetrating injuries in the Vietnam War, McNamara et al. [107] described a reduction in mortality after early thoracotomy. Indication criteria for thoracotomy were given as an initial blood loss after chest drainage of 1,000-1,500 ml and a blood loss of 500 ml during the first hour after insertion of the drain.

Kish et al. [108] analyzed 59 patients in whom one thoracotomy was necessary. A thoracotomy was performed in 4 out of 44 patients with penetrating injuries and in 2 out of 15 patients with blunt trauma 6-36 hours after the accident where there was continuous bleeding of 150 ml/hour over more than 10 hours or 1,500 ml over a shorter time span. The strategy of performing a thoracotomy where there is an initial blood loss of > 1,500 ml after insertion of a chest drain or a continuous hourly blood loss of > 250 ml over 4 hours is accepted for penetrating injuries [109].

In a multicenter study of 157 patients who had a thoracotomy because of chest bleeding, there was a correlation between mortality and the level of thoracic blood loss [110]. With a blood loss of 1,500 ml compared to 500 ml, the mortality risk was increased by the factor 3.2. The authors thus conclude that a thoracotomy should be considered in patients with penetrating and blunt trauma with a thoracic blood loss of 1,500 ml in the first 24 hours after admission even if there are no signs of hemorrhagic shock.

In the current version of the NATO Handbook [111], an initial blood loss of 1,500 ml and drainage of 250 ml over more than 4 hours are given as indication for a thoracotomy. The different volumes given as threshold values for indicating a thoracotomy were checked by the guideline group. Agreement was reached on the volume laid down in the recommendation of > 1,500 ml initially or > 250 ml/h over more than 4 hours.

Key recommendation:

An emergency thoracotomy should not be performed in the emergency room on patients with blunt trauma and absence of vital signs at the accident scene.	**GoR B**

Explanation:

If vital signs are absent at the accident scene, an emergency thoracotomy is not indicated in the emergency room for patients with blunt trauma. Vital signs include pupillary reaction to light, any type of spontaneous breathing, movement caused by painful stimulus or supraventricular activity in the ECG [112]. However, if cardiac arrest only develops on admission to hospital, an immediate thoracotomy should be performed particularly in the case of penetrating trauma.

Boyd et al. carried out a retrospective study of 28 patients who underwent a thoracotomy in the emergency room for the purpose of resuscitation. A meta-analysis was also carried out [112]. The survival rate was 2 out of 11 patients with penetrating trauma and 0 out of 17 patients with blunt trauma, with the survival rate (2 out of 3 patients) being highest if vital signs were present both at the accident scene and in the emergency room. A meta-analysis of 2,294 patients yielded a survival rate of 11% with the survival rate being significantly better after penetrating trauma compared to blunt trauma (14% versus 2%). There were no survivors in the patient group with absent vital signs at the accident scene and there were no survivors of blunt trauma without neurologic deficit among the patients with absent vital signs in the emergency room.

Velhamos et al. [113] retrospectively analyzed 846 patients, who underwent an emergency thoracotomy in the emergency room. All patients presented a loss of vital signs at the time of admission or cardiac arrest in the emergency room. Out of 162 patients who were successfully resuscitated, it was possible to discharge 43 (5.1%) from hospital with 38 of these patients having no neurologic deficit. Out of 176 patients with blunt trauma, only 1 patient (0.2%) survived with serious neurologic deficits.

Branney et al. [114] found an overall survival rate of 4.4% in 868 patients who underwent emergency thoracotomy. Eight out of 385 patients with blunt trauma survived (2%). Of these, 4 patients had no neurologic deficit. Out of patients with blunt trauma and absent vital signs at the accident scene, 2 patients survived with serious neurologic deficit. In contrast, the outcome for absent vital signs at the accident scene and penetrating trauma was markedly better with 12 neurologically-intact surviving patients out of 355. This result differs markedly from the above-mentioned meta-analysis by Boyd et al. [112] and later studies by Esposito et al. [115], Mazzorana et al. [116], Brown et al. [117], and Lorenz et al. [118], which described no surviving patients among those with penetrating trauma and absent vital signs.

Another retrospective study of 273 thoracotomies performed in the emergency room yielded 10 surviving patients without neurologic deficit [119]. These all had penetrating injuries and presented vital signs either at the accident scene or in the emergency room. Out of 21 patients with blunt trauma, no patient survived. The authors thus conclude that an emergency room thoracotomy should only be performed on patients with penetrating trauma who show vital signs either at the accident scene or in the emergency room. Out of 19 patients with blunt trauma, Grove et al. [120] were also unable to list any surviving patients after an emergency thoracotomy. On admission, 5 of these patients showed no vital signs and 14 patients showed vital signs. All patients died within 4 days. The survival rate for penetrating trauma was 3 out of 10 patients.

Based on a meta-analysis of 42 outcome studies with a total of 7,035 documented “Emergency Department Thoracotomies”, the American College of Surgeons has published a guideline on the indication and performance of an emergency room thoracotomy [131]. The resulting statements are based chiefly on the finding that, with an overall survival rate of 7.8%, only 1.6% of patients survived after blunt trauma but 11.2% after penetrating trauma. More recent studies have also confirmed that an emergency thoracotomy during cardiopulmonary resuscitation (CPR) can improve the prognosis particularly in the case of penetrating trauma and appears to be particularly expedient if vital signs are initially present [132, 133, 134, 135].

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2.5 Abdomen

Key recommendation:

The abdomen must be examined although a normal finding does not exclude a relevant intraabdominal injury even in the alert patient.	**GoR A**

Explanation:

In a prospective study of hemodynamically stable patients after blunt abdominal trauma, Miller et al. describe how, out of 372 patients examined, an intraabdominal injury could be detected by CT in only 25.5% of 157 with a painful abdomen or pelvis. The CT detected an injury in only 20% of patients with "seatbelt sign" [24].

Livingston et al. [18] report in a multicenter prospective study of 2,299 patients with blunt abdominal trauma (exclusion criteria: GCS $\leq$ 14, children $\leq$ 16, patients having undergone emergency laparotomy) that 1,406 (61%) of patients had a positive clinical examination with regard to external signs of injury or stomach pain. Of these, an abdominal injury could only be detected by CT in 26 % whilst the clinical examination was recorded as normal in 11% of patients with an injury detected in the CT. Out of 265 patients with free intraabdominal fluid detected in the CT, 212 (80%) had an abnormal finding in the clinical examination. In the study, the sensitivity of the clinical examination for free fluid detected in CT is 85%, specificity 28%, the positive predictive value 63%, and the negative predictive value 57%.

In a prospective study of 350 patients, Ferrara et al. studied the informative value of abdominal painfulness for the presence of an intraabdominal injury which had been verified either by CT or diagnostic peritoneal lavage (DPL) [6]. They calculated a sensitivity of 82%, a specificity of 45%, and a positive predictive value of 21% with a negative predictive value of 93%.

In a prospective study of 162 patients (2001-2003, Level 1 trauma center) after blunt trauma with a state of clear consciousness (GCS ≥ 14) and normal clinical examination of the abdomen (but with the necessity of an emergency extraabdominal surgical intervention [88% trauma surgery] and a CT scan of the abdomen), Gonzalez et al. [7] showed that these patients do not need to receive any CT diagnostic test prior to the emergency intervention being carried out as the clinical examination offers sufficient reliability in this patient population. The CT diagnostic study produced pathologic intraperitoneal findings in only 2 cases (1.2%), which did not require further intervention (spleen injury, mesenteric hematoma).

Concomitant injuries

In a study of 1,096 patients with blunt abdominal trauma, Grieshop et al. [9] attempted to discriminate clinical options by which patients who do not require a further diagnostic test such as CT or DPL could be filtered out. Patients in a state of shock with a GCS value < 11 or who had suffered spinal trauma were analyzed but due to the limited possibility of clinical examination were not included in the statistics (n = 140). The authors came to the conclusion that besides an abnormal clinical examination (abdominal tenderness, guarding or other signs of peritonism) the presence of gross hematuria or chest trauma (fractures in ribs 1 or 2, multiple rib fractures, sternum fracture, scapula fracture, mediastinal widening, hemo- or pneumothorax) must also be viewed as risk factors. According to them, the risk of an intraabdominal injury with concomitant chest trauma increases by a factor of 7.6 and in the case of a concomitant gross hematuria by a factor of 16.4. All patients with relevant intraabdominal injuries (n = 44) belonged to the group with either an abnormal clinical examination or the presence of either or both cited risk factors (n = 253) corresponding to a sensitivity of 100%. To exclude an injury to an organ, the authors further claim that additional diagnostic tests, e.g., performing a computed tomography scan of the abdomen, must be carried out in such cases. No intraabdominal injuries were found in the remaining 703 patients who had neither an abnormal clinical examination nor a risk factor. The calculated negative predictive value was 100% so that further diagnostic tests could be dispensed with in these cases. A concomitant bony pelvic injury, a closed traumatic brain injury, spinal injuries, and fractures of the long bones in the lower extremity are not significant independent risk factors according to this study.

In contrast, Ballard et al. and Mackersie et al. found in prospective studies that pelvic fractures are also linked to an increased risk of intraabdominal organ injury so that a computed tomography diagnostic test is thus required for several reasons [2, 20].

Schurink et al. [39] studied the importance of the clinical examination in a retrospective study of 204 patients with further subdivision of the collective into 4 groups: patients with isolated abdominal trauma (n = 23), patients with lower rib fractures (ribs 7-12) (n = 30), patients with isolated head injury (n = 56), and multiply injured patients (ISS ≥ 18) (n = 95). All patients received an abdominal ultrasound examination. With reference to the group with isolated abdominal trauma, the researchers found in the clinical examination of 20 patients a sensitivity of 95%, and a negative predictive value of 71% with a positive predictive value of 84% for the presence of an intraabdominal injury. In the patients with rib fractures, there was a sensitivity and a negative predictive value of 100% in 4 abnormal clinical findings.

Ultrasonography

Key recommendations:

Initial focused abdominal ultrasonography should be performed to screen for free fluid, "focused assessment with ultrasonography for trauma" (FAST).	**GoR B**
Ultrasound examinations should be repeated at intervals if a computed tomography scan cannot be performed promptly.	**GoR B**
If computed tomography cannot be performed, a focused ultrasonographic search for parenchymal injuries can represent an alternative to FAST.	**GoR 0**

Explanation:

In a systematic review of 4 randomized controlled trials on the value of ultrasound-based algorithms in diagnosing patients after blunt abdominal trauma, Stengel et al. showed that there is no evidence at present to recommend ultrasound-based algorithms [45]. The same author carried out an earlier meta-analysis/systematic review on the topic of the diagnostic value of ultrasonography as the primary test tool for detecting free intraabdominal fluid (FAST) (19 studies) or an intraabdominal organ injury (11 studies) after blunt abdominal trauma. The 30 analyzed studies included studies up to July 2000 with a total of 9,047 patients and evidence levels from IIb-IIIb [44]. One reported result of the analysis is that abdominal ultrasonography has only low sensitivity in diagnosing free fluid and intraabdominal organ injuries. It is stated, for example, that 1 in 10 organ lesions are not identified in primary ultrasonography. For this reason, ultrasonography is considered inadequate in the primary diagnostic study after abdominal trauma, and additional diagnostic tests (e.g., helical CT) are recommended both in the case of a negative and a positive finding [44, 45].

FAST

In a prospective study of 359 hemodynamically stable patients, Miller et al. studied the importance of FAST under the hypothesis that confidence in the reliability of a FAST examination leads to intraabdominal injuries after abdominal trauma being missed [24]. As the gold standard, an abdominal CT scan was performed on all patients within 1 hour of the ultrasound examination. FAST was carried out in 4 views and positively assessed if there was evidence of free fluid. The FAST examination yielded 313 true-negative, 16 true-positive, 22 false-negative, and 8 false-positive findings. This led to a sensitivity of 42%, a specificity of 98%, a positive predictive value of 67%, and a negative predictive value of 93%. Of the 22 patients with a false-negative diagnosis, 16 had parenchymal damage of the liver or spleen, one each had a mesenteric injury and a gallbladder rupture, 2 had a retroperitoneal injury, and 2 further patients had free fluid without any injury detectable by CT. Six patients in this group required surgery and one underwent vascular embolization by means of angiography. Among the 313 patients with a true-negative FAST finding, a further 19 hepatic and splenic injuries, and 11 retroperitoneal injuries (inter alia hematoma in the aortic wall, bleeding from pancreas head, renal contusion) were diagnosed by the CT scan. None of these patients had to undergo surgery. Consequently, irrespective of the FAST examination finding, the authors call for further assessment of the adequately hemodynamically stable patient by a CT scan of the abdomen and pelvis [24].

In a systematic review of studies by McGahan et al. on the importance of FAST in the diagnostic study after abdominal trauma, the sensitivity of the examination for detecting free fluid ranged widely from 63 to 100%. McGahan et al. are critical of the fact that, in the studies which gave high sensitivities and which cited FAST as a suitable initial screening method, significant weaknesses can be found in the study design (no standard reference, no consecutive inclusion) [22].

Various other authors also report on organ injuries which could not be diagnosed by FAST and led to subsequent surgical intervention. In a retrospective study of 2,576 patients, Dolich et al. found that there were false-negative FAST findings in 1.7% (43 patients) [5]. Ten of these patients had to undergo a laparotomy as a result. The lack of hemoperitoneum in detected intraabdominal injuries is described as a limitation of the FAST examination, which is intended to be used for the primary rapid screening of free fluid. In a retrospective study, it was demonstrated that 34% of patients (157 out of 467 patients) with an intraabdominal injury had no hemoperitoneum and thus eluded diagnosis. Twenty-six of these patients had to undergo surgery [40].

Soyuncu et al. describe a prospective case series with 442 included patients who sustained a blunt abdominal trauma. They were able to show that a FAST examination carried out by an operator experienced in abdominal ultrasonography (minimum 1 year's experience) has a sensitivity of 86% and a specificity of 99% with 0.95% false-positive and 1.1% false-negative results (verified by laparotomy, CT, autopsy) [43].

Ultrasonography with organ diagnosis

In a prospective study, Liu et al. [17] compared among 55 hemodynamically stable patients the diagnostic evidential value of ultrasound (with screening for free fluid and organ lesion), computed tomography, and DPL each on the same patients. The DPL was carried out after the imaging procedures so that they did not falsify the diagnosis of free fluid. In the diagnosis of an intraabdominal injury (without differentiating between the detection of free fluid and the direct detection of an organ lesion), the authors found a sensitivity of 91.7% and a specificity of 94.7% for ultrasound, which lay below the results of DPL and CT. The disadvantages of ultrasound are: (1) the technical difficulty of ultrasound in subcutaneous emphysema, (2) in pre-operated patients free fluid possibly may not flow into the Douglas space and thus elude diagnosis, (3) pancreas and hollow organ injuries might not be well assessed and (4) the poor assessability of the retroperitoneal space. In conclusion, the authors recommended ultrasound because of its practicability as a primary diagnostic tool in the examination of hemodynamically unstable patients. However, due to the limitations cited, they warned against overestimating its informative value.

In a study of 3,264 patients, Richards et al. [34] examined the quality of the abdominal ultrasound examination in the diagnosis of free fluid and parenchymal organ lesions after abdominal trauma. Diverging from the FAST examination, ultrasound was thus used explicitly in this study to detect parenchymal organ lesions in the liver and spleen or kidneys. The results were verified by CT, laparotomy, DPL or clinical observation. Free fluid was detected by ultrasonography in 288 patients and checked by CT and laparotomy. This yielded a sensitivity of 60%, a specificity of 98%, a negative predictive value of 95%, and a positive predictive value of 82% for the diagnosis of free fluid alone. Specific organ lesions were found in 76 cases, 45 with simultaneously occurring free fluid. The simultaneous focused ultrasound for a parenchymal organ lesion increased the sensitivity of the diagnosis of an intraabdominal injury to 67%.

Like Richards and Liu et al., Brown et al. [4] examined 2,693 patients after abdominal trauma for free fluid and also focused for parenchymal injuries. Of these, 172 had an intraabdominal injury which had been verified by laparotomy, DPL, CT, clinical course or autopsy. In 44 patients (26%) no hemoperitoneum could be detected in the ultrasound but in 19 of these patients (43%) an organ lesion could be diagnosed in the ultrasound. The authors conclude that organ injuries are missed by limiting to short ultrasonography focused (FAST) on the diagnosis of free fluid. As part of the emergency diagnostic study, therefore, an ultrasound examination must be carried out to look for free fluid and injuries to parenchymal organs.

In a prospective study of 800 patients, higher sensitivities (88%) for the detection of an intraabdominal injury were found by Healey et al. [10]. This study also included screening for free fluid and organ lesions, which were compared to CT, DPL, laparotomy, repeated ultrasonography or clinical course.

In a comparative study design, Poletti et al. [33] also reported higher sensitivities. They examined 439 patients after abdominal trauma. Of these patients, 222 were not further examined after the primary normal finding and were discharged with the proviso that they should return if they thought there was deterioration. Only the remaining 217 patients were analyzed: For the ultrasonography, a sensitivity of 93% (77 out of 83 patients) was demonstrated for detecting free fluid and a sensitivity of 41% (39 out of 99 patients) for the direct detection of a parenchymal organ injury, injuries to the liver being well diagnosed compared to other organ lesions. In a repeat examination in the case of a primary negative finding, these values could be increased further but a pathologic finding had previously been found in a CT examination and was also known to the examiner. A total of 205 patients underwent a follow-up CT examination.

Likewise, in these two studies and in another by Yoshii et al. [52], the high sensitivities for detecting free fluid are debatable as not all patients received a baseline examination and/or different baseline examinations (DPL, CT, laparotomy, repeat ultrasonography, clinical observation) had been used. In addition, patients with primary normal findings were discharged and did not receive a follow-up examination either [31].

McElveen et al. [21] studied 82 consecutive patients (for free fluid and organ lesion) and verified all these patients with a baseline examination (71 by CT, 6 by repeat examination, 3 by DPL, and 2 by laparotomy) and a follow-up for a period of 1 week after trauma, either as an inpatient or an outpatient. With a sensitivity of 88% and a specificity of 98%, accompanied by a negative predictive value of 97% for the diagnosis of an intraabdominal injury, they recommended the ultrasound examination as the initial examination method after abdominal trauma.

In a prospective examination of 210 consecutively included, hemodynamically stable patients after blunt abdominal trauma, Poletti et al. compared the diagnostic quality of ultrasonography (with and without intravenous contrast agent) with CT. The patients first received conventional ultrasonography (including organ diagnostic workup) and then a CT scan. Patients with false-negative findings in the primary ultrasonography then received conventional repeat ultrasonography and, if that yielded a negative finding as well, contrast agent enhanced ultrasound examination. Poletti et al. [32] showed that neither conventional repeat ultrasonography nor contrast agent enhanced ultrasonography achieved the quality of computed tomography in detecting organ injuries. In the computed tomography, 88 organ injuries (solid organs) were detected in 71 patients. Out of 142 patients in whom no free fluid (intra- or retroperitoneal) could be detected in the CT, 33 (23%) organ lesions (all organs) were found. Four of these patients (12%) required an intervention (laparotomy/interventional angiography). Primary ultrasonography identified 40% (35 out of 88), monitoring ultrasonography 57% (50 out of 88), and contrast agent enhanced ultrasonography 80% (70 out of 88) of injuries to solid organs. They concluded that even contrast agent enhanced ultrasonography cannot replace computed tomography in hemodynamically stable patients.

Repeat examinations

With regard to the importance of repeat sonographic monitoring of the patient after abdominal trauma, Hoffmann et al. [13] showed that in 19 (18%) of 105 patients with a primary unclear finding it was only possible to definitely detect free fluid intraabdominally with a repeat ultrasound examination in the emergency room (after circulation-stabilizing procedures). The authors pointed out that, if possible, the examination should be carried out by the same examiner to achieve optimum monitoring. The monitoring examination should be carried out about 10-15 minutes after the primary examination in patients with initially minimal evidence of fluid (1-2 mm border) or unclear findings. Compared to a DPL, a possible increase in free fluid can by documented by repeat ultrasonography and the ultrasonography can also be used to diagnose retroperitoneal and intrathoracic injuries.

In the above-mentioned study, Richards et al. [34] also report an increase in sensitivity of the ultrasound examination through a repeat examination.

In a prospective study of 156 patients after blunt or penetrating abdominal trauma, Numes et al. [29] showed that, through repeat ultrasound examinations during the course, false-negative results for the detection of free intraabdominal fluid could be reduced by 50% and thus the sensitivity of 69% (with a single scan) was increased to 85%.

Practitioners

With regard to the question as to who must carry out the examination, Hoffmann et al. [13] are of the opinion that stand-alone screening for free fluid by ultrasound is easily learnt and can then be reliably carried out by a member of the emergency room team. However, the extent to which specific questions can be reliably answered depending on the type and length of training remains unclear.

A prospective study by Ma et al. [19] showed that a 10-hour theory introduction coupled with carrying out 10-15 examinations on healthy subjects is sufficient to achieve diagnostic certainty in emergency ultrasonography of the abdomen provided this is restricted to detection/exclusion of free fluid.

McElveen et al. [21] make the same recommendation although it is not based on a study. They stipulate 15 examinations on normal patients and 50 monitored examinations on trauma patients.

A retrospective study by Smith et al. [42] on the quality of the ultrasound by trained, experienced surgeons showed that previous extensive ultrasound experience is not required and there is no learning curve.

Although also without a comparator study, Brown et al. [4] call for screening for specific organ lesions to be also included in terms of increasing the sensitivity of the ultrasound examination, and recommend that this is carried out by an experienced practitioner.

Diagnostic peritoneal lavage (DPL)

Key recommendation:

Diagnostic peritoneal lavage (DPL) must only be used in exceptional cases.	**GoR A**

Explanation:

With a sensitivity of 100% and a specificity of 84.2%, DPL was the most sensitive method for detecting an intraabdominal injury in the comparative study with CT and ultrasonography by Liu et al. [17]. As the authors argue, however, the high sensitivity (e.g., by detection of blood from catheter insertion) leads to a relevant number of non-therapeutic laparotomies. Lui et al. are critical of DPL also when a retroperitoneal hematoma is present as even small tears in the peritoneum were reported to yield a positive result, which led to an unnecessary laparotomy in half of the 6 patients with a retroperitoneal hematoma.

DPL is rapid and, like ultrasonography, can be carried out in parallel with stabilization of the patient. Its interpretation is not as practitioner-dependent as ultrasonography, it is easy to learn and can also be repeated. The complication rate is generally given as approximately 1% [8, 23, 47]. Limitations of DPL are its invasiveness and lack of ability to confirm precisely the underlying injury type and location of the injury and thus the assessment of its clinical relevance. Using a study of 167 patients with stable circulation with suspected intraabdominal lesion, Mele et al. showed that, firstly, the number of missed injuries could be reduced by combining a positive DPL with a subsequent specific examination such as CT compared to a single diagnostic test by CT and, secondly, as with stand-alone DPL, the number of unnecessary laparotomies could be reduced [23].

Gonzalez et al. [8] came to the same results in a study of 252 hemodynamically stable patients.

Due to the lower complication rate, with identical diagnostic accuracy, preference should be given to the open technique over the closed technique for carrying out DPL [12].

Hoffmann [13] sees the indication for DPL only in exceptional cases where patients cannot be examined with ultrasound (e.g., extreme obesity or abdominal wall emphysema) as DPL permits no conclusion on retroperitoneal injuries compared to ultrasound and to CT. Waydas cites prior laparotomies in the lower abdomen in particular as a contraindication of DPL. However, in a prospective study of 106 multiply injured patients, the authors found a marked lower sensitivity for ultrasonography (88%) compared to DPL (95%). Despite the lower sensitivity, they recommended ultrasound as the initial screening method because it is non-invasive, never contraindicated, and as a diagnostic tool is also able to detect specific organ lesions. In the case of hemodynamic instability with unclear or negative ultrasound finding, this method can be supplemented by DPL to increase sensitivity [47].

Indications for primary use of DPL theoretically exist for hemodynamically unstable patients and if other diagnostic tools (ultrasonography) have failed.

Computed tomography

Key recommendation:

Multi-slice helical CT (MSCT) has a high sensitivity and the highest specificity for identifying intraabdominal injuries and must therefore be carried out after abdominal trauma.	**GoR A**

Explanation:

In the prospective study by Liu et al. [17], the authors compared among 55 hemodynamically stable patients the diagnostic evidential value of ultrasound (with screening for free fluid and organ lesion), computed tomography, and DPL each on the same patients. They found a sensitivity of 97.2% with a specificity of 94.7% for CT. Correspondingly good results are also separately described in more recent studies [15, 30] for the detection of a hollow organ injury by computed tomography (after administration of an oral, intravenous contrast agent) but in other studies this was identified as a diagnostic weak point of CT [41]. In addition, Liu et al. describe the advantages of computed tomography of the abdomen compared to ultrasonography and DPL because of the option of reliably imaging the retroperitoneum as well. CT can differentiate well between hemoperitoneum and fluid retention and can localize fresh bleeding by means of contrast agent. In addition, computed tomography of the abdomen (through the bone window) could simultaneously provide a diagnostic study of the spine and the pelvis (or a full-body helical scan depending on the injury pattern) [28]. Due to the results likewise already reported, Miller et al. and other authors recommend computed tomography of the abdomen in patients with stable circulation irrespective of the ultrasound result from a FAST examination as CT appears, in comparison, to be more sensitive in diagnosing an intraabdominal lesion [24].

With regard to the technicalities of the examination, Linsenmaier recommends a multi-slice helical CT (MSCT) with regular venous administration of contrast agent for abdominal trauma. At a pitch of 1.5, the layer thickness should be a minimum of 5-8 mm in the craniocaudal scanning direction. If there is a suspected injury to the genitourinary system, a delayed scan (3-5 minutes after bolus dose) should be carried out [16]. If it is feasible, an oral contrast agent can also be administered in principle to improve the diagnosis of intestinal injuries [16, 28]. Novelline describes the administration of Gastrografin via nasogastric tube first in the emergency room directly after insertion, then shortly before transfer, and lastly in the gantry. Normally, the stomach, duodenum, and jejunum could be visualized in this way. It is also possible to contrast the rectum/sigmoid via administration of a contrast agent through a rectal drain [28].

In a retrospective case-control study of 96 patients (54 consecutively included with intestinal/mesenteric injury and 42 matched pairs without injury) with laparotomy after abdominal trauma and with pre-operative CT (standardized with administration of an oral contrast agent via the nasogastric tube while still in the emergency room), Atri et al. [1] showed that the multi-slice CT reliably detects relevant injuries in the intestine/mesentery and has a high negative predictive value. Three radiologists at different stages of training evaluated the CTs without knowing the outcome. Thirty-eight (40%) of those examined had surgically relevant injuries, 58 (60%) had either no or negligible injuries in the intestine or mesentery. Sensitivity was between 87-95% for the 3 examiners. Only 10 CTs were carried out without oral contrast agent as the patients were transferred immediately to CT.

In contrast, Stuhlfaut et al. came to the conclusion in a retrospective study of 1,082 patients (2001-2003) who underwent a multi-slice CT of the abdomen and pelvis without oral contrast agent that this procedure is sufficient to detect intestinal and mesenteric injuries that require surgical treatment. Fourteen patients had a suspected intestinal or mesenteric injury after the CT. Four CTs of these patients showed a pneumoperitoneum, 2 a mesenteric hematoma and intestinal wall changes, and 4 each showed only a mesenteric hematoma or intestinal wall thickening. In 11 of these patients, an intestinal/mesenteric injury was surgically confirmed. There were 1,066 true-negative, 9 true-positive, 2 false-negative, and 5 false-positive results. Sensitivity was 82% and specificity 99%. The negative predictive value of the multi-slice helical CT (MSCT) examination without contrast agent was 99% [46].

In cases of unclarity (only unspecific radiologic findings), Brofman et al. [3] recommend a clinical re-evaluation and a repeat examination for the possible presence of intestinal/mesenteric injuries.

The introduction of multi-slice helical CTs is evaluated unanimously by expert opinion as progress in helical CT technology because, in addition to better resolution, the scanning period can be considerably shortened and motion artifacts have less effect [16, 28, 33, 35]. The same authors point out the importance of using pre-programmed protocols for CT diagnosis of recently injured persons (positioning, layer thickness, table advance, time and type of administration of contrast agent, bone/soft tissue window, reconstructions) as the examination can thereby be considerably shortened. In considering the concomitant injuries, some authors recommend the use of a full-body MSCT after stabilization, if necessary (during which ultrasonography of the abdomen must be carried out to detect free fluid). Besides the examination of the abdomen, the full-body MSCT also allows the diagnostic study of head, thorax, skeletal trunk, and the extremities in one examination round [35].

Computed tomography is the only diagnostic method for which injury scores [25] exist, on the basis of which treatment decisions can be derived [38].

Carrying out an MSCT can be restricted by the hemodynamic status of the patient (see section “Influence of the hemodynamic status of the patient on diagnostic study”).

Influence of the hemodynamic status of the patient on the diagnostic study

Key recommendation:

An emergency laparotomy should be introduced without delay in patients who cannot be hemodynamically stabilized because of an intraabdominal lesion (free fluid). The possibility of shock of non-abdominal origin should be considered here.	**GoR B**

Explanation:

The diagnostic algorithm of a patient with blunt abdominal trauma is fundamentally influenced by his vital parameters.

The immediate evaluation and stabilization of the vital parameters thus have top priority in the early phase of treatment. In this section of the early hospital treatment phase, a systolic blood pressure of > 90 mmHg after infusion of 2,000 ml of crystalloid solution (or > 100 mmHg in elderly patients) is considered hemodynamically stable with regard to circulatory stability. If, despite immediate volume replacement and massive transfusion, adequate circulatory function cannot be restored, Nast-Kolb et al. call for an immediate emergency laparotomy to be performed in the event of a positive accident anamnesis and existing suspicion of an intraabdominal injury [27]. It is imperative that, even with unstable vital parameters, the indication for emergency laparotomy should be supported by ultrasonography of the abdomen in parallel with polytrauma management. This basic diagnostic work-up is possible without an additional delay in time [17, 33]. Nast-Kolb's working group calls for early laparotomy when a state of shock exists and in multiply injured patients (ISS ≥ 29) even if the detection of fluid is only small. The authors justify this with the fact that a retrospective, non-therapeutic laparotomy, compared to the necessary secondary operation in the case of primary missed organ injury, represents considerably less traumatization and danger [27].

A CT examination of the abdomen should not be carried out until there is adequate circulatory stability [26, 27, 35, 36, 48] as therapeutic interventions which can sometimes be necessary for stabilizing the patient are only possible to a limited extent in the CT gantry [27, 35, 36, 48]. According to some authors, this recommendation maintains its validity despite the integration of the CT in the emergency room (in terms of a priority-oriented use of the emergency room CT after ABC with basic diagnostic work-up) [14, 49, 50], while Hilbert et al. [11] already discuss the primary use of CT even in unstable patients.

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2.6 Traumatic brain injury

Acute management in the emergency room

Once the clinical finding has been checked and the vital functions secured, an imaging diagnostic study that includes the brain is generally required for multiply injured patients with traumatic brain injury. As the immediate elimination of intracranial bleeding can be life-saving, there is no reason for delay if both respiratory and circulatory functions are stable. This requirement also applies to the responsive injured person at the accident scene who is sedated for intubation and transport because only a CT examination can differentiate between intracranial bleeding that is developing and a drug cause for unconsciousness.

Monitoring the clinical finding

Key recommendation:

State of consciousness with pupil function and Glasgow Coma Scale (bilateral motor function) must be recorded and documented at repeated intervals.	**GoR A**

Explanation:

In the literature, the only clinical findings with a prognostic informative value are the presence of wide, fixed pupils [11, 23, 26] and a deterioration in the GCS score [11, 15, 23], both of which correlate with a poor outcome. There are no prospective randomized controlled trials on using the clinical findings to guide the treatment. As such studies are definitely not ethically justifiable, the importance of the clinical examination was upgraded to a Grade of Recommendation A during the development of the guideline on the assumption, which cannot be confirmed at present, that the outcome can be improved by the earliest possible detection of life-threatening conditions with corresponding therapeutic consequences (see the following recommendations).

Despite various difficulties [3], the Glasgow coma scale (GCS) has established itself internationally as the assessment of the recorded severity at a given point in time of a brain function impairment. It enables the standardized assessment of the following aspects: eye opening, verbal response and motor response. The neurologic findings documented with time of day in the file are vital for the sequence of future treatment. Frequent checks of the neurologic finding must be carried out to detect any deterioration [11, 13].

However, the use of the GCS on its own carries the risk of a diagnostic gap, particularly if only cumulative values are considered. This applies to the initial onset of apallic syndrome, which can become noticeable through spontaneous decerebrate rigidity which is not recorded on the GCS, and to concomitant injuries to the spinal cord. Motor functions of the extremities must therefore be recorded with separate lateral differentiation in arm and leg as to whether there is incomplete, complete or no paralysis. Attention should be paid here to the presence of decorticate or decerebrate rigidity. Providing no voluntary movements are possible, reaction to painful stimulus must be recorded on all extremities.

If the patient is not unconscious, then orientation, cranial nerve function, coordination, and speech function must also be recorded.

2.7.3.2 Vital functions

Key recommendations:

The goals are normoxia, normocapnia, and normotension. A fall in arterial oxygen saturation below 90% must be avoided.	**GoR A**
Intubation with adequate ventilation (with capnometry and blood gas analysis) must be carried out in unconscious patients (reference value GCS ≤ 8).	**GoR A**
The goal in adults should be arterial normotension with a systolic blood pressure not below 90 mmHg.	**GoR B**

Explanation:

Prospective randomized controlled trials which study the effect of hypotension and/or hypoxia on the outcome are certainly indefensible on ethical grounds. However, there are many retrospective studies [11, 25] which provide evidence of a markedly worse outcome if hypotension or hypoxia is present. The first priority is to avoid all conditions associated with a fall in blood pressure or reduction of oxygen saturation in the blood. Due to side effects, however, aggressive treatment to raise blood pressure and oxygen saturation has not always proved successful. The goals are normoxia, normocapnia, and normotension.

Intubation is necessary in the case of inadequate spontaneous breathing but definitely also in the case of unconscious persons with adequate spontaneous breathing. Unfortunately, the literature does not contain any high quality evidence on this to prove a clear benefit for the intervention. The main argument in favor of intubation is the efficient prevention of hypoxia. This is a threat in unconscious persons even with adequate spontaneous breathing as the impaired protective reflexes can cause aspiration. The main argument against intubation is the hypoxic damage that can occur through misplaced intubation. In the conditions of the emergency room, however, it can be assumed that misplaced intubation can be recognized and corrected immediately. After intubating, it is frequently necessary to ventilate, the effectiveness of which must be monitored by capnometry and blood gas analyses.

Procedures to secure cardiac circulatory functions are arresting obvious bleeding (provided this has not already been done), monitoring blood pressure and pulse, and replacing fluid losses, as described in this guideline. Specific recommendations cannot be made for the infusion solution to be used in the case of concomitant traumatic brain injury [11].

Imaging diagnostic tests

Key recommendations:

A CCT scan must be performed in the case of polytrauma with suspected traumatic brain injury.	**GoR A**
A (monitoring) CT scan must be performed in the case of neurologic deterioration.	**GoR A**
A monitoring CCT should be performed within 8 hours on unconscious patients and/or if there are signs of injury in the initial CCT.	**GoR B**

Explanation:

The literature does not disclose any high quality evidence on which situations require cranial imaging when there is suspected traumatic brain injury. In TBI on its own, the following findings are associated with an increased risk of intracranial bleeding (absolute indication [16]).

- coma
- clouded consciousness
- amnesia
- other neurologic disorders
- vomiting if there is a close time relationship to the impact of force
- cramp seizure
- clinical signs or roentgenologic evidence of a brain fracture
- suspected impression fracture and/or penetrating injuries
- suspected cerebrospinal fluid fistula
- evidence of a coagulation disorder (third party medical history, “marcumar pass”, non-arresting bleeding from superficial injuries, etc.)

Optional indications that require close monitoring as an alternative to imaging comprise:

- unclear information about the accident history
- severe headache
- intoxication through alcohol or drugs
- evidence of high-energy trauma. These are [1] a vehicle speed > 60 km/h, a large deformation of the vehicle, penetration of > 30 cm into the passenger cabin, time required to rescue from vehicle > 20 min, a fall > 6 m, a rollover trauma, a pedestrian or motorbike collision at > 30 km/h or the rider being thrown from his motorbike.

As a bigger impact force can always be assumed in a multiply injured patient, there was consensus in the development of the guideline that cranial imaging must be performed in the event of symptoms of brain damage. If symptoms first occur during the course of treatment or increase in severity during the course, the imaging must be monitored as intracranial bleeding can have a delayed onset or can increase in size. The finding of compressive intracranial bleeding (see Chapter 3.5) requires surgical intervention without delay.

This recommendation is based on the clinical observation that in patients with initially apparently normal cranial computed tomogram (CCT), intracranial bleeding causing compression can develop or smaller findings not requiring surgery increase markedly in size and thus represent a surgery indication. The occurrence of neurologic symptoms can take several hours and is concealed by the intensive care treatment of unconscious patients. For this reason, there was agreement that monitoring of CCT should be carried out regularly in these cases.

Computed tomography is the gold standard of cranial imaging because of its generally rapid availability and easier examination procedure compared to magnetic resonance imaging [28]. Magnetic resonance imaging has a higher sensitivity for localized tissue injuries [10]. For this reason, it is recommended particularly in patients with neurologic disorders without pathologic CT finding.

Cerebral protection treatment

Key recommendation:

Glucocorticoids must not be administered in the treatment of TBI.	**GoR A**

Explanation:

Replacement of failed functions (respiration, nutrient intake [17, 25] etc.) is necessary in brain-injured patients. In the current state of scientific knowledge, the most important goal is to achieve homeostasis (normoxia, normotension, prevention of hyperthermia) and avert threatening (e.g., infectious) complications. Sepsis, pneumonia, and blood coagulation disorders are independent predictors of a poor clinical outcome [18]. The goal of these measures is to limit the extent of secondary brain damage and to provide those brain cells which have functional impairment but which have not been destroyed with the best conditions for functional regeneration. This applies equally if a traumatic brain injury is present in multiple injuries.

Controversy has surrounded the necessity of antibiotic prophylaxis in frontobasal fractures with liquorrhea. However, there is no evidence for administering antibiotics [5, 27].

Thrombosis prophylaxis by means of physical measures (e.g., compression stockings) is an undisputed measure for preventing secondary complications. When administering heparin or heparin derivatives, the benefit must be weighed up against the risk of an increase in the scale of intracranial bleeding as these drugs are not approved for brain injuries and thus their off-label use must be approved by the patient or his legal representative.

Antiepileptic treatment prevents the incidence of epileptic seizures in the first week after trauma. However, the incidence of a seizure in the early phase does not lead to a worse clinical outcome [22, 25]. Administration of antiepileptics extending over 1-2 weeks is not associated with a reduction in late traumatic seizures [6, 22, 25].

Up till now, the available data in the scientific literature has been unable to prove the benefit of other treatment regimens regarded as specifically cerebral-protective. At present, no recommendation can be given on hyperbaric oxygen treatment [4], therapeutic hypothermia [12, 21], administration of 21-aminosteroids, calcium antagonists, glutamate receptor antagonists or TRIS buffer [11, 14, 20, 30].

Administering glucocorticoids is no longer indicated due to a significantly increased 14-day case fatality rate [2, 7] with no improvement in clinical outcome [8].

Treatment of increased intracranial pressure

Key recommendation:

If severely elevated intracranial pressure is suspected, particularly with signs of transtentorial herniation (pupil widening, decerebrate rigidity, extensor reaction to painful stimulus, progressive clouded consciousness), the following treatments can be given: ▪ **Hyperventilation** ▪ **Mannitol** ▪ **Hypertonic saline solution**	**GoR 0**

Explanation:

In cases of suspected transtentorial herniation and signs of apallic syndrome (pupil widening, decerebrate rigidity, extensor reaction to painful stimulus, progressive clouded consciousness), hyperventilation can be introduced as a treatment option in the early phase after trauma [11, 25]. The guide values are 20 breaths/min in adults. However, hyperventilation, which used to be used because of its often impressive effect in reducing intracranial pressure, also causes reduced cerebral perfusion because of the induced vasoconstriction. With aggressive hyperventilation, this involves the risk of cerebral ischemia and thus deterioration in clinical outcome [25].

The administration of mannitol can lower intracranial pressure [ICP] for a short time (up to 1 hour) [25]. Preference should be given to managing treatment through ICP measurement [29]. Mannitol can also be given without measuring ICP if transtentorial herniation is suspected. Attention must be paid to serum osmolarity and renal function.

Up till now, there has been a paucity of evidence on the cerebral-protective effect of hypertonic saline solutions. Mortality appears to be somewhat less compared to mannitol. However, this conclusion is based on a small number of cases and is statistically not significant [29].

The raised position of the upper body to 30 ° is often recommended although CPP is not affected by this. However, extremely high ICP values are reduced.

(Analgesic) sedation per se has no ICP reducing effect. However, restless states with abnormal independent breathing can lead to an increase in ICP but can be favorably influenced. In addition, improved oxygenation can be achieved through improved breathing. There is insufficient evidence [19] for the administration of barbiturates, which was recommended in previous guidelines for intracranial pressure crises not controllable by other means [23]. When administering barbiturates, attention must be paid to the negative inotropic effect, possible fall in blood pressure, and impaired neurologic assessment.

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2.7 Pelvis

What importance does the initial clinical evaluation of the pelvis have?

Key recommendations:

An acute life-threatening pelvic injury must be excluded when the patient is admitted to the hospital.	**GoR A**
The stability of the patient's pelvis must be clinically examined.	**GoR A**

Explanation:

Circulatory unstable polytrauma with external pelvic massive bleeding represents an acute life-threatening situation. There is no alternative to immediate surgery to arrest bleeding and to accelerated blood replacement (expert opinion with strong evidence from medical experience in general). A life-threatening pelvic injury must therefore be excluded at the earliest opportunity within the first minutes after arrival in the emergency room [1].

Prerequisites for making the diagnosis are the pelvic examination for stability and external injury signs and inspection of the abdomen by ultrasonography.

As a rollover trauma is associated with a pelvic fracture in approximately 80% of cases, the detailed circumstances of the accident event should be ascertained.

The following definitions are commonly used for the most serious type of pelvic fracture with threatened vitals:

"in extremis" pelvic injury: external pelvic massive bleeding such as, for example, in traumatic hemipelvectomy or crush injuries after a severe rollover trauma

complex trauma of the pelvis and acetabulum: pelvic and acetabular fractures/ dislocations with additional peripelvic injuries to the cutaneous muscle sheath, the genitourinary system, the intestine, the great vessels and/or the major neural pathways

complex pelvic trauma, modified according to *Pohlemann* [43, 45]: similar see above including pelvic bleeding from torn pelvic veins and venous plexus

traumatic hemipelvectomy: unilateral or bilateral tearing of the bony hemipelvis combined with the tearing of the major intrapelvic neural and vessel pathways

pelvic-induced circulatory instability (importance of initial blood loss, e.g., > 2,000 ml according to Bone [6] and > 150 ml/min according to Trunkey [62])

If, based on the clinical assessment, a complex pelvic trauma in terms of an "in extremis" situation is probable (complex trauma with circulatory instability), the pelvic ring must be closed immediately, if possible while the patient is still in the emergency room.

The priorities of individual injuries should be weighed up against each other if several injuries are present. If one or several injuries per se are also life-threatening, only emergency pelvic stabilization is initially undertaken.

What procedures should be performed during the primary diagnostic study if pelvic injuries are suspected?

Key recommendation:

During the diagnostic study a pelvic survey radiograph should be taken and/or computed tomography (CT) be performed.	**GoR A**

Explanation:

Clinical examination

If the patient does not have acute life-threatening injuries, the physical examination can be carried out in more detail. It consists of an external inspection and palpation of the pelvic region ventrally and dorsally. The examination comprises the external search for bruising or hematomas, checking pelvic stability, and inspection of body orifices with vaginal and rectal examination. Shlamovitz et al. attest only a low sensitivity of the clinical examination of the pelvis for detecting a, by definition, mechanically unstable pelvic ring fracture [52]. In a study from Essen, the sensitivity and specificity of the clinical examination of the pelvis for instability was 44% and 99%, respectively. However, approximately 1/5 of the unstable pelvic injuries were first diagnosed using the survey radiograph of the pelvis [38]. In contrast to Kessel et al. [33] and Their et al. [57], who questioned the necessity of an emergency pelvic survey radiograph if there is provision for an emergency CT, the pelvic survey should continue to remain part of the emergency room diagnostic study of polytrauma, according to Pehle [38]. This also corresponds to the current recommendation of the ATLS® algorithm. The circulatory situation must be given priority in decision-making: according to the data from Miller et al. [35], if blood pressure does not respond to volume replacement, a 30% specificity can be concluded for relevant intrapelvic bleeding. Conversely, relevant bleeding can be excluded with a high degree of certainty if blood pressure exceeds 90 mmHg (negative predictive value 100%).

Imaging diagnostic tests:

The radiograph diagnosis should consist of a minimum of an a.p. (anteroposterior) view, which is then supplemented if necessary by inlet/outlet or oblique views according to Judet. Young et al. [66] describe that 94% of all pelvic fractures are correctly classified with only an a.p. view of the pelvis. Edeiken-Monroe [19] found a success rate of 88% for the a.p. view of the pelvis. Petrisor [41] found that the Judet views usually provide no relevant information.

There are several studies available on the comparison of CT and radiography diagnostic tests with respect to pelvic fractures: In a retrospective study by Berg [4], 66% of all pelvic fractures were detected in the a.p. radiograph whereas this rate was 86% in the CT scan with 10-mm axial slices. The inlet/outlet views also only achieved a success rate of 56%. The study by Harley [30] also found a higher sensitivity in the CT scan especially for identifying fractures in the sacrum and acetabulum. Resnik [46] also described how the plain radiograph misses 9% of fractures but noted that these missed fractures were not clinically relevant. In contrast, Stewart [55] recommends that plain radiography should be omitted if computed tomography is already planned. Kessel et al. [33], Their et al. [57], and Duane et al [18] also question the necessity of an emergency pelvic survey radiograph if there is provision for an emergency CT.

There is also a series of studies on the different modalities of CT diagnostic tests, which suggest the conclusion that a 3D reconstruction and particularly the multi-plane reconstruction provide clear information and simplify the presentation of the extent of the injury.

Naturally, the plain radiograph is of little help in diagnosing bleeding from the pelvic vessels. Such bleeding can be excluded with high probability only in cases in which no fracture can be detected in the radiograph. Individual studies have examined to what extent a classification of fractures can be deduced using conventional diagnostic radiology of vessel lesions. Thus, Dalal et al [15] found a significantly higher volume requirement particularly in critical anteroposterior pelvic fractures but which can also be explained by the intraabdominal injuries.

In addition, there are figures on the comparison of CT and angiography in the diagnostic study of relevant pelvic bleeding: In the study by Pereira [39], an accuracy exceeding 90% was demonstrated for the dynamic helical CT in identifying pelvic bleeding which required embolization. Similarly, Miller [35] also reports a sensitivity and specificity of 60% and 92%, respectively. For Kamaoui, the CT scan of the pelvis with or without contrast agent extravasation also assists in selecting patients who should undergo angiography [32].

In a study by Brown et al [9], 73% of patients with pelvic fracture and contrast blush in the CT showed relevant bleeding in the subsequent angiography. Conversely, a source of bleeding was found in the angiography in almost 70% of patients with a negative CT so that the relevance of the bleeding must be questioned here. Brasel et al. also describe contrast agent extravasation in the CT as a marker for the injury severity of pelvic injuries which, however, do not make angiography compulsory. Similarly to Brown, even though the CT was negative, they found bleeding in the pelvic region in 33% of cases, which benefit from angiography and embolization [8].

Blackmore [5] suggested inferring intrapelvic bleeding from contrast agent extravasation in the CT of 500 ml or more. The analysis of 759 patients produced a highly significant association for this correlation with a relative risk of 4.8 (95% CI, 3.0-7.8). With an extravasate exceeding 500 ml, bleeding is thus present in almost half of cases. However, provided that less than 200 ml extravasate is visible, it can be assumed with 95% certainty that there is no bleeding. Sheridan [51] reports that the bleeding can also be estimated in the plain CT as a correlation exists in the CT between hematoma formation and bleeding area exceeding 10 cm^3.

A current study from 2007 [24] studied as an alternative to CT the sensitivity and specificity of FAST in patients with pelvic fracture as a decision aid between emergency laparotomy and emergency angiography. The sensitivity and specificity for FAST yielded 26% and 96% but the emergency ultrasonography with negative result did not assist in deciding between the need for a laparotomy and angiography in patients with pelvic fracture [24]. A CT scan of the abdomen is stipulated for this decision and an ultrasound examination in terms of FAST is not classified as adequate [8].

Classification of injuries

The injuries of the bony pelvis should be classified using imaging diagnostic tests. A precise classification of the pelvic fracture forms the basis of prioritized treatment [19]. This classification should also be undertaken as soon as possible in patients with life-threatening vitals.

Generally, the classification of the Working Group on Osteosynthesis is used here, which distinguishes according to Tile between 3 groups:

- stable **A** injuries with osteoligamentous integrity in the posterior pelvis ring, intact pelvic floor; the pelvis can resist physiologic forces without dislocation
- rotationally unstable **B** injuries with partially retained stability in the posterior pelvic ring
- translationally unstable **C** injuries with disruption in all posterior osteoligamentous structures and also in the pelvic floor. The dislocation direction (vertical, posterior, distraction, excess rotation) plays a subordinate role. Thus, the pelvic ring is disrupted anterior and posterior and the pelvic halves are unstable.

The concept of a complex pelvic fracture applies to all bony injuries of the pelvis with an injury to the hollow visceral pelvic organs being simultaneously present or injuries to nerves and vessels or to the efferent urinary tract.

In addition, it is helpful to differentiate between open and closed pelvic injuries. A pelvic injury is described as open in the following situations:

- primary open pelvic fractures: according to the definition, direct link between bone fracture and skin or membrane of vagina or of anorectum
- closed pelvic fracture with enclosed tamponades for hemostasis
- closed pelvic lesion with documented contamination of the retroperitoneum due to an intraabdominal injury [31]
- In contrast, pelvic fractures only with an injury to the bladder or urethra should not be described as open but instead as complex. Due to the concomitant intraabdominal injuries with the risk of acute exsanguination and late onset sepsis, open pelvic injuries also have a high mortality rate of approximately 45% [17].

How is an unstable pelvic fracture detected?

Instability, particularly in the posterior pelvic ring, is accompanied by a strong bleeding tendency from the presacral venous plexus. Detection of instability should lead to increased attention being paid to the circulatory situation. Instabilities are described, depending on the rotational ability of the iliac wing, inwards or outwards, as internal and external rotational instability. In the case of translatory instability, this can be present in the horizontal plane as craniocaudal instability or in the sagittal direction as anteroposterior instability. Besides increased risk of bleeding, the instability can lead to further complications such as thrombosis and secondary nerve, vessel and organ injuries. The last-cited injuries can also be primary and have to be excluded during the primary diagnostic study of unstable pelvic injuries. The pelvic instability should be managed by early surgery which, depending on the condition of the patient, can only be done as an emergency procedure initially or can be definitive straightaway, which often takes more time.

Signs of pelvic instability can be identified in imaging diagnostic tests. These include, for example, a widening in the symphysis or in the SI joints. A displacement of the iliac wings in a horizontal or vertical direction should likewise be interpreted as instability. It must always be borne in mind that the dislocation at the time of the accident is often more drastic than at the time of the diagnostic study. Thus, the fracture in the transverse process of the 5th lumbar vertebra should also be classed as a sign of instability if there is simultaneously a pelvic injury but no displacement of the iliac wing can be detected in the imaging diagnostic study.

The direction of the pelvic instability is important for classification. If there is only rotational instability of the pelvis around the vertical axis of the posterior pelvic ring, this is a group B injury. If there is translational instability in the vertical or horizontal direction, this is a group C injury.

How is emergency stabilization of the pelvis carried out?

Key recommendation:

Emergency mechanical stabilization should be carried out if the pelvic ring is unstable and there is hemodynamic instability.	**GoR B**

Explanation:

Only simple and rapidly applicable procedures are suitable for emergency stabilization of the pelvis. With regard to the mechanical stability achieved, wrapping a sheet round the pelvis or using a pneumatic or other type of industrial pelvic girdle is clearly inferior to the ventral external fixator and the pelvic C-clamp. Nevertheless, both procedures represent an effective emergency procedure at least temporarily in the emergency situation [16]. On the other hand, the *Ganz* pelvic C-clamp or an external fixator differs in the achievable mechanical stability depending on the fracture type.

Controversy remains around the question of whether to use the ventral external fixator (supraacetabular) or the pelvic C-clamp. In unstable pelvic injuries of type C according to Tile et al., preference should be given to the pelvic C-clamp over the external fixator as evidenced by biomechanical studies [44]. In unstable pelvic injuries of type B, no notable differences could be found between the external fixator and pelvic C-clamp. There have also been no studies to date on the question of which method of emergency stabilization has the best effect on arresting bleeding [10, 14].

Overall, the pelvic C-clamp is used less often than the fixator as it is of a preliminary nature with regard to pelvic stabilization and is not without risk in its use compared to the external fixator. Trans-iliac pelvic fractures represent a contraindication because, in the event of dislocation, the pins can lead to an organ injury in the lesser pelvis. On the other hand, reliable stabilization with an external fixator is not always possible in dorsal instabilities. Siegmeth et al. [53] hypothesize that an external fixator is sufficient for instabilities in the anterior pelvic ring but that an injury to the posterior pelvic ring also requires additional compression in an emergency. As early as the 1980s, Trafton et al. [61] also stipulated the same. The most recent studies on a commercial emergency pelvic girdle produce contradictory results regarding the reduction in mortality and the reduction in transfusion of packed red blood cells and the length of hospital stay due to the accident. While Croce [13] found advantages in applying the pelvic girdle studied by him, this assumption was not confirmed in the results by Ghaemmaghami et al. [25].

What procedures should be applied in pelvic fractures with regard to concomitant hemodynamic instability?

Key recommendation:

In the case of persistent bleeding, surgical hemostasis or selective angiography with subsequent angioembolization should be performed.	**GoR B**

Explanation:

Depending on the degree of dislocation of the posterior pelvic ring, an unstable pelvis fracture often leads to a strong bleeding tendency. If an unstable pelvic fracture is diagnosed in combination with circulatory instability, the pelvic fracture should be considered as the possible cause of the circulatory instability. Except in the case of severe pelvic rollover trauma, emergency stabilization of the pelvis can effectuate sustained circulatory stabilization with the methods already illustrated in combination with the infusion treatment so that the indication for surgical hemostasis should be re-considered.

If circulatory instability continues despite the previous procedures, further measures should be taken. There are principally 2 options available: surgical packing and embolization. In selecting the procedure, it should be considered that only arterial bleeding can be embolized and that it is estimated that it is the cause of bleeding in severe pelvic injuries in only 10-20% of cases. The remaining 80% of bleeding is of venous origin [36].

In view of these circumstances, arrest of bleeding through surgically undertaken packing of the lesser pelvis appears expedient and, at least in the German-speaking world, is considered to be the first line choice in such a case ([20], prospective study with 20 patients). Likewise in a prospective study with 150 patients, Cook [11] showed the advantage of rapid mechanical stabilization and subsequent surgical arrest of bleeding or packing. Pohlemann [43] also came to similar recommendations based on a prospective study with 19 patients, as did Bosch [7] after a retrospective analysis of 132 patients.

But embolization can also be considered. Miller [35] values angiography and embolization over mechanical stabilization. He considers surgical stabilization as simply constituting a delay in effective hemostasis and moreover as an avoidable surgical trauma for the patient. According to Hagiwara as well, patients with hypotension and partial responders after 2 l fluid with blunt abdominal trauma and injuries to the pelvis and/or liver and/or spleen, etc. benefit from angiography and subsequent embolization. Volume requirement fell significantly after embolization and the shock index normalized [28, 29].

Agolini [2]states that only a small percentage of patients with pelvic fractures require embolization. However, if applied, it can then be almost 100% effective. The age of the patient, the time of embolization, and the extent of the initial circulatory instability influence the survival rate; e.g., angiography performed 3 hours after the accident showed a mortality of 75% compared to 14% at less than 3 hours after the accident. In their article from 2004, Pieri et al. also report 100% effectiveness in emergency angiography with embolization in pelvic-induced circulatory instability and bleeding from the obturator artery and the gluteal arteries [42]. In a more recent study by Tottermann, 2.5% of patients with pelvic injury showed significant arterial bleeding from the internal iliac artery. With an all-cause mortality of 16% in the patient population, he found an inverse proportionality between age and survival probability [59].

Panetta [37] postulated early embolization with his own time of 1-5.5 hours (mean: 2.5 hours) but sees no correlation between the time of the procedure and mortality. No advantages from embolization were found in outcome reports with a success rate of approximately 50% with a time of procedure of less than 6 hours after the accident [39]. The group from Kimbrell [34] und Velmahos [63] confirms the liberal use of embolization in abdominal and pelvic injuries with detected arterial bleeding even in patients without initial signs of hemodynamic instability.

Gourlay et al. [26] describe angiography as the gold standard in arterial bleeding with pelvic fractures. A special subpopulation of approximately 7-8% even needed follow-up angiography due to persistent circulatory instability. In a study by Shapiro [50], indicators for re-angiography were persistent shock symptoms (BP < 90 mmHg), absence of any other intraabdominal injury, and persistent base excess of < -10 for more than 6 hours after admission. In the subsequent re-angiography, there was pelvic-induced bleeding in 97% of cases.

In a study by Fangio, approximately 10% of patients with pelvic injury were circulatory unstable. Subsequent angiography was successful in 96% of cases. Angiography enabled pelvic-independent bleeding to be diagnosed and treated in 15% of cases. This led to the rate of false-positive emergency laparotomies falling in the stated patient population [23]. Sadri et al [47] also discovered that a specific subgroup of pelvic injuries (approximately 9%) with persistent volume requirement benefited from emergency mechanical stabilization of the pelvic ring with the pelvic C-clamp and subsequent angiography/embolization.

On the other hand, Perez [40] basically considers embolization a reliable procedure as well but sees a need for clarification of the parameters that define the indication and the effectiveness. In a study by Salim et al., the following parameters were found to have significant predictive values in identifying the patient population which benefits from angioembolization: SI joint disruption, female gender, and persistent hypotension [48].

According to Euler [21], interventional-radiologic procedures such as embolization or balloon catheter occlusion only have importance in the later, post-primary treatment phase and not during the management of polytrauma. Only 3-5% of patients with unstable circulation with pelvic injury require or benefit from embolization [3, 22, 36].

As illustrated, there are differing opinions in the literature. To some extent, these differences can be explained through considerable differences in the patient collectives and their injury severity.

Ultimately, no exclusive recommendation can be given due to the lack of high quality evidence both for packing and for embolization. Which procedure is given preference in each case certainly also depends on the local conditions. Besides the availability of embolization, it should be particularly taken into account that no other procedures can be carried out in parallel on the patient during this procedure. Finally, reference is made to strict time management, which should be adhered to in each case.

It is an interesting fact that 2 studies with favored pelvic packing turn up for the first time in the North American studies of 2007 which originally emphasized angiography: this corresponds to a paradigm shift. In his study, Tottermann found a significant BP increase after surgical packing was carried out. In the subsequent angiography, evidence of arterial bleeding was still demonstrated in 80% of cases in the patient population studied so that a graduated scheme with surgical packing and subsequent embolization has been proposed by him [60]. In the study by Cothren, a significant reduction in packed red blood cells requirement within 24 hours after hospital admission (approximately 6 versus 12 packed red blood cells (ECs);[12]) was demonstrated in the pelvic packing-only group compared to the angiography group.

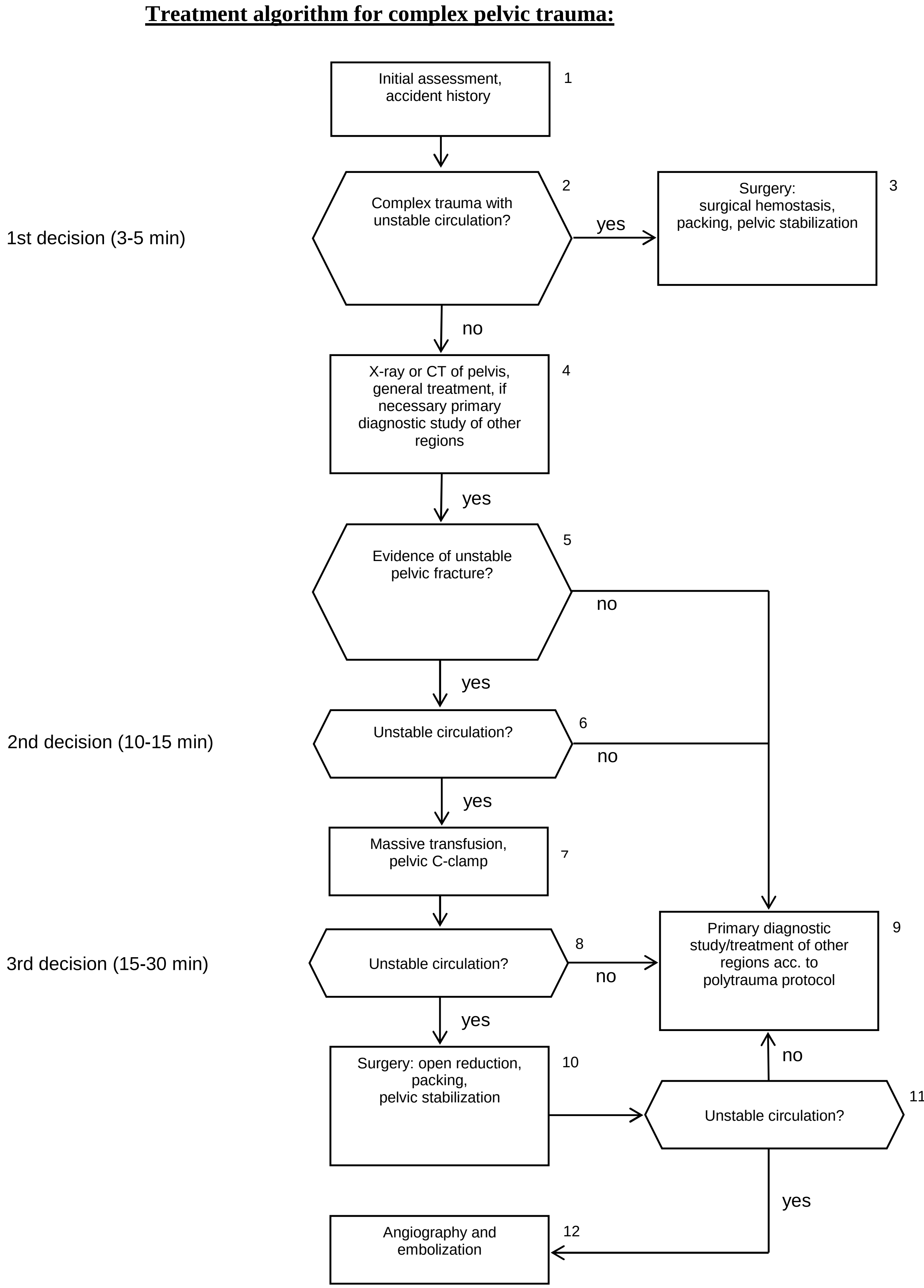
In contrast to this, the latest but not yet published data of the Working Group Pelvis III of the DGU indicate an increase in emergency angiographies carried out in Germany from approximately 2% to 4%. In 2008, Westhoff recommended the early clinical integration of interventional emergency embolization for pelvic fractures if the appropriate infrastructure was available [65].

Verbeek also discussed the necessity of adapting current treatment protocols in the management of seriously injured patients with pelvic fractures. The goal is to arrest the pelvic-induced bleeding, and non-therapeutic and false-positive laparotomies in particular must be avoided in the future [64].

Are there abnormalities present in children and elderly persons with pelvic fractures which must be noted?

A severe pelvic injury is much more life-threatening to a child and also to the elderly than to a middle-aged adult, thus requiring even more rapid action. The physiologic compensation options for circulatory regulation and homeostasis are markedly fewer. The time pressure for decision-making is increased. The challenge with regard to the child is firstly to identify the threat to vital function. Circulatory decompensation does not emerge but appears suddenly as the physiology of the child scarcely offers compensation options. Emergency stabilization of the pelvis can be carried out through simple, lateral compression on both sides, if necessary using the hands. There are no large series of pediatric pelvic fractures in the literature. The papers of Torode [58], Silber [54], and Tarman [56] can be cited, which all report that the treatment guidelines essentially do not differ from those for adults. There are no reports of the use of a pelvic C-clamp in a child. The requirements of infusion treatment and surgical arrest of bleeding apply as for adults. Regarding the imaging diagnostic tests, magnetic resonance imaging has the advantage over computed tomography in the young growing skeleton in representing structures that are not yet ossified, thus enabling a multi-planar presentation of a pelvic injury as well. Compared to computed tomography, plain radiographs have a markedly weaker informative value in diagnosing bony pelvic structures and, according to Guillamondegui et al. [27], can be subordinate to CT or completely omitted. As part of screening for injury, the conventional pelvic survey radiograph is only definitely indicated in patients with unstable circulation, according to the authors. The elasticity of the pediatric pelvis should be particularly taken into account; it can lead to a complete restoration of the pelvic skeleton despite severe rollover trauma. In 20% of pediatric complex pelvic injuries, a normal pelvic skeleton is visualized in the plain radiograph and in the computed tomography.

Figure 3: Treatment algorithm for complex pelvic trauma [49]



Despite the varying and in part quite weak level of evidence, a treatment algorithm can be derived from the current state of knowledge which can, however, be modified depending on local logistic conditions.

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2.8 Genitourinary tract

Primary clinical diagnostic study

Key recommendation:

During the initial exploratory survey, the external urethral meatus and the transurethral bladder catheter (if the latter is already inserted) should be examined for blood.	**GoR B**

Explanation:

Gross hematuria is the cardinal symptom for injuries to the kidney, bladder and/or urethra whereas in this primary survey ureter injuries are clinically normal in about half of cases [15]. For this reason, the urinary catheter or the meatus should be inspected for blood during the primary survey of the undressed patient. Blood at the urethral meatus and hematuria must be differentiated in the clinical examination because they have different diagnostic meanings.

Key recommendation:

The region of flank, abdomen, perineum, and external genitals should be inspected for hematomas, ecchymoses, and external injuries.	**GoR B**

Explanation:

As the external physical examination can be carried out rapidly and easily, it should be carried out in full on all multiply injured patients even if it has only low diagnostic informative value [16]. The examination includes the search for external injury signs (hematomas, abrasions, swellings, etc.) in the region of the flanks, perineum, groins, and external genitals. Cotton et al. and Allen et al. showed that ecchymoses and abrasions in the abdominal region have a close correlation with the risk of an intraabdominal injury [17, 18]. However, a hematoma on the penile shaft or a perineal butterfly hematoma indicates an anterior urethral injury.

The value of the digital rectal examination is very critically evaluated in the current literature [19, 20] as abnormalities are generally found only rarely. In addition to assessing sphincter tone in the patient with spinal cord injury, the rectal examination should also be carried out if blood on the meatus or the presence of a relatively severe pelvic fracture indicates a urethral injury. The finding of a non-palpable, dislocated or hematoma-surrounded prostate represents additional clinically valuable information which in turn indicates a prostato-membranous tear.

The responsive patient can be questioned about possible details of the accident and pain from an injury to the genitourinary organs. Abdominal pain can give nonspecific clues to the presence of intraabdominal lesions [17, 21, 22]. In addition, a bladder rupture is specifically indicated if a patient experiences the urge to urinate before the trauma but no longer experiences this urge after the trauma (without evidence of neurologic lesions) [23] or if the patient tries to urinate without success [24].

Further information is provided by the circumstances of the accident, the mechanism of injury [25, 26], and the general condition of the patient [27]. In the injury pattern, particular attention should be paid to the close relationship between a pelvic fracture and efferent urinary tract lesions; this will be differentiated below according to organ. From a general view, injuries to the bladder and/or urethra are present in 6% of all pelvic fractures but on an Abbreviated Injury Scale (AIS) ≥ 4 injuries are markedly more frequent at 15% than on an AIS ≤ 3 injuries at 5% [25]. With the same severity of pelvic injury, men have almost double the risk for urologic injuries due to their anatomy, in particular the urethra [25, 28]. Rib fractures and injuries to intraabdominal organs increase the probability of injuries being present in the kidneys, ureters, and bladder [29]. If hypotension cannot be explained by blood losses of other origin, this can indicate a relatively severe injury to the kidney.

If there is complete urethral rupture, this can cause the transurethral catheter to go off-course [13, 14]. Likewise, an already existing urinary tract injury can be aggravated by the insertion of a transurethral catheter [30]. Based on these considerations, the patient with clinical signs of a urethral injury can have a transurethral catheter inserted during the diagnostic examination in the emergency room in order to better monitor the patient's urination. Contraindications for catheterization only exist in very unstable patients for whom catheter insertion would represent an unnecessary time delay and in unclear conditions even during the diagnostic test (e.g., retrograde urethrogram). This also applies to the possibility that transurethral catheterization is impossible, e.g., due to a complete urethral tear. A more detailed diagnostic work-up follows below.

Key recommendation:

In the case of circulatory instability that does not permit initial continuing diagnostic tests and if it is impossible to insert a transurethral bladder catheter, a suprapubic urinary diversion should be performed percutaneously or by laparotomy (with simultaneous exploration).	**GoR B**

Explanation:

If circulatory instability is present and if the patient cannot be diagnosed further due to the time delay and for these reasons a laparotomy should be performed, a suprapubic catheter should be inserted during this intervention [31] as this can then also be used subsequently for diagnostic purposes [30]. A rapid urine test and measurement of serum creatinine should be carried out for laboratory tests.

A rapid urine test (e.g., strip test) of the urine should be carried out to detect hematuria. Compared to the microscopic examination, the rapid urine test (e.g., strip test) has over 95% sensitivity and specificity [32-36]. The advantage of the rapid test lies in the results being available in less than 10 minutes. It is also helpful for the further course of action to have verification of bacteriuria; this occurs more frequently in elderly patients and can then be particularly problematic when combined with a urinary tract injury.

Measurement of serum creatinine can assist the ongoing course assessment and the detection of pre-existing kidney diseases. Hematologic parameters which permit the detection of bleeding, e.g., from the kidney, are also measured.

Calling on a qualified urologist is considered advisable for all patients with evidence of genitourinary injuries [37-39], even if this naturally depends on the qualifications of the physicians involved and the physical and organizational conditions.

The necessity of imaging diagnostic tests

Key recommendation:

All patients with hematuria, blood discharge from the urethral meatus, dysuria, impossibility of catheterization or any other medical history information (local hematoma, concomitant injuries, mechanism of injury) have an increased risk of genitourinary injuries and should be given a focused diagnostic work-up of the kidney and/or the efferent urinary tract.	**GoR B**

Explanation:

Even if lesions in the upper and lower urinary tract occur simultaneously in only approximately 0.6% of patients with urologic injuries [40], a complete urological diagnostic study is still usually carried out in all patients with corresponding indications as this normally records the complete urinary system in the form of computed tomography with confirmed microscopic or gross hematuria [41, 42].

Whereas gross hematuria is pathognomonic for genitourinary injuries, microscopic hematuria represents a borderline situation. In general, however, it is accepted nowadays that microscopic hematuria should only entail further diagnostic study if other diagnostic injury evidence is simultaneously present [43-47].

In a large series of 1,588 patients with microscopic hematuria after sharp trauma, only 3 patients were found with relevant kidney injury [48]. In a similar study of 605 patients with blunt trauma, none of the patients with only microscopic hematuria had an injury requiring surgery [49]. This rate was 1 out of 77 in Fallon et al. [50]. Prospective series have confirmed these results [51]. In a pseudo-randomized study [52], in which the patients received different care depending on the admission team, Fuhrmann et al. compared 2 different indications for a cystogram: They were either examined for pelvic fracture, gross or microscopic hematuria (n = 134 patients) or the examination was limited to patients with gross hematuria only (> 200 erythrocytes per field of view). All urological injuries in the two groups were correctly identified. Thus, further acute diagnostic study of the kidneys can be dispensed with in patients who only have microscopic hematuria without additional injury signs. There are similar results for pediatric trauma and multiple injuries [53-56].

An important exception is the fact that vertical deceleration trauma in particular contains an increased risk for kidney injuries [57], which show up as normal in the primary clinical examination. Biomechanical studies support this argument so that further diagnostic study is recommended in strong deceleration trauma even without other criteria being present.

Key recommendation:

Further imaging diagnostic tests should be carried out on the efferent urinary tract if one or more of the following criteria apply: hematuria, bleeding from the urethral meatus or vagina, dysuria, and local hematoma.	**GoR B**

Explanation:

Numerous studies have shown that bladder ruptures are associated with a pelvic fracture in 80-90% of cases [24, 25, 58, 59]. This correlation varies slightly depending on what severity grade the injuries have [11]. Hochberg and Stone [60] found a direct correlation between the number of fractured pubic rami (1, 2 or 3, 4) and the frequency of bladder ruptures (4%, 12%, 40%). Aihara et al. [61] also found that the symphysis or the sacroiliac joint had separated in 75% of bladder ruptures after blunt trauma. Nevertheless, a bladder rupture cannot be deduced from the presence of a complex pelvic fracture because only 20% (positive predictive value) of patients with symphysis and sacroiliac joint separation had a bladder rupture.

The close correlation between pelvic fracture and urethral injury is also well documented. However, the severity grade of injuries again plays a major role [25, 62, 63]. Koraitim et al, Morgan et al. and Aihara et al. showed consistently that fractures to the pubic rami increase the risk of a urethral injury, but that this risk rises hugely particularly in more complex pelvic fractures (type C) [61, 64, 65]. Aihara et al. emphasize that fractures of the lower pubic rami in particular indicate a urethral injury [61]. Palmer et al. noticed in a series of 200 patients with pelvic fracture that 26 out of the 27 patients with urologic lesions had a fracture in the anterior and posterior pelvic ring [66]. This association is less marked in women due to the shorter length and less connective tissue fusing in the female urethra [67]. Urethra injuries in women are usually accompanied by bleeding vaginal injuries [68-70].

The classic combination of pelvic fracture and gross hematuria allows the conclusion of a bladder and/or urethral injury to be made with great certainty [71]. Rehm et al. found that of 719 patients with blunt pelvic/abdominal injury all 21 cases with bladder injury were indicated by the presence of hematuria, which showed up in 17 cases also as gross hematuria [72]. Morey et al. [71] also reported that all their 85 patients with pelvic fracture had gross hematuria with simultaneous bladder rupture. In Palmer et al. this rate was in 10 out of 11 patients [66], in Hsieh et al. in 48 out of 51 [73]. A gap in the symphysis and separation in the sacroiliac joint doubled the risk for a bladder injury in the study by Aihara et al [61]. But even without a pelvic fracture being detectable, patients with gross hematuria or blood discharge from the urethral meatus must be assumed to have an injury to the efferent urinary tract [74].

The difference between hematuria and blood at the urethral meatus can be helpful in differentiating between bladder and urethral injuries. Thus, Morey et al. describe how all 53 patients with bladder rupture had a hematuria but that the simultaneous presence of blood at the urethral meatus correctly indicated in all 6 cases a concomitant urethral injury [71].

Studies available internationally show clearly that the absence of hematuria and the simultaneous exclusion of a pelvic fracture definitely exclude a relevant injury to the bladder or urethra. This assessment is somewhat more difficult if there is positive evidence of a pelvic fracture. Hochberg and Stone found that a urologic injury is very unlikely here as well provided the pelvic fracture does not affect the pubic rami [60].

Imaging diagnostic test of kidneys and ureters

Key recommendations:

Computed tomography with contrast agent should be performed in the case of suspected kidney injury.	**GoR B**

Explanation:

The importance of computed tomography (CT) in the primary assessment of blunt abdominal trauma is not the subject of this text as the diagnostic test focuses on all intraabdominal trauma. Thus, only the degree of accuracy with which injuries to the kidney and efferent urinary tract can be detected in the CT will be discussed below. In the literature review, the CT diagnostic test appears to be the most reliable, comfortable method in assessing blunt abdominal trauma [9, 41, 47, 75-82].

Intravenous pyelography is inferior to CT with respect to diagnostic accuracy [44, 76] yet represents an important option if CT cannot be performed. This may be the case if the admitting hospital does not have the necessary equipment available or, more usually, if the patient is hemodynamically unstable and requires immediate emergency surgery [83]. In such cases, i.v. pyelography makes it possible to carry out the urologic diagnostic study directly during surgery [9, 41, 44]. The images are available approximately 10 minutes after administration of the contrast agent (2 ml/kg). For 284 patients with blunt kidney trauma, Nicolaisen et al. report perfect sensitivity of i.v. pyelography for identifying blunt injuries and state that in 87% of cases it was also possible to classify the injury severity grade correctly [29]. Although in 5 cases of 60 patients with normal excretory urography Halsell et al. found smaller renal lesions in the computed tomography [84], these lesions were clinically less important and could be conservatively treated.

Various studies report a sensitivity of over 90% in detecting renal injuries by ultrasonography [85, 86] but the sensitivity is obviously less if the injury has not resulted in free fluid in the abdomen [85]. This can occur in about 10-20% of cases [87]. Overall, however, ultrasonography is not sufficiently reliable. On average, intraabdominal lesions will be present in 10-20% of cases despite negative ultrasonography [87, 88]. Ultrasonography is therefore only suitable as an additional diagnostic test. However, a randomized study showed that primary ultrasonography could reduce the necessity of a CT diagnostic test [89] as negative ultrasonography was assessed as adequately reliable in individual patients without evidence of abdominal injuries.

Angiographic techniques have much more of a therapeutic role than a diagnostic one as angiography does not really provide any additional diagnostic information compared to CT [77, 90]. In cases where an injury to the renal artery or its lateral branches can be assumed or active bleeding is detected by computed tomography, it is expedient to use angiography as preparation for an embolization [91-95]. In vascular injuries to the renal pedicle (e.g., intimal tear), this enables the patency of the renal artery to be restored using an endovascular stent. Moreover, in relatively severe renal injuries with massive bleeding, selective embolization of the bleeding vessel should be carried out [9, 41, 42] provided the patient has stable circulation. The number of primary operated patients can be minimized through this radiologic intervention option, which leads to a reduction in the nephrectomy rate. The success rate of radiologic intervention is about 70-80% [42]. Angiography can also be necessary if CT equipment is not locally available and the i.v. pyelography does not show the kidney.

In addition to the methods cited, magnetic resonance imaging has been tested by Leppaniemi et al. [96-98] and it can image some details better than CT [96, 99]. Due to the increased time involved, however, it is seldom advisable to use this procedure in multiply injured patients during the acute phase. Magnetic resonance imaging could be beneficial in rare cases if CT is unavailable or cannot be used because of an allergy to the contrast agent or the CT finding is unclear.

Detecting a ureter lesion is much more difficult [100-102]. Medina et al. described a sensitivity of 20% although a very wide range of diagnostic modalities (CT, intravenous pyelography [IVP], and retrograde pyelogram) was used [15]. In 81 patients with non-iatrogenic blunt ureter injury, Dobrowolski et al. [103] found i.v. and retrograde pyelography helpful. Ghali et al. [102] considered only pyelography to be diagnostically reliable even when compared to intraoperative inspection.

Imaging diagnostic tests of the lower urinary tract

Key recommendation:

If prioritizing permits, retrograde urethrography and a cystogram should be performed in patients with clinical reference points for a urethral lesion.	**GoR B**
If prioritizing permits, a retrograde cystogram should be performed in patients with clinical reference points for a bladder injury.	**GoR B**

Explanation:

If there is a suspected urethral and/or bladder lesion, retrograde urethrography and a cystogram should be performed [30]. Retrograde urethrography consists of the transurethral administration of approximately 400 ml of contrast agent. Provided the urethra is uninjured, urethrography enables the bladder to be adequately filled with contrast agent. Thereafter, a radiograph is taken, ideally on 2 planes but often limited for practical reasons to the anteroposterior plane in multiply injured patients [72]. However, both planes should be represented so that retrovesicular extravasates are not missed [23]. The cystogram consists of an image after drainage in addition to the voided image and the filling image as otherwise there will be approximately 10% false-negative results [104]. In cases where no retrograde bladder filling can be achieved, the bladder must be filled via a suprapubic catheter as combined injuries to the bladder and urethra make up 10-20% of all bladder or urethral injuries [61].

In multiply injured patients, due to concomitant injuries, it is not possible in about 20% of cases to carry out the cystogram within the initial emergency room phase [73]. This may be unavoidable in individual cases but the diagnostic test must be carried out as soon as possible thereafter so that no injuries are missed. On the other hand, Hsieh et al. [73] saw no serious disadvantages in the cases where the diagnosis of a bladder rupture had been delayed until later.

Ultrasound does not play a big role in assessing bladder or urethral injuries but is very helpful in localizing the bladder for inserting the suprapubic bladder catheter. I.v. pyelography is also unreliable in assessing uncertain bladder injuries as the bladder resting pressure is too low and dilutes the contrast agent too much. Several clinical studies have shown that i.v. pyelography does not detect 64%-84% of bladder injuries [105-108].

Although computed tomography cannot make definite statements on urethral injuries, it is still very valuable in diagnosing bladder ruptures [109]. However, without separate filling of the bladder with contrast agent, the CT diagnostic test can only supply indirect evidence. Although the absence of pelvic fluid collections makes bladder ruptures less likely [110], it can never definitely exclude a relevant injury. Only the CT cystogram is suitable for this, and it can also be performed as an alternative to the normal cystogram. In a series of 316 patients, Deck et al. found evidence of a sensitivity and specificity of 95% and 100%, respectively, for the CT cystogram in identifying bladder ruptures [111, 112]. Even if these values were somewhat worse for intraperitoneal ruptures (78% and 99%), the authors still consider that the CT cystogram ranks at least equally with the conventional cystogram. Other groups have reported similar results [113, 114]. For this reason, the CT cystogram can offer time and organizational advantages particularly in multiply injured patients as the CT diagnostic test is often indicated here because of other injuries. However, the prerequisite for a definite diagnosis is the sufficient administration of contrast agent (> 350 ml) to be able to produce and detect an extravasate at all in the presence of a rupture through sufficient fill pressure [104, 109, 115].

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2.9 Spine

A suspected spinal injury exists in principle in patients who are transferred to hospital with suspected multiple injuries. In our own hospital population between the years 2000-2002, 34% of the multiply injured patients (245 out of 720) had a spinal injury. Other studies have found a rate of 20% [29]. Conversely, about 1/3 of all spinal injuries are associated with concomitant injuries [34, 91]. Overall, the figure for Germany is approximately 10,000 serious spinal injuries per year, of which 1/5 involve the cervical spine and 4/5 the thoracic/lumbar spine [31]. Approximately 10% of multiply injured patients will have a cervical spine injury [33]. At 1-27 injuries/million children/year in Western Europe/North America, pediatric spinal injury is relatively rare [9].

The presence of a spinal injury as part of multiple injuries has considerable consequences for the diagnostic study and therapeutic course of action. Typical concomitant injuries, e.g., thoracic or abdominal, must first be excluded. If surgical stabilization is necessary, a comprehensive pre-operative CT diagnostic work-up is required of the injured region. Intensive care positioning options depend on the stability of a detected spinal injury. For this reason, it is desirable to assess the stability of a spinal injury if the general condition of the patient permits this (circulation, temperature, coagulation, intracranial pressure, etc.) and before the trauma patient is transferred from the emergency room or from the operating room to the intensive care unit.

Medical history

Key recommendation:

The medical history has high importance and should be taken.	**GoR B**

Explanation:

In the case of multiply injured patients, the medical history is usually taken from a third party. The mechanism of injury is an important piece of information here and should be passed on from the prehospital to the hospital care. Multiple injuries as such [4, 39, 49], high energy road traffic accidents [4, 16, 34, 101, 115, 149], road traffic accidents involving persons not restrained by belt or airbag [81, 101], pedestrians who have been run over [16], falls from a great height [14, 39, 49, 128, 132], alcohol or drug influence [138], and advanced age [16, 100, 134] represent predispositions for a spinal injury. In the unconscious patient, the medical history should also include active movement of the extremities and information about pain before loss of consciousness or intubation.

Traumatic brain injury and facial injuries are considered risk factors for the presence of a cervical spine injury. According to the multivariate analysis by Blackmore et al. [16], patients with a head fracture or continued unconsciousness have a markedly higher risk of having a cervical spine injury (odds ratio 8.5) whereas with milder injuries such as facial/jaw fracture or temporary unconsciousness, for example, this is less common (OR 2.6). Similarly, Hills and Deane [73] found that the risk of a cervical injury in patients with TBI is about 4 times higher than in patients without TBI. With a GCS below 8, the risk is actually 7 times higher. Other studies on the importance of traumatic brain injury [73, 83], loss of consciousness [46, 77, 79, 131, 149], and craniofacial fractures [63, 73, 103, 122] confirm the association with spinal injuries. Only one study with a large number of patients described a tendentially reduced risk of cervical injuries in patients with facial or head injuries [165] but where the GCS was significant as a predictor. It is debatable whether clavicular fractures can also be considered as a predictor [165].

Clinical examination

Key recommendation:

The clinical examination for spinal injuries has a high importance in the emergency room and should be carried out.	**GoR B**

Explanation:

Due to its simplicity and speed, the clinical examination of the spine is a valuable diagnostic aid in the emergency room [49]. It comprises the inspection and palpation of the spine where contusions and hematomas are seen and displacement or malposition of the spinal process and indentations in the segments concerned can be felt. Information about pain in the head and torso can indicate a spinal injury. Tenderness, distraction or movement and involuntary malpositions are additional features of spinal injury [25, 128]. Provided the patient is conscious, motor functions and sensitivity should be tested. If there are existing deficits, the neurologic examination should document a precise, standardized finding, if possible according to the ASIA-IMSOP (American Spinal Injury Association - International Medical Society of Paraplegia) classification sheet [32, 33].

Although there are well-validated clinical decision rules for monotrauma [11, 74, 150, 151] that enable a spinal injury to be definitely excluded, in turn saving on unnecessary diagnostic radiology, these decision rules cannot be transferred to polytrauma because prehospital interventions (particularly intubation) and concomitant injuries (particularly to the head) generally make it impossible to obtain a reliable medical history and carry out an examination [36, 159]. Thus, Cooper et al. [39] found that pain from a spinal fracture could only be found in 63% of severely injured patients compared to 91% of the minor injured, patients with a TBI not being included. Meldon and Moettus reported quite similar figures (58% versus 93%) [105] so that a clinical examination was only considered reliable if there was a GCS of 15. Mirvis et al. and Barba et al. observed that about 10-20% of all apparently severely injured patients were actually less severely injured and thus adequately evaluable to be able to exclude a spinal injury clinically [12, 108]. This shows that the clinical examination of multiply injured patients is heavily dependent on the overall injury severity. The radiologic work-up of the spine can perhaps only be dispensed with in those cases where a patient is admitted with suspected multiple injuries but the injury severity then turns out to be less (ISS < 16). This is, however, outside the focus of this guideline. The clinical diagnostic study is not sufficiently reliable in polytrauma for clearing with adequate certainty a suspected spinal injury.

On the other hand, if specific signs of a spinal injury are present, the clinical examination can affirm a suspected diagnosis [16, 59, 149]. Despite low sensitivity but due to its high positive predictive value (> 66%), the following signs permit the suspected diagnosis of spinal injury in polytrauma [80]: palpable step formation in the median-sagittal plane, pain on palpation, peripheral neurologic deficits or blood effusion around the spine. The papers by Holmes et al. [79], Gonzalez et al. [59], and Ross et al. 1992 [131] support the valency of the clinical finding. For the clinical examination, Gonzalez et al. and Holmes et al. report overall a sensitivity exceeding 90% in the cervical spine and up to 100% in the thoracic/lumbar spine but patients with a medical history of risk factors (painful or concomitant injuries affecting level of consciousness) were separately distinguished as a clinical risk group. These studies are thus not transferable to polytrauma.

In unconscious trauma patients, slack muscle tone, particularly also the anal sphincter, lack of pain resistance, solely abdominal breathing, and priapism indicate a transverse lesion. Thus, the overall data status is somewhat better than the medical history for rating the clinical examination even if some of the studies have been conducted on monotrauma or mixed patient populations. In essence, a spinal injury can be predicted by the presence of clinical symptoms. Their absence, however, does not definitely exclude a spinal injury.

Imaging diagnostic tests

Key recommendation:

After circulatory stabilization and before transfer to the intensive care unit, a spinal injury should be cleared by imaging diagnostic tests.	**GoR B**

Explanation:

In principle, the diagnostic study of the spine should be concluded as early as possible because otherwise the continuing immobilization makes medical and nursing procedures more difficult (e.g., positioning, central venous access, intubation) and immobilization itself can lead to side effects (e.g., pressure sores, infection) [110, 161].

The diagnostic work-up of the multiply injured patient with unstable circulation presents a challenge. Prioritization is applied here, giving priority to treatment and also surgery of life-threatening injuries (e.g., epidural hematoma, pneumothorax). If this goal is achieved and there are no other contraindications (e.g., hypothermia), the spine is cleared by imaging technology as described above before transfer to the intensive care unit. If this is not advisable because of the situation, e.g., there is no current consequence, then the spine is usually cleared by imaging technology the next day, after stabilization of the overall condition [160].

In individual cases, other injuries can make it necessary to dispense with the primary imaging diagnostic study of the spine [160]. If such be the case, the usual safety precautions must be applied until further notice: cervical collar, positioning and turning en bloc, re-positioning using a rollboard, vacuum mattress, etc. [56, 136]. “Excluded by imaging” means no dislocation or unstable spinal fracture in evaluable X-ray images or in a CT scan of the spine. The immobilization of the spine can only be terminated when the imaging diagnostic study has been completed or the patient has recovered sufficiently that a spinal injury can be excluded by the clinical finding. However, a few authors deliberately dispense with the primary diagnostic radiology in patients with minor injuries if it is foreseeable that the patient can be clinically evaluated again within 24 hours so that diagnostic radiology can definitely be circumvented [25]. However, this is rarely the case in polytrauma so that this course of action is not recommended here.

Key recommendation:

Depending on the facilities of the admitting hospital, the spine should be cleared if circulation is stable during the emergency room diagnosis: preferably by multi-slice helical CT from head to pelvis or alternatively by conventional diagnostic radiology of the entire spine (a.p. and lateral, odontoid view).	**GoR B**

Explanation:

Plain diagnostic radiology with focused CT work-up is clinically common in many cases [50, 109]. The radiologic cervical work-up has the highest priority over the rest of the spine. This work-up is possible by means of CT and conventional diagnostic radiology (a.p., lateral, and odontoid view). A lateral-only view of the cervical spine has proved to be inadequate to enable bony injuries to be adequately excluded [37, 143, 152, 162, 169]. The following requirements must be met: all 7 cervical vertebrae should be viewed in the lateral plane [55, 111]. An a.p. projection should be taken of the C2-T1 spinous process; the C1 and C2 lateral masses should be easy to evaluate in the odontoid view [48]. The 45 ° oblique views for the C7/T1 alignment, swimmer's and similar projections are of subordinate priority as they provide less informative value, waste time, and have a higher radiation dose [52, 102, 125]. If necessary, oblique views should take priority over swimmer's views [84]. On the other hand, other authors have found that patients with inadequate visualization of the C7-T1 junction in the primary imaging were then better cleared using oblique views than using computed tomography [88] because the CT diagnostic study could be avoided in over 10% of all cases.

Functional views of the cervical spine of unconscious patients should be held under image converters by the physician to exclude ligamentous injuries if there is justified suspicion [3, 45, 97, 142]. Their sensitivity is 92%, their specificity 99% in patients with maintained consciousness [25]. However, as morbid findings are overall only seldom revealed in the functional views, the routine and also selective use of functional views in the primary diagnostic study is of questionable effectiveness [6, 62, 97, 121]. Computed tomography or particularly magnetic resonance imaging provides an alternative (see below).

Missed musculo-skeletal injuries comprise approximately 12% in polytrauma [51]. The cervical spine is the first priority [5, 30, 133, 155]. The causes are radiology examinations that are inappropriate or not carried out, or a required diagnostic test not followed consistently [55, 104, 106, 133], which is why CT should be used for clearance in unconscious patients with lack of visualization in the C0-C3 and C6/7 regions [25, 157]. Twenty per cent of spinal injuries are missed because the diagnostic study is incomplete [19, 42]. This is confirmed by data on 39 multiply injured patients, 9 of whom had a cervical spine injury which could be diagnosed using conventional radiography in only 6 of these patients. In contrast, supplementary examinations (1x functional views and 2x CT) were necessary in the remaining 3 patients [141].

The diagnosis of polytrauma contains per se a considerable risk that important injuries will be missed in the primary survey [129]. Fifty percent of missed injuries in polytrauma affect the whole spine. The result is an extended length of hospital stay and additional follow-up operations [133]. It is therefore recommended in polytrauma to clear the whole spine as a matter of routine [44, 116]. Particularly in the case of blunt, high energy traumas and falls from a great height, injuries with second fractures at other levels are seen with a frequency of 10%. For this reason, thoracic and lumbar spine must also be X-rayed in 2 planes [32, 166].

Computed tomography

Key recommendation:

Pathologic, suspect and non-evaluable regions in conventional radiography should be further cleared with CT.	**GoR B**

Explanation:

Due to greater diagnostic accuracy in detecting spinal injuries, preference should be given to the CT diagnostic test, if available [7]. Another practical advantage of the CT diagnostic test is the markedly faster clearing of the spine compared to conventional diagnostic radiology [68, 71, 72] because non-evaluable views virtually no longer occur. The CT diagnostic test is usually performed with administration of i.v. contrast agent. The CT diagnostic test is also considered to be advantageous in children even though the radiation dose at approximately 400 mrem (millirem) is higher than in conventional diagnostic radiology (150-300 mrem), as shown by a pseudo-randomized study [2]. Despite the above-mentioned problems, it is recommended that the options for clinical findings are exhausted fully in children [65]. Essentially, the procedure for children in the emergency room is no different from that for adults.

Detected spinal injuries should not be operated on without CT [75] as fracture evaluation and classification is often changed decisively through CT compared to the plain radiograph [68, 70]. The preceding CT visualization and analysis is necessary particularly for rotationally unstable fractures [144]. The helical CT examination from head to pelvis without conventional diagnostic radiology is particularly suitable for clearing the spine in polytrauma because it saves time, has greater reliability compared to conventional diagnostic radiology, is associated with less discomfort, and costs less [112]. If the spine is visualized normally in the CT, additional conventional radiology is superfluous [26, 28, 35, 123, 135] as the negative predictive value reaches almost 100%. With today’s permanent availability, the CT diagnostic study appears at present to be the tool of choice for detecting spinal injuries in polytrauma in the emergency room phase [86].

Cervical spine (C)

Harris et al. (2000) [66] describe the conventional diagnostic radiology in cervical spine injuries as not satisfactory so that CT or, if applicable, magnetic resonance imaging (MRI) is recommended particularly in polytrauma. CT is markedly more accurate than conventional diagnostic radiology for cervical spine injuries: The cervical spine injury was detected in 38 out of 70 patients using the conventional X-ray image and 67 out of the same 70 patients using CT [139]. Similar results are provided by a current meta-analysis [78] and the reviews by Crim et al. (2001) [41] and Link et al. (1994) [99]: using conventional lateral radiographs, 60-80% of cervical spine injuries were identified, and 97-100% with CT [119] (Table 2). Further studies show that the layer thickness in computed tomography affects the diagnostic accuracy [70], which must also be taken into account when assessing older studies with CT equipment which is obsolete by today’s standards.

Based on the figures in the literature, Blackmore et al. also come to the conclusion that the primary CT diagnostic study has better clinical and economic results compared to conventional radiography in patients with average and high risk of a spinal injury [17].

Thoracic/lumbar spine (T/L)

Table 3 gives a summary of important studies on the CT diagnostic test in the emergency room for thoracic/lumbar spine injuries as part of polytrauma. This also shows a clearly greater sensitivity of the CT diagnostic test compared to the conventional diagnostic test. It must be noted that not all additional findings such as transverse process avulsions were clinically relevant in the CT but could easily refer to other relevant injuries (abdominal injuries). In addition, there are advantages with regard to time and planning of surgery. According to Hauser et al. (2003) [68], the time for sufficient clearing of the spine was 3 hours for conventional diagnostic radiology, and one hour for CT. Moreover, the rate of false fracture classifications in CT was 1.4% and in radiography 12.6%.

Concomitant injuries in head/thorax/abdomen

To clear the spine and concomitant injuries in polytrauma, a standard CT from head to pelvis is recommended initially in polytrauma, which takes approximately 20 minutes [96]. Computed tomography is indicated on the day of admission particularly for cervical spine injuries combined with TBI [141]. For thoracic spine fractures, the emergency CT examination of the thorax is indicated because of the high risk of complex thoracic-pulmonary injuries [58]. The constellation of lumbar spine injuries and abdominal trauma in the form of bleeding into the abdominal wall after a belt injury also supports the clearing of the spinal injury by CT in order to enable a simultaneous evaluation of the abdomen [13]. Miller et al. (2000) [107] and Patten et al. (2000) [117] also refer to the importance of transverse process fractures in the lumbar spine as important indications of a concomitant abdominal injury, which is why CT is recommended. Moreover, clearing the thoracic-lumbar spine by CT is also recommended for acetabular and pelvic fractures [8, 70]. In conventional diagnostic radiology, significant spinal fractures are missed in 11% of cases of transverse process fractures. These are only picked up by CT, which is why it is stated that CT is necessary for clearing these fractures [92].

Magnetic resonance imaging (MRI)

Magnetic resonance imaging examinations play a quantitatively subordinate role overall in polytrauma during the emergency room phase [148]. For logistic reasons (access, metal objects, time, availability), an MRI examination in the acute phase is usually not expedient for polytrauma. The main indication for MRI is in clearing unclear neurologic deficits. In particular, lesions on the spinal cord, the invertebral disc, and ligaments can be visualized [41, 57, 89]. However, in view of the rarity of this injury, Patton et al. [118] considered a search for ligamentous injuries using MRI to be superfluous. There are no studies on the direct comparison between conventional functional views and MRI imaging so that both options appear to be worthy of recommendation. With a sensitivity of only 12% and a specificity of 97%, MRI is little suited to the detection of fractures [90].

MRI examinations are indicated for neurologic symptoms during the further course and have partially replaced the functional views for defined research questions such as in the case of the hangman fracture, for example [87]. In general, there is no need to worry about false-negative results but specificity is low [25]. If a neurologic deficit without morphologic correlation is present in the CT, the corresponding spinal segment must be examined by MRI as a matter of urgency. Additional indications arise occasionally in the early post-operative or post-traumatic course to be able to evaluate, e.g., intraspinal epidural hematomas, prevertebral bleeding or invertebral disc injuries [43, 147, 163].

Emergency procedures such as reduction and cortisone treatment

Key recommendations:

In the exceptional case of a closed emergency reduction of the spine, this should only be carried out after sufficient CT diagnostic study of the injury.	**GoR B**
Administration of methyl prednisolone (“NASCIS scheme”) is no longer standard practice but can be introduced within 8 hours after the accident if there is neurologic deficit and evidence of injury.	**GoR 0**

Explanation:

A precise analysis of the spinal injury must be made before each reduction, i.e. preceded by a careful analysis of the imaging (CT). Despite the poor quality of evidence, the recommendation has been upgraded because of the risk of complication. Generally, reduction is directly carried out preoperatively in the operating room or open during surgery, followed by surgical stabilization of the reduced injury. Care must be taken in closed reduction without surgical stabilization or invertebral disc removal as it can herniate dorsally during reduction and have a detrimental effect on the neurology [60].

A Cochrane Review [21] found on the basis of 3 randomized studies [22, 114, 120] that, compared to a placebo, methyl prednisolone improves the neurologic outcome one year after the accident if it is given within 8 hours after the accident. The recommended dose ("NASCIS scheme") is methyl prednisolone 30 mg/kg body weight i.v. over 15 minutes in the first 8 hours after the accident, thereafter 5.4 mg/kg BW each hour for 23 hours. In the NASCIS-3 study, administration of methyl prednisolone over 48 hours proved at best to have a trend towards improvement [23] and was recommended only for patients who could be started on the treatment after 3 or more hours.

If there is evidence of neurologic symptoms or they can be assumed, with corresponding CT morphologic evidence of narrowing of the spinal canal, a NASCIS (National Acute Spinal Cord Injury Study) scheme can be started early [10]. The rehabilitation time can thus be shortened. However, other analyses show no effect from cortisone treatment [145, 146] or do not recommend cortisone treatment because the positive effect was not seen [82]. In addition, the validity of the NASCIS-2 study has been questioned [38]. The more recent results on administering corticosteroids for TBI [40] also cast a shadow on the efficacy of steroids for spinal cord trauma.

Although, overall, the high-dose steroid administration to surgical/traumatologic patients can be seen as safe and to some extent even as advantageous [130, 137, 154], the possible side effects are an important argument against administration of steroids according to the NASCIS protocol [94, 153]. Known complications of steroid treatment in patients with spinal cord injury are: infections [53, 54], pancreatitis [69], myopathies [124], psychologic problems [158], and severe lactic acidosis when combined with the high dose of methyl prednisolone with i.v. adrenaline supply [67].

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2.10 Extremities

The importance of evaluation and examination

Even if there are no scientific studies on the importance and the necessary scope of the physical examination in the emergency room examination, it is still an indispensable requirement in identifying symptoms and in making (suspected) diagnoses. The systematic examination of the extremities of the undressed patient “in craniocaudal sequence” serves primarily to detect relevant, partially threatening injuries which can lead to a radiologic diagnostic study, immediate specific treatment and, in many cases, also a logistic decision taken while still in the emergency room [2, 14]. Its intended use is to estimate the overall injury severity.

The examination in the region of the extremities consists of the detailed inspection and manual examination of the extremities for any type of external injury signs such as swelling, hematoma or wounds. Any closed or open soft tissue damage present is also classified. Definite fracture signs should be noted down. The systematic examination of the extremities allows fractures, dislocations, and dislocation fractures to be clinically detected or at least delimited. The stability test should be carried out on the large and small joints.

The purport of the primary survey is also to distinguish a disorder in circulation, motor functions, and sensitivity. The possibility of compartment syndrome should be excluded. The neurologic finding for all extremities can only be collected from alert patients; otherwise, the reflex status must be checked as a minimum. It is essential for the treatment of extremity injuries to distinguish again between neurologic disorders in the central nervous system and those from peripheral causes.

Missed injuries are also found retrospectively in the extremities region, particularly in unconscious and multiply injured patients. These injuries often require surgical management [3]. The incidence of missed injuries is independent from any interruption in emergency room diagnosis due to emergency surgery.

The examination of the extremities is sometimes neglected in an unstable patient and injuries are missed [4, 5]. Another source of error is the examiner-dependent evaluation of radiographs, which can be subject to a false interpretation [6, 7, 8].

In this context, process optimization and monitored training [9], and the introduction of guidelines lead to an improvement in patient care [10]. However, missed injuries to the extremities are rarely life-threatening and, after the multiply injured have been stabilized, can often be diagnosed in the secondary survey and surgically managed [32].

Diagnostic equipment

Key recommendations:

If there are confirmed or unconfirmed fracture signs, extremity findings should be assessed depending on the patient’s condition using a suitable radiologic procedure (plain radiograph in 2 planes or CT).	**GoR B**
The radiologic diagnostic study should be performed at the earliest possible opportunity.	**GoR B**

Explanation:

The length of stay in the emergency room affects the treatment results and the morbidity/case fatality rate of a severely injured patient [10]. There is no absolute value to adhere to such as the “golden hour”, for example [11].

In certain regions, the scope of diagnostic radiology can be limited by the confirmed clinical examination. For example, without weight-bearing pain, effusion or hematoma, a fracture has been excluded in knee injuries (as monotrauma) [12].

A lateral radiograph is sufficient for specific screening of a knee fracture. It is 100% sensitive [13].

If a bony extremity injury is clinically suspected in stable patients, a radiograph should be taken in at least 2 planes. Deliberately dispensing with the radiologic visualization is only justifiable if the emergency room diagnostic tests are interrupted due to emergency surgery [14].

Studies on length of stay in the emergency room and on treatment results specifically on extremity injuries are not known. There are also no studies on the issue of whether a deliberate postponement of diagnostic radiology on extremity injuries to shorten the emergency room phase affects the treatment results of the injured.

There are several scientific studies with a poor outcome on the delayed management of injuries to the extremities. However, they are not considered in conjunction with a postponement in the emergency room diagnostic tests.

Diagnostic study/Treatment

Should obvious malpositions in the extremities be reduced?

Key recommendations:

Malpositions and dislocations in the extremities should be reduced and stabilized.	**GoR B**
The reduction outcome should not be altered through other interventions.	**GoR B**

Explanation:

An injured extremity that has been correctly immobilized by the emergency services should be left alone in the emergency room until definitive care. Any alteration in immobilization in the actual injury area can potentially lead to a worsening in soft tissue damage and pain reactions, particularly in bony unstable conditions [15]. A reliable interface with the emergency services avoids unnecessary repositioning. To date, there have been no scientific studies on whether repositioning measures in the emergency room affect the extremity injury.

With the prehospital care of the injured by an emergency services system, it can be assumed that extremity injuries are immobilized in the neutral position. If this immobilization is correctly performed, repositioning measures of the whole patient have virtually no effect on the individual injury to the extremities. If immobilization is correctly performed, removing/altering the immobilization of an extremity is unnecessary until in the operating room.

Lack of pulse after a prehospital fracture reduction has not been described in the literature up till now.

Open fractures

Key recommendations:

If sufficiently reliable information has been provided by the emergency services, a sterile emergency dressing should be left in place until entry to the operating room.	**GoR B**

Explanation:

In the emergency room, open fractures should be managed according to the basic principles of aseptic wound management. In principle, open fractures are a surgical emergency, requiring immediate surgery. The decisive factors for a possible infection lie outside the emergency room: for infectiologic reasons, do not repeatedly open. This is because resistant hospital germs are more dangerous than the germs collected at the accident scene. A direct correlation between frequency of infection and exposure could not be proven by Merritt [35, 36].

Pulseless extremity

Key recommendations:

If there is no peripheral pulse (Doppler/palpation) in an extremity, further diagnostic tests should be carried out.	**GoR B**
Depending on the finding and condition of the patient, conventional arterial digital subtraction angiography (DSA), duplex ultrasonography or angio-CT (CTA) should be performed.	**GoR B**
Intraoperative angiography should be given priority in vascular injuries to the extremities that were not diagnosed in the emergency room in order to shorten the period of ischemia.	**GoR B**

Explanation:

Compared to the sensitivity of the other diagnostic equipment, the duplex ultrasonography examination is at least equivalent to invasive arteriography [19]. Good results from ultrasonography are to a large extent dependent on the examiner [20. 21].

The period of ischemia is crucial for the prognosis of the extremity as well as the whole body. A quick diagnosis with localization of potential injuries is essential to then enable rapid surgical management.

The diagnosis of a vascular lesion cannot be made solely on the basis of the clinical examination. Vascular injuries require a rapid, definite emergency room diagnostic study. Depending on the examiner, the duplex ultrasound examination best fulfills the above requirements. If there is already a clear clinical indication for surgery, preference should be given to intraoperative angiography over the emergency room diagnostic tests. Here, as in the above-mentioned studies on ultrasonography, the hospital structure plays a considerable role so that a generally valid recommendation can only be made with reservations.

More recent papers show that preference should be given to CT angiography over conventional arterial digital subtraction angiography (DSA) in appropriately stable patients. The procedure of computed tomography angiography (CTA) takes up markedly less time and is also cheaper [31]. It is less invasive than DSA and the rapid development in technology now permits visualization of all arteries in a short time. However, its value is limited by the large quantity of iodinated contrast agent and the high radiation exposure. Calcified plaques also compromise the detailed visualization of medium and small arteries (33, 34). The extent of ischemia in peripheral extremities depends on the localization and length of the vascular obstruction as well as on the possible presence of developed collaterals. In a healthy vascular system, even a short length of obstruction or an isolated break in an extremity artery can lead to necrosis of the dependent musculature.

The tolerated ischemia period is shorter the healthier the vascular system.

In polytrauma, there is the added difficulty that the injury to the extremity triggers arterial vascular spasms, which themselves entail a marked decrease in blood flow to the extremity [22].

If there is insufficient blood flow to the peripheral muscle tissue after 3 hours, the risk of compartment syndrome following revascularization must be taken in to account. Very pronounced direct soft tissue trauma can worsen the prognosis of revascularization.

Compartment syndrome

Key recommendation:

If there is suspected compartment syndrome, the invasive compartment pressure measurement can be used in the emergency room.	**GoR 0**

Explanation:

Compartment syndrome is a time-dependent noxious agent and can develop dynamically. It arises from an increase in intrafascial pressure in the compartments. It can affect all regions of the extremities, primarily the ankle. Burns and positioning damage as well as injuries are also part of the etiology. In the clinical examination, there are many compartment signs which are nevertheless not all evidentiary: pain, intensified through passive exertion of the muscle part involved, swelling of the muscle part involved, sensitivity disorders in the muscle dermatome.

In a suspected diagnosis, based on the above-mentioned clinical signs, the intrafascial pressure is measured objectively without delay, if applicable as the baseline value in the emergency room. It is advantageous to carry out continuous pressure measurements. A diastolic blood pressure in mmHg minus the compartment measurement value in mmHg less than 30 mmHg is given as the pathologic value [23, 24].

Particularly in polytrauma, the onset of compartment syndrome must be taken into account in massive infusion and massive transfusion. The possibility of clinically assessing a threatening or manifest compartment syndrome is often inadequate in anesthetized patients so that only the blood measurement of the intrafascial pressure permits an indicatory statement. It must be noted here that the accuracy of the compartment pressure measurement depends on the examiner and can be false-positive/negative.

Amputation injuries

In the multiply injured, the meaningfulness of attempting to salvage the extremity needs to be discussed for soft tissue damage grade 3 of closed and grade 4 of open fractures. Particularly in the multiply injured patient, it must be taken into account that a protracted salvage attempt with long surgery times can endanger the patient’s vital functions.

The decision to attempt to salvage an injured extremity is advisable only after the primary survey according to ATLS® and ETC has been completed. Only then can the complete injury pattern be evaluated with regard to a stable patient for extended surgical management.

On the other hand, from experience, the indication for attempting to salvage an extremity should only be made by a competent surgeon after a detailed inspection of the injured soft tissue. This can only be done in the operating room.

Thus, emergency completion of a subtotal amputation on an unstable patient in the emergency room remains an unresolved issue. These are case-by-case decisions, which depend more on the remainder of the injury pattern and less on the extremity finding. There are many case histories to be found on this topic in the literature, such as successful reconstructions or replantation of extremities. It is not possible to conclude recommendations. It appears unrealistic to conduct a study.

In the case of open extremity injuries, a decision should be taken in the emergency room on the operability in relation to the expected operating time to salvage the extremity in the multiply injured patient.

An emergency completion of an amputation in the emergency room remains subject to the unstable patient and requires an individual decision from the trauma surgery team leader.

CT diagnostic test

The use of computed tomography (CT) in emergency room diagnostic tests primarily concerns torso injuries including pelvic fractures. Ultimately, the CT diagnostic test in emergency room management is being increasingly preferred over conventional diagnostic radiology of the extremities because of structural measures and ongoing software development.

Whether this allows conventional diagnostic radiology to be dispensed with can only be decided on a case-by-case basis at present. A generally valid recommendation is not possible. In a retrospective study, Wurmb et al showed that, in a comparative patient collective of a first group of 82 patients who received a complete CT work-up of their injuries and a second group of 79 patients who first received conventional conservative diagnostic radiology and then a focused CT scan, there was a time saving of 23 minutes versus 70 minutes in the second group [27]. However, Ruchholtz et al. in their study highlight missed injuries in the CT as well and also cite the increased radiation exposure [28].

A CT diagnostic test can be performed after conventional diagnostic radiology in the emergency room on a stable patient with a suspected talus or scaphoid fracture in order to plan surgery and so as not to miss fractures in this region [29, 30].

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2.11 Hand

There are no studies above a Level of Evidence 4 on the diagnostic tests and surgical treatment for hand injuries, particularly in polytrauma. The available literature describes only injury frequencies and combinations. Recommendations on diagnosis and treatment methods exist only in the form of expert opinions. The following evidence-based recommendations must therefore be based on studies in which monotrauma in the hand have been studied.

Hand injuries, especially fractures, can occur in up to 25% of cases of multiply injured patients [1, 12, 15, 18]. The most common injury here involves fractures of the hand skeleton including the distal radius; the latter occurs in 2-16% of all multiply injured patients [1, 4, 10, 13, 19]. Tendon and nerve injuries are less common at 2-11% and 1.5%, respectively [15]. Amputations to the hand occur in only 0.2-3% of polytrauma cases [3, 11]. Severe combination hand injuries are also seldom found in polytrauma [17].

Primary diagnosis

Key recommendation:

The clinical evaluation of the hands should be carried out during the basic diagnostic work-up as it is crucial for establishing the indication for carrying out further examinations requiring the use of equipment.	**GoR B**

Explanation:

The probability of the occurrence of a hand injury does not depend on the severity of the polytrauma. In addition, it cannot be assumed that the probability for missing a hand injury increases with the injury severity [15]. However, primary missed and untreated hand injuries can later lead to considerable function impairments [8]. During the emergency diagnostic study, closed tendon injuries (tractus intermedius, distal extensor tendon, avulsion of deep flexor tendon), carpal fractures, and dislocations are frequently missed [6, 9, 16]. The clinical basic diagnostic work-up should comprise the examination for skin damage, swelling, hematoma, abnormal position and mobility, and monitoring perfusion (radial and ulnar arteries, capillary refill in finger pads) [17].

Key recommendation:

If there is clinical suspicion of a hand injury, basic radiologic work-up should consist of a radiographic examination of the hand and wrist on 2 standard planes for each.	**GoR B**

Explanation:

Radiographs of the hand and wrist should be taken on 2 planes in unconscious patients with clinical evidence of a hand injury (see above). Special attention should be paid to the possible presence of carpal fractures and dislocations. If there is clinical evidence of phalangeal fractures and if radiographs of the full hand cannot definitely exclude these or define them in a clear morphologic way, particularly in the case of a series fracture of several digits, it is advisable to radiograph the injured digit in isolation on 2 planes at the earliest possible opportunity [16, 17].

Key recommendation:

If there is clinical suspicion of an arterial vascular injury, Doppler or duplex ultrasonography should be performed.	**GoR B**

Explanation:

If there is clinical suspicion of an arterial vascular injury, a rapid, accurate diagnosis can be made by Doppler or duplex examination [5, 7, 14]. In the remaining unclear cases with urgent clinical suspicion of an arterial injury, angiography is only indicated if the general condition of the patient forbids surgical exploration [7] or the localization of the lesion is uncertain [2]. The Allen test permits definite confirmation of the patency of the arterial radio-ulnar link and the two forearm arteries [5].

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2.12 Foot

Diagnostic study of foot injuries

In the unconscious multiply injured patient, foot injuries can be excluded by repeated clinical examinations. Foot injuries are initially missed with an above average frequency in multiply injured patients. The reasons for this are more eye-catching and life-threatening injuries, deficient radiography technique in the emergency situation, extremely variable clinical standards, lack of experience on the part of the examiner with to some extent low case numbers of different foot injuries, and breakdown in communication in the treatment of the multiply injured by several teams [4–6, 9, 11, 16]. In the unconscious patient, repeated clinical examinations are thus necessary in the case of partially subtle injury signs in order not to miss foot injuries with potentially serious late complications [6, 17]. In a retrospective analysis, Metak et al. [9] found that 50% of all missed injuries to the lower extremities related to the foot and recommended a thorough clinical examination every 24 hours. If foot injuries are clinically suspected, radiography follow-up in the standardized settings (see below) is initially indicated and, if this does not provide adequate clarification, then stress views and a foot CT.

Standard projections on the foot (review in [16, 17]):

- Pilon, ankle joint — ankle joint ⊥
- Talus — ankle joint ⊥, foot dorsoplantar (beam tilted 30 ° in craniocaudal direction)
- Calcaneus — calcaneus lateral, axial, foot dorsoplantar (beam tilted 30 ° in craniocaudal direction)
- Chopart/Lisfranc — foot true lateral, foot dorsoplantar (beams for Chopart tilted 30 °, for Lisfranc tilted 20 ° in caudocranial direction), 45 ° oblique view midfoot
- Midfoot/toes — mid/forefoot a. p., 45 ° oblique views, true lateral

The occurrence of tension blisters on the foot must also be taken as an indicator for ischemic damage to the skin [10]. Besides clinical criteria, Doppler ultrasonography is recommended for the initial assessment of the vascular status of the foot [2, 12]. Controversy surrounds routine angiography where there is no Doppler signal [13] but it is indicated if the goal is for more complex reconstructions [7]. An important indicator for skin nutrition is the *ankle brachial index*. If the Doppler flow detects at least 50% of the brachial artery value, the wound healing rate is 90% [14]. The same was confirmed for transcutaneously measured oxygen tension exceeding 30 mmHg [15]. Poorer healing rates after surgical interventions can be expected in elderly persons (peripheral arterial obstructive disease [pAOD]), in diabetics, and in smokers [1, 3, 8].

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2.13 Mandible and midface

The frequency of injuries to the mandible and midface in multiply injured patients is about 18% [2, 19].

The most common concomitant injuries in craniofacial fractures are cerebral hematomas at over 40% followed by pulmonary contusions at over 30% [1].

Examination

Key recommendation:

Functional and esthetic injuries should be excluded in the clinical examination of the head-neck region in multiply injured patients.	**GoR B**

Explanation:

Calling on qualified specialists (maxillofacial specialists/otorhinolaryngologists, depending on availability or in-house arrangement) is considered advisable for all patients with evidence of mandible and maxillofacial injuries, even if this naturally depends on the qualifications of the physicians involved and the physical and organizational conditions [12, 15, 22].

The examination should comprise a thorough inspection and palpation [3, 7]. It serves inter alia to confirm external and internal injuries (e.g., bruising, hematomas, abrasions, soft tissue injuries, bleeding, tooth injuries, eye injuries, cerebrospinal fluid leak, intracranial leak, and mandible and maxillofacial fractures).

Diagnostic study

Key recommendation:

If there is clinical evidence of mandible and maxillofacial injuries, further diagnostic interventions should be carried out to provide a complete evaluation of the situation.	**GoR B**

Explanation:

Conventional radiography and/or computed tomography are used for the diagnostic tests [13]. In order to visualize corresponding regions, a panoramic slice view (orthopantomogram), paranasal sinuses view, specific dental X-rays, and a Clementschitsch p.a. view of the skull or a lateral view of the skull are taken. Using computed tomography, progressive intracranial pressure signs, asymmetries, fractures, and larger maxillofacial defects as well as the degree of dislocation can be visualized [9, 11, 23, 24]. Axial, sagittal, and coronal slices can be calculated [9, 18] (EL 3, EL 4). Preoperative planning can be carried out in more detail using computed tomography [4, 9]. This entails a reduction in operating time and higher quality [9, 21].

For small deformities, preference can be given to radiographic visualization on 2 planes with lower radiation exposure [17]. Pages et al. point out that, especially in children who are more sensitive than adults to the effects of ionizing rays by a factor of 3, particular attention should be paid because of the danger to eyes [14].

The methods of the imaging diagnostic test (radiography or CT) are usually determined by the type of concomitant injuries and the local availability of equipment.

In the case of orbita involvement, some authors recommend visually evoked potentials (VEP) or electroretinograms (ERG) to evaluate the optic nerves [5, 6, 8]. Particularly in the cases where the clinical function diagnosis of the optic path is not possible or uncertain (as a result of unconsciousness, morphine doses, massive swelling), this can serve to objectify the optic path function and thus enable an early intervention.

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2.14 Neck

Key recommendations:

Securing the airway must take priority when treating injuries to the neck.	**GoR A**
In the case of tracheal tears, avulsions or open tracheal injuries, surgical exploration with insertion of a tracheostoma or direct reconstruction should be carried out.	**GoR B**
In the case of all neck injuries, intubation or, if not possible, insertion of a tracheostoma should be given early consideration.	**GoR B**

Explanation:

Depending on the injury pattern, intubation must be given early consideration. This can be done transorally, transnasally, transvulnar or via tracheostomy. Even in the case of complete rupture of the trachea, distal sections can be intubated with defect bridging via endoscopic intubation. If oral or transnasal intubation is not possible, a tracheotomy must be considered [2].

A tracheostomy is always an elective operation; in the acute emergency, access should be made via a coniotomy as an emergency tracheotomy [13]. In the case of tracheal tears, avulsions or open tracheal injuries, surgical exploration with insertion of a tracheostoma or direct reconstruction is recommended. In the case of injuries of short length not involving all layers, conservative treatment can be attempted [6]. The same applies to trauma in the region of the larynx [2, 3, 14].

Diagnostic study

Key recommendations:

To confirm the type and severity of the injury, computed tomography of the neck soft tissues should be performed on hemodynamically stable patients.	**GoR B**
In the case of clinically or CT suspected neck injury, an endoscopic examination should be carried out on the traumatized region.	**GoR B**

Explanation:

In order not to generate any additional trauma through diagnostic or therapeutic measures, a search should first be made for injuries to the cervical spine or these should be minimized as much as possible through immobilization techniques [10, 12, 14]. Although the resulting injury sequelae from tracheal tears or avulsions can be visualized by means of imaging diagnostic tests (CT/MRI/conventional radiography), part of the actual lesion is often difficult to see. Skin emphysema after tracheal injury is given as an example, whereby the actual lesion can often not be identified in the imaging or cannot be visualized in conservative imaging if there is a pronounced hematoma on the neck without detectable source of bleeding. In addition, endoscopic examinations are recommended in the diagnostic evaluation of cervical injuries [1]. If there are suspected vascular injuries, an alternative diagnostic procedure is duplex ultrasonography, which is a non-invasive examination procedure and equivalent to angiography [7, 8]; both thus represent the gold standard for injuries to the neck vessels. This applies especially to the neck zones I and III according to Roon and Christensen [12]. Surgical exploration is additionally recommended for zone II. Although this is hotly debated in the literature, it is not in dispute that 100% of defects can be identified and if necessary treated in this way [7, 12].

Treatment

Key recommendations:

Open neck trauma with acute bleeding should be compressed initially and then managed by surgical exploration thereafter.	**GoR B**
In the case of closed neck trauma, an assessment of the vascular status should be carried out.	**GoR B**

Explanation:

The angiography or alternatively duplex ultrasonography represent the gold standard for injuries to the neck vessels, especially in zones I and III according to Roon and Christensen [12]. Surgical exploration is additionally recommended for zone II.

The first-line choice for function and trauma diagnostic tests is Doppler ultrasonography, being the least invasive, rapid, and not cost-intensive examination method. This is at least equal in diagnostic evidence to angiography and computed tomography, and even superior due to its lesser invasiveness and lower costs and higher speed [7, 8, 12].

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2.15 Resuscitation

Criteria for cardiac arrest

Key recommendations:

In the case of definitive cardiac arrest, uncertainties in detecting a pulse or other clinical signs that make cardiac arrest likely, resuscitation must be started immediately.	**GoR A**

Explanation:

A cardiac cause accounts for around 70-90% of patients affected by cardiac arrest. A post-traumatic cause accounts for only 3.1% of cases [1] and these patients have a markedly worse prognosis. Based on retrospective analyses of patient collectives, mainly from the 1980s to 1990s, an average survival rate of about 2% and, in the absence of serious neurologic deficits, only 0.8% is given in the "ERC Guidelines for Resuscitation 2005", with slightly better survival for penetrating injuries than for blunt trauma [2]. Somewhat better prognoses have been published in more recent studies [3-5]. In an analysis of the DGU Trauma Registry of 10,359 patients from the period 1993-2004, 17.2% of the multiply injured patients were successfully resuscitated after traumatic cardiac arrest, 9.7% of whom with a moderate to good neurologic outcome (Glasgow Outcome Scale [GOS] ≥ 4, Table 12). Seventy-seven (10%) of the resuscitated patients received an emergency thoracotomy with a survival rate of 13% [6]. In some studies, survival after traumatic and non-traumatic cardiac arrest was even comparable [7].

Table 12: Glasgow Outcome Scale (GOS) [8]:

Classification of course after traumatic brain injury with intracranial lesions and neuronal damage (point scale 1-5):

1. Died as a result of acute brain damage
2. Apallic, permanent vegetative condition
3. Severely disabled (mentally and/or physically), requiring permanent care, no earning capacity
4. Moderately disabled, mostly independent but marked neurologic and/or psychiatric disorders, considerable restriction in earning capacity
5. Not/mildly disabled, normal life despite possible minor deficits, only slight or no restriction in earning capacity

The criteria for detecting cardiac arrest in trauma patients do not differ from the criteria in non-traumatic cardiac arrest. The diagnosis to resuscitate the trauma patient must be made according to the guidelines of the European Resuscitation Council and, when indicated, must be started or continued [37]. The main criterion in the diagnosis of cardiac arrest in a traumatized patient in the emergency room is also apnea in combination with absence of pulse with/without electrical activity of the heart. In earlier resuscitation guidelines, the conscious state, breathing, and circulation were checked first [8, 9]. However, studies have meanwhile shown that both

checking for the absence of spontaneous breathing [10, 11] and particularly checking for absence of pulse [11, 12] is beset with a high error rate even by trained personnel. Low specificity in particular could lead to a delay in resuscitation.
Medical personnel in the emergency room should search for a maximum of 10 seconds for the presence or absence of a central pulse. In case of doubt or if there are other clinical signs that make cardiac arrest likely, resuscitation should be started immediately [13].

An allegedly normal ECG does not exclude cardiac arrest in terms of an electromechanical decoupling (pulseless electrical activity) any more than a pathologic or even possibly artificially altered ECG provides evidence of blood circulation [13]. Nevertheless, an immediate ECG recording is an essential component in monitoring in the emergency room and is always included in the evaluation of the cardiovascular situation.

If there is suspicion or evidence of cardiac arrest, the ECG and its changes also determine the use and timing of defibrillation treatment [13]. Pulse oxymetry and particularly also capnography are essential components in monitoring a multiply injured patient. Both procedures are able to indicate cardiac arrest (absent pulse wave in pulse oxymetry, rapidly falling $etCO_2$ in capnography). However, the limitations of pulse oxymetry in shock, centralization, and hypothermia should be noted.

Are there special features to note when resuscitating trauma patients?

Key recommendation:

During resuscitation, trauma-specific reversible causes of cardiac arrest (e.g., airway obstruction, esophageal intubation, hypovolemia, tension pneumothorax or pericardial tamponade) should be diagnosed and treated.	**GoR A**
An intraarterial catheter should be inserted for invasive continuous blood pressure measurement.	**GoR B**

Explanation:

In principle, establishing the indication for resuscitation even in the trauma patient must be done according to the guidelines of the ERC [2, 13]. More recent analyses on trauma-associated cardiac arrest show much better survival [3-6]. This is chiefly due to more advanced emergency systems and more consistent application of resuscitation guidelines (see Figure 4) as well as to adherence to emergency room algorithms. The survival rates correlate above all with the prehospital rescue time and the period of cardiopulmonary resuscitation [2, 14–17].

The main causes of cardiac arrest after a trauma are severe traumatic brain injury and massive bleeding [2, 18, 19]. The success of cardiopulmonary resuscitation is only ensured if the cause of cardiac arrest can be treated. To ascertain the trauma-specific reversible causes of cardiac arrest, the tube placement should be monitored by auscultation and capnometry/capnography, ultrasonography of the abdomen, pleural space, cardiac ventricles, and pericardium (standardized procedure if possible, e.g., FAST), and the hemoglobin value in the BGA measured during ongoing cardiopulmonary resuscitation.

Current studies in the Federal Republic of Germany have detected a frequency of esophageal intubations in up to 7% of cases, and so immediate monitoring of the correct placement of the tracheal tube by auscultation and capnometry/capnography is indispensable immediately after intubation both by the emergency physician and after the patient has arrived in the emergency room [20].

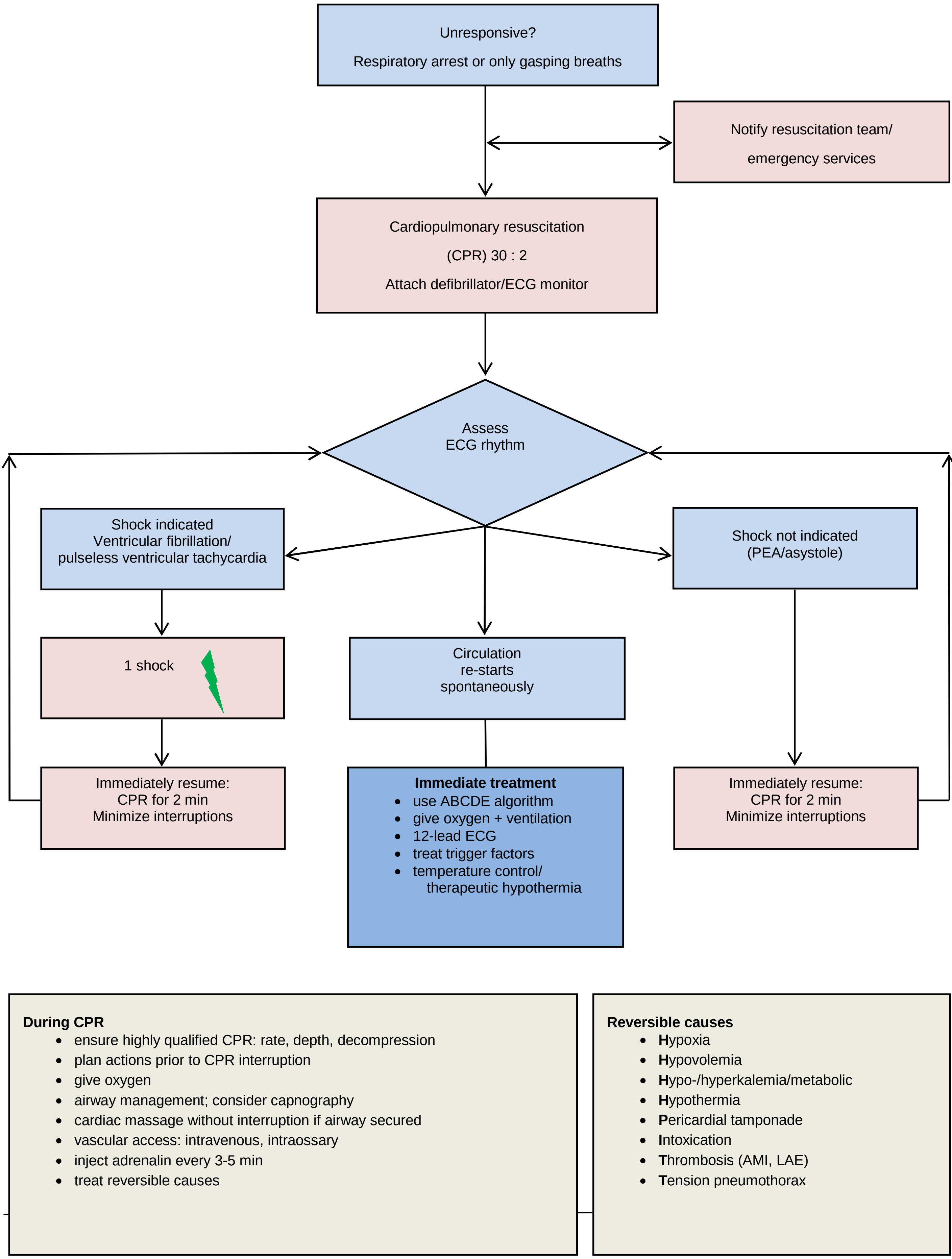
With emergency ultrasonography (e.g., FAST) [21, 22] and with recording the hemoglobin value in the (arterial or venous) blood gas analysis, etiologic abdominal or thoracic massive bleeding should be recorded during resuscitation and appropriate aggressive volume replacement and specific surgical treatment carried out. With pronounced hypovolemia, the use of hyperosmolar solutions and dispensing with PEEP ventilation can be expedient to improve preload and cardiac fill rapidly. If hypovolemia is the cause of cardiac arrest, the success rate of cardiopulmonary resuscitation can be increased with these measures [19, 23].

Retrospective analyses showed that the insertion of chest drains could be valued as a positive predictor for survival after post-traumatic cardiac arrest, which could be explained by the removal or prevention of a tension pneumothorax [6, 24–26].

According to expert opinion of the guideline project group, the early insertion of an intraarterial catheter into the femoral artery for invasive continuous blood pressure measurement can objectify the diagnosis of cardiac arrest and the efficiency of resuscitation efforts in the emergency room. In so doing, there must be no interruption or delay in cardiopulmonary resuscitation due to the insertion of the intraarterial catheter.

Figure 4: CPR algorithm according to the ERC Guidelines [36]

Advance Life Support for Adults (ALS):



Failure and discontinuation criteria

Key recommendation:

If resuscitation is unsuccessful after eliminating possible trauma-specific causes of cardiac arrest, cardiopulmonary resuscitation must be stopped.	**GoR A**
If there are definite signs of death or injuries that are not compatible with life, cardiopulmonary resuscitation must not be started.	**GoR A**

Explanation:

Most multiply injured patients die in the early phase from the consequences of severe traumatic brain injuries and massive bleeding [2, 18, 19]. Injuries not compatible with life may be present (e.g., injuries to the great vessels). The success of cardiopulmonary resuscitation firstly depends on the time since cardiac arrest occurred and secondly on the possibility of eliminating trauma-specific causes of cardiac arrest during resuscitation. Despite implementation of the afore-mentioned therapeutic measures (e.g., insertion of a chest drain) to eliminate trauma-specific causes of cardiac arrest, cardiopulmonary resuscitation can be unsuccessful. If no causes can be established during cardiopulmonary resuscitation or if the elimination of possible trauma-specific causes does not lead to a return of spontaneous circulation [ROSC]), resuscitation must be discontinued. The recognized definite signs of death signal an irreversible cell death of organs essential for life and are therefore indicators for failure of cardiopulmonary resuscitation. If there are definite signs of death or injuries that are not compatible with life, cardiopulmonary resuscitation must not be started. The decision to continue or discontinue cardiopulmonary resuscitation is the responsibility of the treating physicians and must be made in consensus. A time limit for unsuccessful resuscitation cannot be given.

What importance does the emergency thoracotomy have in post-traumatic cardiac arrest in the emergency room?

Key recommendation:

Emergency thoracotomy should be performed in the case of penetrating injuries, particularly if the onset of cardiac arrest is recent and vital signs are initially present.	**GoR B**

Explanation:

Performing an emergency thoracotomy is described as being relatively straightforward [27, 28] but requires, according to the ATLS® criteria of the American College of Surgeons [29], a trained, experienced surgeon and, according to the DGU guidelines [30], the availability of a thoracotomy set in the emergency room.

Based on a meta-analysis of 42 studies with a total of 7,035 documented "emergency department thoracotomies", the American College of Surgeons has published a guideline on the indication for and performance of an emergency room thoracotomy under cardiopulmonary resuscitation [31]. The resulting statements are based chiefly on the finding that, with an overall survival rate of 7.8%, only 1.6% of patients survived after blunt trauma but 11.2% after penetrating trauma. An emergency room resuscitative thoracotomy can improve the prognosis particularly in the case of penetrating trauma and appears to be particularly expedient if vital signs are initially present [31-33]. Appropriate logistic equipment is mandatory [34]. In blunt trauma, on the other hand, an emergency thoracotomy should be carried out more reluctantly. If an emergency thoracotomy is performed and there is simultaneously intraabdominal massive bleeding, a laparotomy to arrest the bleeding should be performed parallel to the thoracotomy. Appropriate logistic equipment is mandatory [35].

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2.16 Coagulation system

The term “polytrauma” refers to a very heterogeneous patient group. Perioperative coagulation therapy, particularly in this patient population, was carried out for decades according to gut instinct. The attempt to find a broader basis for medical management led to expert recommendations, which were based on physiologic concepts as well as pharmacologic and pharmacodynamic considerations. Increasingly, there are experimental and clinical studies on individual research questions. Even if the pathophysiologic correlations between the therapy choices described and the impaired coagulation can be presented conclusively and coherently, confirmation through randomized controlled trials is still awaited for virtually all recommendations. As with the 4th edition of the “Cross-Sectional Guideline on Therapy using Blood Components and Plasma Derivatives” by the German Medical Association (BÄK), the following recommendations are largely based on case observations and not randomized studies. Thus, the majority of conclusions can only be awarded a grade of recommendation [GoR] 0. For this reason, and also because of the partly considerable costs of the replacements described, it must be emphasized that the listed threshold values should in no way be seen as a cue for simply improving laboratory measurements. Rather, the indication for replacement using the cited drugs is only given in the event of massive, life-threatening bleeding [70].

Trauma-induced coagulopathy

Key recommendations:

Trauma-induced coagulopathy is an autonomous clinical picture with clear influences on survival. For this reason, coagulation diagnostic tests and therapy must be started immediately in the emergency room.	**GoR A**
Thrombelastography and thrombelastometry can be carried out to guide the coagulation diagnostic test and coagulation replacement.	**GoR 0**

Explanation:

The early trauma-induced mortality is usually a consequence of traumatic brain injury (40-50% of deaths) or of massive bleeding (20-40%). Bleeding is greatly increased by additional coagulopathy [102]. A coagulation disorder in multiply injured patients (trauma-induced coagulopathy [TIC]) has been known for over 20 years [61]. This coagulopathy was originally seen as a secondary occurrence, i.e. caused by loss/dilution and intensified by acidosis and hypothermia (“lethal triad”, “bloody vicious circle”) [55]. However, evidence of the existence of an autonomous, multifactorial, primary disease, which is intensified by the secondary factors (consumption, loss, dilutional coagulopathy), has been found in the present literature [9, 95], even in the Federal Republic of Germany [76]. TIC significantly influences the survival of multiply injured patients [72, 74]. It is independently correlated with a 4 to 8 times increased all-cause case fatality rate [72] and 8 times increased case fatality rate within 24 hours [76]. Patients who are coagulopathic on admission to the emergency room remain longer in the intensive care unit and in hospital, have a higher risk of renal insufficiency and multi-organ failure, have to be ventilated for longer, and exhibit a trend towards increased lung failure [8, 76]. An internationally valid, uniform term for this clinical picture is still lacking; suggestions are “acute traumatic coagulopathy” [10], “coagulopathy of trauma” [47], and “acute coagulopathy of trauma shock” [46]. The hypoperfusion and hyperfibrinolysis induced by the tissue injury and the shock are the triggers of TIC [9, 46]. The extent of hyperfibrinolysis appears to be correlated to the injury severity [67]. In a retrospective analysis, Schöchl et al. [102] found evidence of hyperfibrinolysis with an ISS > 25 in almost 15% of cases. TIC is already present on arrival in the emergency room in about 30% of the multiply injured and leads to an increased case fatality rate [10, 72, 74, 76, 95]. As there is no intravasal coagulation and thrombosis in the early phase of a trauma, this clinical picture does not involve disseminated intravasal coagulopathy (DIC) [34, 47].

The definition of massive bleeding consists of a blood loss of ≥ 100% of blood volume within 24 hours, of ≥ 50% within 3 hours, and 150 ml/min or 1.5 ml/kg BW/min over 20 minutes [114].

Diagnostic test: While the clinical picture of TIC is characterized by non-surgical, diffuse bleeding from mucous membrane, serous membrane, and wound areas, occurrence of bleeding from puncture sites of intravasal catheters and bleeding from indwelling bladder catheters or abdominal tubes, there is a gross lack of suitable laboratory parameters [70]. The prothrombin time/Quick test/INR and the partial thromboplastin time are poor determinants of a reduced level of coagulation factors and weak predictors for bleeding tendency in critically ill patients [15, 66]. In addition, these parameters only measure the time to the start of clot formation. A conclusion on the clotting strength and quality, its fibrinolytic activity or platelet function is not possible [7]. A prompt diagnostic test on the patient is also not possible.

The “classic” laboratory parameters are measured at 37 °C, buffered, with excess of calcium in serum and plasma. Thus, acidosis, hypothermia, hypocalcemia, and anemia are not included [36, 71] although these factors can have a considerable effect [71]. However, due to the epidemiologically increasing number of elderly patients, anticoagulation must be assumed in the case of trauma in this clientele. An INR > 1.5 in the over-50s is thus correlated with a significantly increased case fatality rate; this applies particularly to traumatic brain injuries [134]. Data from trauma registries showed that a prolonged prothrombin time in traumatized patients is a predictor for mortality [10, 72, 94]. Hess et al. [48] were able to confirm that pathologic “classic” laboratory parameters occurred with increasing frequency with increasing injury severity. These pathologic values, particularly the Quick test/INR, were associated with an increased case fatality rate.

Thrombelastography: (Rotational) thrombelastography (TEG) and (rotational) thrombelastometry (RoTEM) are being increasingly studied for the monitoring of multiply injured patients. In contrast to the standard coagulation test, this allows not only the time until onset of coagulation but also the speed of clot formation and the maximum clotting firmness to be recorded. This test procedure can be carried out without delay in the emergency room. Thus, treatment decisions can be made sooner [92, 95]. Several TEG/RoTEM-based algorithms for trauma management have already been published (e.g., [36, 59, 64]).

In the pig model for massive bleeding, Martini et al. [80] found a better correlation of thrombelastographic parameters compared to the Quick test, to PTT (partial thromboplastin time) or to INR. In a prospective observation study, Rugeri et al. [95] showed in 88 patients that different RoTEM parameters with a sensitivity and specificity between 74 and 100% are suitable for visualizing in vivo the changes in coagulation. The results from Levrat et al. [67] on 87 trauma patients lay in the same range for sensitivity and specificity. The trauma-induced hyperfibrinolysis in particular could be effectively confirmed. In 44 soldiers with penetrating injuries, Plotkin et al. [92] noted the TEG as a more precise indicator than the Quick test, PTT or INR for the need for blood products. Schöchl et al. [101] measured mortality-predicting hyperfibrinolysis using ROTEM in 33 critically injured patients: The time of fibrinolysis within 30 minutes after the start of coagulation, after 30-60 minutes, and after more than 60 minutes correlated with the mortality rate (100%, 91%, 73%), late fibrinolysis allowing the best prognosis ($p = 0.0031$). The results were available within 10-20 minutes and showed an increasing number of hyperfibrinolyses with increasing injury severity.

The use of thrombelastography and thrombelastometry in traumatized patients is very promising for guiding the coagulation diagnostic tests and replacement, particularly in the case of hyperfibrinolyses [11], but requires further prospective evaluation [70, 111].

Damage control resuscitation

Key recommendations:

In patients who are actively bleeding, the goal can be set at permissive hypotension (mean arterial pressure ~ 65 mmHg, systolic arterial pressure ~ 90 mmHg) until surgical hemostasis. This strategy is contraindicated in injuries of the central nervous system.	**GoR 0**
Suitable measures should be taken and treatment given to avoid the patient cooling down.	**GoR B**
Acidemia should be avoided and treated by suitable shock treatment.	**GoR B**
Hypocalcemia < 0.9 mmol/l should be avoided and can be treated.	**GoR 0**

Explanation:

Similar to damage control surgery, where definitive anatomic management is temporarily deferred in favor of stabilizing the vital physiologic signs, the concept of damage control resuscitation was developed to prevent trauma-induced coagulopathy [2]. Permissive hypotension, the prevention of acidemia, hypocalcemia and hypothermia, and the administration of coagulation-promoting products are part of this procedure [111]. The prerequisite for determining these parameters is consistent, invasive hemodynamic monitoring and the possibility for prompt, repetitive blood gas analyses.

Permissive hypotension: The term describes 2 approaches: firstly, to tolerate a lower than normal blood pressure and even to aim towards that in order to support thrombus formation and, secondly, to infuse only a small amount of fluid in order to prevent iatrogenic dilution while still ensuring adequate perfusion of the end organs. The correlation between “normal” blood pressure and bleeding tendency in trauma was already known by the end of the First World War [12]. The idea evolved in the military environment of tolerating low blood pressure values with a radial pulse that could still be felt as long as no surgical hemostasis is warranted [2].

The basis for the clinical application is a study by Bickell et al. [3] from 1994 of penetrating injuries in which patients with prehospital replacement therapy had an increased case fatality rate. The accompanying editorial [57] and a large number of readers’ letters mentioned the deficiencies in study design, conduct, and interpretation. Using the data from the German trauma registry, Maegele et al. [76] were able to show that an increasing frequency in coagulopathy occurred with increasing prehospital fluid therapy. In a randomized controlled trial with paramedics, Turner et al. [127] found no evidence in trauma patients of either advantage or disadvantage in prehospital fluid therapy (odds ratio [OR] for death from volume administration: 1.07 with 95% CI: 0.73-1.54; with exclusion of ambiguous patient data: OR 1.04; 95% CI: 0.70–1.53). Dutton et al. [28] noted no change in the duration of active bleeding in each of 55 traumatized patients (51% penetrating injury), whose volume replacement was titrated to a systolic blood pressure of > 100 mmHg or 70 mmHg. However, the authors showed that a sudden reduction in fluid requirement with increasing blood pressure is a sign of arrested bleeding [26]. A Cochrane Review from 2003 [65] also found no evidence for or against early, greater volume therapy for uncontrolled bleeding.

Due to pathophysiologic considerations, a target blood pressure of 65 mmHg as mean pressure or 90 mmHg as systolic value is recommended in current review papers for patients with massive bleeding despite a lack of evidence-based proofs. As adequate perfusion pressure is necessary if there is damage to the central nervous system, this recommendation does not apply to patients with a traumatic brain injury [53, 74, 106, 123].

Warming up: Hypothermia ≤ 34 °C has a major effect on platelet function and the activity of coagulation factors [71]. For the cooling down of the patient to be kept to a minimum, the initial fluid therapy must be provided exclusively by warmed infusions [2, 124] and, from the emergency room onwards, any volume therapy must be administered only via infusion warming devices with an infusion temperature of 40–42 °C [97, 124]. Both passive (e.g., foil space blankets, blankets, removal of wet clothing) and active measures (e.g., replacing infusions brought in with warmed infusions, constant use of heating pads, radiant heaters, hot air fans) are helpful. Both during the diagnostic study and later in the operating room, the room temperature should be as high as possible - in the thermoneutral zone if possible, i.e. 28–29 °C [97, 106, 126].

In the pig model, hypothermia reduces thrombin formation in the initial phase and impairs fibrinogen formation [79]. The hypothermia-induced platelet dysfunction can be partially corrected in vitro with an infusion of desmopressin (DDAVP) in the typical dose of 0.3 µg/kg [135]. In a thrombelastography study, Rundgren et al. [96] found evidence of an increasing effect of coagulation with decreasing temperature in a temperature range of 25 to 40 °C. There are no randomized controlled trials on trauma patients.

Acidosis balance: Acidosis ≤ 7.2 has a marked negative effect on coagulation [11, 71]. As the main cause of acidemia is hypoperfusion, acidosis will persist until adequate tissue perfusion is restored. Interventions that can intensify acidosis such as hypoventilation or NaCl infusion, for example, should be avoided [2]. The base excess (BE) also impairs coagulation [71] and can be used as prognostic evidence of complications and death [106]. Using data from Meng et al. [84], Zander et al. [137] showed that with a BE of - 15 the activity of various coagulation factors is halved. Critical values for the BE start in a range from - 6 to - 10 [106, 136].

In the pig model, Martini et al. [81] could not achieve any improvement in coagulopathy through buffering. As a single measure, buffering to pH values of ≥ 7.2 thus apparently leads to no improvement in coagulopathy [7] and is only meaningful from a hemostaseologic viewpoint in combination with the administration of coagulation products. Even a massive transfusion of stored PRBC can strongly increase acidosis [107]. The BE of fresh PRBC is - 20 mmol/l but after 6 weeks - 50 mmol/l [71]. Acidosis reduces thrombin formation in the propagation phase and accelerates fibrinogenolysis [79]. In the pig model, Martini et al. [82] proved that sodium bicarbonate balances pH and BE but cannot normalize either the fibrinogen level or the impaired thrombin formation. Tris(hydroxymethyl)aminomethane (TRIS, THAM) also did not impair the reduction in fibrinogen but stabilized the kinetics of thrombin generation in pigs. At present, it cannot be concluded which of the two substances is better suited for buffering for hemostaseologic reasons.

Calcium replacement: The reduction in ionized calcium (Ca^{++}) after transfusions depends on the citrate used as anticoagulant in the banked blood and is particularly marked in fresh frozen plasma (FFP). The reduction is more marked the quicker the banked blood is transfused, particularly at a transfusion speed > 50 ml/min [11]. The calcium monoproducts available in Germany for intravenous use contain very variable amounts of calcium ions [69]. This must be taken into account during replacement. A marked impairment of coagulation must be assumed below an ionized Ca^{++} concentration of 0.9 mmol/l [11].

Replacement of coagulation-promoting products

Key recommendations:

A specific massive transfusion protocol should be introduced and continued.	**GoR B**
In an actively bleeding patient, the indication for transfusion can be made at hemoglobin levels below 10 g/dl or 6.2 mmol/l, and the hematocrit value maintained at 30%.	**GoR 0**
If coagulation therapy in massive transfusions is carried out by administering FFP, the FFP:PRBC target ratio should be in the range of 1:2 and 1:1.	**GoR B**
Replacement of fibrinogen should be carried out if levels are at < 1.5 g/l (150 mg/dl).	**GoR B**

Explanation:

Packed red blood cells (PRBC): An increasing number of publications in the fields of trauma and intensive care point out the negative effect of PRBC administration on survival (see, for example, review in [2] or [125]). Malone et al. [77] noted in 15,534 trauma patients that a blood transfusion was a strong, independent predictor for mortality (OR 2.83; 95% CI: 1.82–4.40; $p < 0.001$). PRBC supplies aged > 14 days result in a significant worsening in survival both for mildly injured [131] as well as severely injured [130] trauma patients [110].

However, the involvement of red blood corpuscles in coagulation is confirmed (see, for example, review in [43] or [71]). In a TIC, a restrictive transfusion trigger can be unfavorable [83] as significant impairments to coagulation develop clearly before oxygenation has an effect [43].

While there are no randomized controlled data on hemostaseologically optimum hemoglobin and hematocrit values in polytrauma, target hemoglobin concentrations until arrest of bleeding should be in the range of 10 g/dl (6.2 mmol/l, hematocrit 30%) according to the German Medical Association, due to the favorable effects of higher hematocrit values on primary hemostasis in the case of massive, non-arrested hemorrhage [11]. The German Medical Association bases this recommendation on the review paper by Hardy et al. [42], which states that in bleeding patients experimental data indicate that hematocrit values of up to 35% are necessary to maintain hemostasis.

Frozen fresh plasma (FFP): In a systematic review of randomized controlled trials, Stanworth et al. [116] found no evidence of efficacy of FFP transfusion either in the group of massive transfusions or in a wide variety of other indications but frequently found problems in study design. Chowdhury et al. [15] studied the efficacy of FFP administration in a cohort study of 22 intensive patients. The often recommended volume of 10-15 ml/kg/BW did not lead to an adequate increase in factor concentration. This was only achieved with 30 ml/kg/BW, for which the patients required a median volume of 2.5 l FFP. A randomized double-blind trial of 90 patients with severe, closed traumatic brain injury (GCS ≤ 8) was carried out by Etemadrezaie et al. [29]. One group received a slow transfusion 10–15 ml/kg BW FFP while the control group received the same amount of common salt. In the FFP group, a new intracerebral hematoma developed more frequently ($p = 0.012$), and the patients had a significantly elevated mortality rate (63% versus 35%, $p = 0.006$). Hedim et al. [44] achieved a plasma dilution of 21% for 2.9 hours with an infusion of only 10 ml/kg BW FFP.

The transfusion of FFP also contains a series of risks: Dara et al. [20] noted a more frequent occurrence of acute lung injuries (ALI; 18% versus 4%, $p = 0.021$) after FFP transfusion in patients in the medical intensive care unit. Sperry et al. [109] found prospectively in 415 patients approximately double the TRALI (transfusion-associated acute lung insufficiency) risk with a ratio of FFP:PRBC > 1:1.5 (47.1% versus 24.0%, $p = 0.001$). Sarani et al. [99] showed after FFP transfusion in non-traumatized patients in the surgical intensive care unit a relative risk for the occurrence of an infection of 2.99, severe, ventilator-associated pneumonia of 5.42, severe bacteriemia of 3.35, and sepsis of 3.2 (each $p < 001$). There was a cumulative risk of infection of ~ 4% per FFP. Chaiwat et al. [14] identified the transfusion of FFP in trauma as an independent predictor for ARDS in 14,070 trauma patients: relative risk after transfusion of 1-5 FFP of 1.66 (95% CI: 0.88–3.15) and at > 5 FFP of 2.55 (95% CI: 1.17–5.55).

The German Medical Association regards the prevention and treatment of microvascular bleeding as an indication for FFP but described the treatment of coagulopathy with FFP alone as of little efficacy (increased rate, volume loading) [11]. It recommends rapid transfusion of initially 20 ml/kg BW but emphasizes that higher volumes may be necessary. There are no controlled studies to determine effective plasma doses [11].

FFP ratio to PRBC: The military field provided the first evidence that the replacement of lost blood volume by “full blood” can provide a survival advantage in critically injured patients with massive transfusions (> 10 PRBC/24 h) [93]. However, full blood is not available in the Federal Republic of Germany.

Hirshberg et al. [51] showed the necessity of early FFP replacement on a computer model and they recommended an FFP:PRBC of 1:1.5 or the transfusion of 2 FFP with the first PRBC. Ho et al. [52] calculated on a mathematical model that a bleeding-induced heavy loss of coagulation factors can only be remedied with a transfusion of 1-1.5 FFP per PRBC; if the FFP administration starts before the factor concentration has dropped below 50%, then a 1:1 ratio is sufficient. Borgmann et al. [6] showed the advantage of a 1:1 replacement of FFP and PRBC in military personnel. A retrospective study was carried out on the survival of 246 soldiers who had received replacement in a ratio of 1:8, 1:2.5 or 1:1.4. The hemorrhage-induced case fatality rates were 92.5%, 78%, and 37% ($p < 0001$). In the regression analysis, the FFP:PRBC ratio was linked independently with survival and discharge from hospital (OR 8.6; 95% CI: 2.1–35.2). Dente et al. [21] prospectively compared 73 civil patients after introducing a massive transfusion protocol containing PRBC, FPP, and platelets in the ratio 1:1:1 with 84 patients before introducing the protocol. The results showed a drastic reduction in early coagulopathy ($p = 0.023$), 24-hour case fatality rate (17% versus 36%, $p = 0.008$), and 30-day case fatality rate for blunt trauma (34% versus 55%, $p = 0.04$). In 135 patients, Duchesne et al. [24] proved a significant survival advantage with an FFP-PRBC ratio of 1:1 compared to 1:4 (26% versus 87.5%, p = 0.0001). Gonzalez et al. [39] compared the results of their massive transfusion protocol on 97 patients for the emergency room (PRBC:FFP > 2:1) with those of the ICU protocol (PRBC:FFP = 1:1). A TIC present on arrival in the emergency room could not be remedied until in the ICU, and the TIC at ICU admission correlated with the mortality rate (p = 0.02). A significantly reduced 30-day mortality was noted by Gunter et al. [41] for patients who received FFP and PRBC in a ratio ≥ 2:3 (41% versus 62%, p = 0.008). In a multicenter study of 466 patients, Holcomb et al. [54] showed that an FFP-PRBC ratio ≥ 1:2 compared to < 1:2 permitted better 30-day survival (40.4% versus 59.9%, p < 001). The combination of a high FFP-PRBC and a high platelet-PRBC ratio increased the 6-hour, 24-hour, and 30-day survival (p < 005). Kashuk et al. [60] showed the advantage of a 1:2 FFP-PRBC ratio (survivors: median 1:2, non-survivors: median 1:4, p < 0001) in 133 civil patients who received a massive transfusion within 6 hours. The authors nevertheless found a U-shaped curve: patients who received FFP and PRBC in the ratio 1:2 to 1:3 had the highest survival rate whereas the predicted mortality probability increased again with a ratio of 1:1. The authors thus recommended a ratio of 1:2 to 1:3. In 713 patients in the German trauma registry who required ≥ 10 PRBC until ICU admission, Maegele et al. [75] detected a survival advantage in relation to the PRBC-FFP ratio of > 1:1, 1:1 or < 1:1 (6 hours: 24.6% versus 9.6% versus 3.5%, p < 00001; 24 hours: 32.6% versus 16.7% versus 11.3%, p < 00001; 30 days: 45.5% versus 35.1% versus 24.3%, p < 0001). The ratio < 1:1 led to a longer ventilation dependency and a longer stay in ICU (p < 00005). In 415 patients with an FFP-PRBC ratio of > 1:1.5, Sperry et al. [109] found prospectively a significant 24-hour survival advantage (3.9% versus 12.8%, p = 0.012) with increased TRALI risk (47.1% versus 24.0%, p = 0.001). Scalea et al. [100] prospectively studied 250 patients. No survival advantage with a PRBC-FFP ratio of 1:1 was registered either in the total population or in the 81 massively transfused patients. With a total mortality within 24 hours of only 4% (6% with massive transfusions), the authors concluded that other (less severely injured) patients had been studied than in the majority of other studies. In 383 trauma patients (exclusion: severe TBI), Teixeira et al. [121] showed a linear increase in survival with increasing FFP-PRBC ratio up to a ratio of 1:3. After the admission GCS, the FFP-PRBC ratio was the second most important predictor for survival. Snyder et al. [105] retrospectively carried out an outcome study on 134 patients who required transfusion ≥ 10 PRBC/24 h. They noted a significantly reduced 24-hour mortality of 40% when FFP and PRBC were administered in a ratio ≥ 1:2 (median 1:1.3) compared to 58% at < 1:2 (median 1:3.7) (relative risk [RR] 0.37, 95% CI: 0.22–0.64). However, the significance could no longer be confirmed if the exact time of FFP transfusion within the first 24 hours was taken into account (RR 0.84, 95% CI: 0.47–1.50). The authors justified this with a potential “survival bias”: the patients did not die because they received less FFP but received less FFP because they died. In a randomized multicenter study, by means of a high FFP-PRBC ratio, Zink et al. [138] significantly improved survival in massive transfusions within 6 hours (37.3% at < 1:4 versus 15.2% at 1:4 to 1:1 versus 2.0% at ≥ 1:1; p < 0001) and lowered the total number of required PRBC (18 PRBC in the first 24 hours at < 1:1 versus 13 PRBC at > 1:1, p < 0001).

The majority of studies available indicate that patients who (will) require massive transfusions or have a life-threatening shock gain from a high FFP-PRBC ratio [111].

Massive transfusion protocol: The term “massive transfusion” mostly implies the transfusion of ≥ 10 PRBC per 24 hours [111]; but as the highest mortality of multiply injured patients occurs within the first 6 hours, some authors also recommend ≥ 10 PRBC per 6 hours [60]. In Cotton et al. [19], the introduction of a massive transfusion protocol with an FFP-PRBC ratio of 1:1.5 led to a 74% fall in mortality probability (p = 0.001) and to a higher 30-day survival rate (56.8% versus 37.6%, p < 0001) [18] with shorter stay (12 days versus 16 days, p = 0.049) and fewer ventilation days (5.7 days versus 8.2 days, p = 0.017). The authors attributed the improved survival to the earlier and faster infusion of the increased FFP-PRBC ratio. After introducing a massive transfusion protocol, Dente et al. [21] found evidence of an improved 24-hour survival (previously 36% versus 14%, p = 0.008) and 30-day survival (previously 55% versus 34%, p = 0.04) and a lower early mortality due to the coagulopathy (previously 21/31 versus 4/13, p = 0.023).

The Trauma Associated Severe Hemorrhage (TASH) Score of the German DGU Trauma Registry [136] can be used in the civil arena for predicting a massive transfusion. It comprises the factors systolic blood pressure, hemoglobin (Hb), BE, heart rate, free intraabdominal fluid, pelvic and femoral fracture, and male sex (0-28 points). An increasing TASH score could be attributed with good accuracy and discrimination to an increasing probability for a massive transfusion (area under the curve [AUC] 0.89). Nunez et al. [88] developed a prediction system for massive transfusions [assessment of blood consumption (ABC)] with the parameters penetrating injury, positive finding from focused trauma sonography (FAST), systolic blood pressure on arrival ≤ 90 mmHg and heart rate ≥ 120/min. For a value ≥ 2, they could attribute a sensitivity of 75% and a specificity of 86% to this score.

Platelet concentrates (PC): In the case of acute loss, platelets are initially increasingly released from bone marrow and spleen, which is why there is quite a delay before the platelet count falls after bleeding starts. After transfusion, the transferred vital platelets are distributed in the blood and the spleen so that the recovery rate in the peripheral blood is only about 60-70% and even lower with DIC [11].

In their retrospective multicenter study of civil trauma patients, Holcomb et al. [54] showed an improved 30-day survival with a PC-PRBC ratio of ≥ 1:2 (40.1% versus 59.9%, p < 001). The PC:PRBC ratio was an independent predictor for mortality. Perkins et al. [90] studied the effect on 694 soldiers who received massive transfusions of apharesis platelet concentrate (aPC) in relation to PRBC in 3 groups (aPC:PRBC 1:16, 1:18 to < 1:8 and > 1:8). The transfusion of aPC and PRBC in a ratio > 1:8 was characterized by a significantly higher 24-hour (64% versus 87% versus 95%, p < 0001) and 30-day survival (43% versus 60% versus 75%, p < 0001). In the multivariate analysis, the aPC-PRBC ratio was independently linked with the 24-hour and 30-day survival. In a PRBC-FFP platelet ratio of 1:1:1, Dente et al. [21] noted a drastic reduction in early coagulopathy (p = 0.023), 24-hour case fatality rate (17% versus 36%, p = 0.008) and 30-day case fatality rate in blunt trauma (34% versus 55%, p = 0.04). The randomized multicenter study by Zink et al. [138] with massive transfusion within 6 hours yielded significantly better values for the high ratio (6-hour survival: 22.8% versus 19% versus 3.2%, p < 0002; hospital survival: 43.7% versus 46.8% versus 27.4%, p < 003) for the 3 groups with a PC-PRBC ratio of < 1:4, 1:4 to 1:1 and ≥ 1:1.

If the patient is in acute danger due to a massive blood loss or due to the location (intracerebral bleeding), the German Medical Association recommends platelet replacement if the value falls below 100,000/µl [11]. If there are resulting platelet dysfunctions and tendency to bleed, a concomitant therapy with antifibrinolytics or desmopressin can be indicated [11].

Fibrinogen: As the substrate of coagulation, factor I (= fibrinogen) is essential not only for the formation of the fibrin network but is also a ligand for the GPIIb-IIIa receptor at the platelet surface and thus responsible for platelet aggregation. During dilution or severe bleeding, fibrinogen appears to be the most vulnerable of all coagulation factors and is the first to reach its critical concentration [11, 50]. As early as 1995, Hiippala [50] had confirmed in patients who received a colloid transfusion that the measurement of derived fibrinogen (measured using the Quick test) as well as fibrinogen measured using the method according to Clauss produces significantly higher values than correspond to the actual fibrinogen levels. According to the German Medical Association, the administration of 3 g fibrinogen in a volume of 3 liters of plasma elevates the measured fibrinogen concentration by approximately 1 g/l; initial doses of (2–) 4 (–6) g are thus necessary in adults [11].

Singbartl et al. [104] illustrated in a mathematical model that the maximum permissible blood loss until the critical fibrinogen value has been reached is dependent on the baseline value. However, this is generally not known in the initial management during emergency admission. Fries et al. [35] showed in an in vitro study that dilution occurs through infusion of crystalloid or colloid solutions, inter alia also through 6% HES 130/0.4. Giving fibrinogen in a concentration which when converted was roughly equivalent to 3 g/70 kg BW was sufficient to achieve an improvement in the RoTEM parameters. The cause of this effect is regarded as an effect of the interaction between thrombin, factor XIII, and fibrinogen; this particularly applies for a dilution through HES [86]. Madjdpour et al. [73] proved in the pig that, with varying molecular weight (900, 500, 130) and the same degree of replacement (0.42), HES impairs coagulation in a similar way. In thrombocytopenia induced in the pig model, Velik-Salchner et al. [128] normalized the impaired coagulation parameters in the TEG by administering fibrinogen. Mittermayr et al. [85] proved in 61 randomized patients with major spinal interventions that colloids reduce the speed and quality of clot formation through impaired fibrin polymerization. Stinger et al. [119] showed a highly significant correlation between the amount of fibrinogen administered and survival in 252 patients who had been injured during the fighting in the Iraq war. Injured patients who received less than 1 g of fibrinogen per 5 PRBC showed a case fatality rate of 52% compared to 24% if more than 1 g/5 PRBC was given. In establishing a concentration of < 2 g/l as indication for fibrinogen replacement (average 2 g, range 1-5 g), Fenger-Eriksen et al. [31] found evidence in 35 severely bleeding patients of a significant reduction in the required PRBC ($p < 00001$), FFP ($p < 00001$) and PC ($p < 0001$) and blood loss ($p < 005$). In 30 massively bleeding patients with hypofibrinogenemia of varying genesis, Weinkove et al. [132] raised the level of 0.65 to 2.01 g/l by giving 4 g of fibrinogen (median, range 2-14 g) (measurement according to Clauss). Farriols Danes et al. [30] showed that patients with acute, bleeding-induced hypofibrinogenemia (compared to chronic deficiency) reacted to fibrinogen replacement with a more marked increase and a significantly better 7-day survival rate ($p = 0.014$).

The widely used optical coagulation monitoring devices measure false elevated fibrinogen values when plasma is displaced by colloids [49]. Determining the derived fibrinogen is not sufficient for deciding whether there is an indication for replacement in massive bleeding [11]. The German Medical Association recommends that in massive bleeding the fibrinogen concentration is measured using the Clauss method and that target values are set at ≥1.5 g/l (150 mg/dl) and with prior colloid exposure ≥2 g/l (200 mg/dl) [11]. If hyperfibrinolysis is suspected, an antifibrinolytic drug should be given beforehand (e.g., 2 g tranexamic acid) [11].

Prothrombin concentrates (PPSB): The mixtures of vitamin K-dependent factors prothrombin = FII, proconvertin = FVII, Stuart factor = FX, and antihemophilic factor B = FIX, and protein C, protein S, and protein Z contain neither fibrinogen nor FV or FVIII [98] and are only standardized with regard to the factor IX content [11]. Activated coagulation factors and activated protein C or plasmin are virtually no longer contained in the PPSB products available now so that undesirable effects such as thromboembolic events, disseminated intravasal coagulation and/or hyperfibrinolytic bleeding are very unlikely even when larger quantities are administered [11]. The thromboembolisms described in the past were thought to be caused by a marked surplus in prothrombin in some PPSB concentrates no longer commercially available [40]. For this reason, it is no longer essential to replace antithrombin [11]. PPSB administration for DIC is only indicated if manifest bleeding exists which is partly caused by a lack of prothrombin complex factors and the cause of DIC is treated [11].

The rationale for the use of PPSB compared to FFP is the absence of risk of transfusion-induced (lung) injuries and viral safety. The main indication for PPSB is the elimination of the effect of vitamin K antagonists. This indication is proven by many studies and, in the case of marcumarized patients, the German Medical Association [11] recommends the preoperative administration of PPSB as a prophylaxis for bleeding. In the case of trauma-induced, consumption, loss or dilutional coagulopathy, the deficiency in the prothrombin complex can be so pronounced that, despite transfusion of FFP, replacement with PPSB is also necessary [11, 98]. Fries et al. [33] carried out dilutional coagulopathy with 6% HES 130/0.4 in the pig model. Fibrinogen and PPSB replacement after a standardized liver laceration led to a significantly lower blood loss (240 ml, range 50-830 versus 1,800 ml, range 1,500-2,500, $p < 00001$) and the survival of all animals whereas 80% of the control group died ($p < 00001$). Also in the pig, Dickneite et al. [22] showed a significant shortening in the time to hemostasis (median 35 versus 82.5 min; $p < 00001$) and a trend towards reduced blood loss (mean value 275 versus 589 ml) through the sole administration of PPSB after arterial bleeding (spleen incision) with dilutional coagulopathy. After venous bleeding (bone fracture), there were significant reductions both in the time to hemostasis (median 27 versus 97 min; $p < 00011$) and in the blood loss (mean value 71 versus 589 ml, $p < 00017$). The same working group [23] studied the efficacy of PPSB compared to FFP administration (15 and 40 ml/kg BW) in pigs with HES-induced dilutional coagulopathy. In this instance as well, PPSB reduced the time to hemostasis (venous bone trauma $p = 0.001$; arterial spleen trauma $p = 0.028$) and blood loss (venous bone trauma $p = 0.001$; arterial spleen trauma $p = 0.015$).

In the case of severe bleeding, the German Medical Association recommends initial bolus doses of 20-25 IU/kg BW; marked individual fluctuations in efficacy must be taken into account [11].

Antifibrinolytic drugs: Hyperfibrinolysis now appears to be more frequently assumed than before in multiply injured patients (~ 15% in [102]) and the extent correlates with the injury severity [67]. Hyperfibrinolysis is most common in patients with chest trauma, blunt abdominal trauma, pelvic trauma, and traumatic brain injury [58]. A prompt diagnosis of hyperfibrinolysis and also of the effectiveness of antifibrinolytic treatment is only possible by means of thrombelastography [67, 101]. The administration of the antifibrinolytic drug must be part of an overall therapeutic plan for the treatment of coagulopathies because hyperfibrinolysis can often involve heavy consumption of fibrinogen or even complete defibrination of the patient [58]. This fibrinogen deficiency must then be appropriately balanced after the manifestation of hyperfibrinolysis [58], i.e. the antifibrinolytic drug should be administered before the fibrinogen if hyperfibrinolysis is suspected [11]. Tranexamic acid is a synthetic lysine analogue, which inhibits the conversion of plasminogen into plasmin by blocking the plasminogen from binding to the fibrin molecule. The onset of effect of tranexamic acid is delayed compared to aprotinin as free plasmin continues to be active [102]. With a lack of evidence for multiply injured patients, it is recommended that initially 2–4 g (10–30 mg/kg BW [36, 58] is administered or a bolus dose of 10–15 mg/kg BW followed by 1–5 mg/kg BW/h [106].

Due to a lack of evidence-based data, a Cochrane Review from 2004 [17] could neither confirm nor refute the administration of antifibrinolytics in trauma patients. Another Cochrane Review from 2007 on the question of reducing perioperative blood transfusions through antifibrinolytic drugs [45] established for tranexamic acid a relative risk for PRBC administration of 0.61 (95% CI: 0.54-0.70) and a trend towards fewer re-operations. Tranexamic acid reduced the necessity of a blood transfusion relatively by 43% (RR 0.57; 95% CI: 0.49–0.66). A cumulative occurrence of serious side effects was not noted. A study published in The Lancet in 2010 (CRASH [Clinical Randomization of Antifibrinolytics in Significant Hemorrhage]-2 Study) [16] supports this conclusion: 1 g of tranexamic acid in 10 minutes + 1 g over 8 hours led to a significant reduction in all-cause mortality and in bleeding-induced mortality without an increased rate in thromboembolisms.

Desmopressin (DDAVP): Desmopressin (1-deamino-8-D-arginine vasopressin) is a synthetic vasopressin analogue. Desmopressin (e.g., Minirin®) effectuates nonspecific platelet activation (increased expression of the platelet GpIb receptor [89]), releases the von Willebrand factor and FVIII from the endothelium of the hepatic sinusoids, and thus improves primary hemostasis [32]. The main indication lies in perioperative treatment of von Willebrand syndrome. DDAVP also shows good efficacy in patients after heparin administration and with restricted platelet function due to taking aspirin (acetyl salicylic acid) or ADP receptor antagonists/thienopyridine derivatives with uremia and with liver disease or thrombocytopenia [32]. The maximum effect after i.v. administration occurs only after about 90 minutes [68]. With repeated administration, the tissue plasminogen activator (tPA) can be released, thereby possibly leading to hyperfibrinolysis. Thus, with repeated administration, some authors recommend simultaneous administration of tranexamic acid [68]. In cardio-surgical patients, a not significantly increased rate in heart attacks was confirmed after DDAVP (OR 2.07; 95% CI: 0.74–5.85; p = 0.19) [68]. Ying et al. [135] corrected in vitro the hypothermia-induced dysfunctions in hemostasis at least partially through DDAVP. Whereas the Cochrane Review of 18 studies with 1,295 patients by Carless et al. [13] could not confirm any efficacy for the prophylactic administration of desmopressin, Zotz et al. [139] searched the same available data for the subgroup of patients who had either > 1 l blood loss or a history of taking aspirin. For the therapeutic use of DDAVP, there was thus a significantly reduced blood loss (weighted mean difference [WMD] = - 386 ml; 95% CI: - 542- - 231 ml per patient; p = 0.0001) and a likewise significantly reduced, transfused blood volume (WMD = - 340 ml, 95% CI = - 547- - 134 ml per patient; p = 0.0001). There are currently no controlled studies of trauma patients.

From a pathophysiologic viewpoint, a treatment attempt with DDAVP can be considered in a dose of 0.3 µg/kg BW over 30 minutes in diffusely bleeding patients with suspected thrombocytopathy.

Factor XIII: In the presence of calcium ions, FXIII effectuates the covalent crosslinking of the fibrin. A three-dimensional fibrin network is thus formed which effectuates definitive wound healing [11]. Factor XIII is not recorded by the Quick and aPTT (activated partial thromboplastin time) coagulation screening tests as these tests only measure the time fibrin formation starts but not fibrin crosslinking [11].

An acquired deficiency is not rare and can arise with a TIC as a result of increased rate (increased blood loss, hyperfibrinolysis, DIC) and consumption (in major surgery). In patients with existing coagulation activation, e.g., through having a tumor, a severe FXIII deficiency and subsequent massive bleeding can result from a trauma or intraoperatively [62]. A lower FXIII level has been shown as a risk factor for bleeding in intracranial [37] and cardio-surgical [4, 38] interventions as well. In elective patients with unexpected intraoperative bleeding, Wettstein et al. [133] established a significantly higher blood loss (1,350 ml versus 450 ml; p < 0001) and a markedly more rapid consumption of fibrinogen and FXIII (p < 0001) compared with a non-bleeding collective. Korte et al. [63] found evidence in a prospective, randomized, double-blind pilot study of 22 patients who were to receive surgery for colon cancer and had activated coagulation (elevated preoperative fibrin monomers) of a significantly smaller reduction in clot firmness) and a trend towards less blood loss with a single dose of 30 IU/kg FXIII. There are no randomized studies on trauma patients.

If testing for FXIII cannot be done promptly, blind administration of FXIII should be considered, especially in severe, acute bleeding [11]. Initially, 15-20 IU/kg BW is recommended as a possible dose until hemostasis. As the concentrate is produced from human plasma, a residual risk of infection cannot be excluded.

Recombinant activated factor VII (rFVIIa): The approval of rFVIIa is restricted to bleeding in antibody hemophilia (antibodies to factors VIII or IX), Glanzmann thrombasthenia (inherited dysfunction of the platelet GPIIb-IIIa receptor), and inherited FVII deficiency. In a supraphysiologic dose, rFVIIa binds to the activated platelets and there effectuates a “thrombin burst”, which leads to the formation of an extremely stable fibrin clot [34]. On activated platelets, rFVIIa can also enable tissue factor-independent thrombin generation.

Off-label use has been described in a large number of case histories. Adverse side effects in the form of thromboembolic events in the arterial and venous vascular system and in perioperatively or traumatically damaged vessels have been reported particularly in off-label use [11]. Perkins et al. [91] showed in soldiers from the Iraq war that early administration of rFVIIa could lower PRBC consumption by 20%. Of 365 massive transfused patients, 117 received rFVIIa. Likewise, in patients in the military who received massive transfusions, Spinella et al. [113] noted a reduced 24-hour (14% versus 35%, p = 0.01) and 30-day mortality rate (31% versus 51%, p = 0.03) in early (median 2 hours after admission and 2.5 hours after trauma) administration of rFVIIa. However, the logistic options for preparation of, for example, blood components under war conditions cannot be compared with those of a European hospital. In the study in 2005 by Boffard et al. [5], the efficacy of 400 µg/kg BW rFVIIa (after the 8th PRBC initially 200 µg/kg BW, then 100 µg/kg BW each after 1 and 3 hours) as adjunctive therapy was tested compared to placebo in 143 blunt and 134 penetrating trauma injuries. In blunt trauma, there was a significant reduction in the number of transfused PRBCs (calculated reduction by 2.6 PRBC, p = 0.02) and in the necessity for a transfusion of ≥ 20 PRBC (14% versus 33%; p = 0.03). In penetrating injuries, there was a trend in this direction for both parameters. Neither a lowering in the mortality rate nor an accumulation of thromboembolic side effects was observed. In 2009, Stein et al. [117] posed the question of costs. With the same rate of mortality and side effects, the authors could establish no significant difference in the costs (mean value US$63,403 conventionally versus US$66,086 in rFVIIa) in 179 patients with traumatic brain injury. For the 110 patients who were placed in the intensive care unit, there was even a significant cost reduction through rFVIIa (mean value US$108,900 conventionally versus US$77,907 in rFVIIa). However, really low doses were used in this study (5.9–115 µg/kg BW; mean value 41.9 ± 35.5 µg/kg BW, median 25.1 µg/kg BW). Several meta-analyses of RCTs have studied the efficacy of off-label use: Stanworth et al. [115] found 13 placebo-controlled, double-blind RCTs on the use of rFVIIa in patients who were not hemophiliac. In prophylactic use (n = 724, 379 received rFVIIa), there was a trend towards reduced transfusion frequency (pooled RR 0.85; 95% CI: 0.72-1.01), which contradicts a trend towards increased thromboembolisms (pooled RR 1.25; 95% CI: 0.76–2.07). In therapeutic use (n = 1,214; 687 received rFVIIa), there was a trend towards reduced mortality (pooled RR 0.82; 95% CI: 0.64-1.04) and again a trend towards increased thromboembolisms (RR 1.50; 95% CI: 0.86–2.62). In 2008, Hsia et al. [56] published the results of 22 RCTs on bleeding of different genesis in 3,184 non-hemophiliac patients (only the study by Boffard et al. [5] contains 301 trauma patients). The result was a reduced need for transfusion (OR 0.54; 95% CI: 0.34–0.86), a trend towards reduced case fatality rate (OR 0.88; 95% CI: 0.71–1.09) and no change in venous but a trend towards cumulative arterial thromboembolisms (OR 1.50; 95% CI: 0.93–2.41). In 2008, Duchesne et al. [25] examined 19 studies of trauma patients: Based on Boffard et al. [5], the authors gave a Level 1 recommendation for the use of rFVIIa in blunt trauma. A Level 2 recommendation was given for trauma-associated hemorrhaging with 400 µg/kg BW (lower dose could also be effective) if other treatment options failed. Early use was assessed as Level 3. In 2009, Nishijima et al. [87] only found the above-mentioned study by Boffard [5] on the question of rFVIIa use in the emergency room. A large international phase III study on the use of rFVIIa in trauma patients was recently discontinued as the planned lowering in mortality could not be achieved [111].

The effectiveness of rFVIIa and of the coagulation sequences thus indicated is linked to a series of “framework conditions”, which should be attained before administration: fibrinogen value ≥ 1 g/dl, Hb ≥ 7 g/dl, platelet count ≥ 50,000 (preferably ≥ 100,000)/µl), ionized calcium ≥ 0.9 mmol/l, core temperature ≥ 34 °C, pH value ≥ 7.2, and the exclusion of hyperfibrinolysis or a heparin effect [11, 34, 106, 120]. A widely-used “standard dose” for off-label use is 90 µg/kg BW [27, 56, 129]. However, the necessary dose remains ambiguous [106]; a very high total dose of 400 µg/kg BW is used in the only class 1 study by Boffard et al. [5]. Due to the very short half-life, a repeat dose can be considered after 2 hours [108] even if the need for a repeat dose is more likely to indicate a lack of effectiveness according to the review by Dutton et al. [27].

The German Medical Association refers in its guidelines to the review article by Mannucci et al. [78]. Its conclusion states that rFVIIa is no wonder substance but possesses efficacy in patients with trauma and excessive bleeding who do not respond to other treatment options. Its use, but only after conventional treatments have not been successful, is also propagated in current reviews [25, 27, 56]. The current summary of product characteristics from NovoNordisc (May 2009) recommends that rFVIIa is not used off-label due to the risk of arterial thrombotic events in the range of ≥ 1/100 to < 1/10.

Antithrombin: There are no prospective randomized studies on multiply injured patients. However, with persistent massive bleeding, administration of antithrombin (formerly ATIII) will only intensify it and cannot therefore be recommended [74, 106]. In their meta-analysis of randomized controlled trials of critically ill intensive care patients (AT: n = 1,447, control: n = 1,482), Afshari et al. [1] recorded a significant increase in the risk of bleeding through the administration of antithrombin (RR 1.52, 95% CI: 1.30–1.78, I2 = 0.3%). Even if this could not confirm any lowering in the case fatality rate, the German Medical Association recommends an off-label use of ATIII only in confirmed DIC with confirmed ATIII deficiency [11].

Summary table

The above-described drug treatment options can be summarized as follows (modified according to [70, 118]):

Table 13: Drug options for coagulation therapy

1. Stabilization of framework conditions (prophylaxis and therapy)	Core temperature ≥ 34 °C pH value ≥ 7.2 ionized Ca^{++}concentration ≥ 0.9 mmol/l
2. Replacement of oxygen carriers	PRBC administration (functional goal: Hb 6 [–8] g/dl but hemostaseologic goal in massive bleeding: Hct ≥ 30% and Hb ~10 g/dl [6.2 mmol/l])
3. Inhibiting potential (hyper)fibrinolysis (always BEFORE administering fibrinogen!)	Tranexamic acid initially 2 g (15–30 mg/kg BW) or 1 g as saturation over 10 minutes + 1 g over 8 h
4. Replacement of coagulation factors (in the case of sustained tendency for severe bleeding)	FFP ≥ 20 (more likely 30) ml/kg BW If coagulation therapy in massive transfusions is carried out by administering FFP, the FFP:PRBC ratio should be in the target range of 1:2 and 1:1. and fibrinogen (2–) 4 (–8) g (30–60 mg/kg BW; goal: ≥ 150 mg/dl and ≥ 1.5 g/l) and if necessary PPSB initially 1,000–2,500 IU (25 IU/kg BW) if necessary 1–2x FXIII 1,250 IU (15–20 IU/kg BW)
and (if suspected thrombocytopathy) nonspecific platelet activation + release of the “von Willebrand factor” and FVIII from the endothelium	if necessary DDAVP = desmopressin 0.3 µg/kg BW over 30 minutes (“1 ampoule per 10 kg BW”)
5. Replacement of platelets for primary hemostasis	platelet concentrates (goal for transfusion-dependent bleeding: 100,000/µl)
6. If necessary, thrombin burst with platelet and coagulation activation (please note requirements!!)	in the individual case & if all other treatment options are unsuccessful if necessary initially 90 µg/kg BW rFVIIa
if active bleeding	no antithrombin

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2.17 Interventional control of bleeding

Key recommendations:

If possible, embolization should be carried out on patients whose hemodynamics can be stabilized.	**GoR B**
A stent/a stent graft must be used if an intimal dissection, vessel tear, AV fistula, pseudoaneurysm or a traumatic aortic rupture is present.	**GoR A**
If a patient with unstable circulation has a ruptured iliac artery or distal abdominal aortic hernia, a balloon occlusion can be temporarily carried out for up to 60 minutes.	**GoR 0**
If there is renewed bleeding after successful embolization, further treatment should also be interventional.	**GoR B**

Explanation:

Indication for interventional treatment and decision algorithm

The basic requirement for carrying out interventional radiology to monitor bleeding should be the multi-slice CT scan (MSCT) with contrast agent. Generally, the source of bleeding can be identified using this examination. Embolization should only be considered if there is evidence of an active contrast agent extravasation in the MSCT as only then is there adequate prospect of a successful visualization of the source of bleeding and subsequent treatment. In particular, interventional treatment may be considered in the following injury patterns:

- pelvic fractures with evidence of contrast agent extravasation in the MSCT
- spinal fractures with clear contrast agent extravasation
- injuries to the great vessels
- parallel or supplementary to surgical control of bleeding

Technical and personnel requirements

Carrying out interventional treatment to control bleeding is only advisable if the following requirements are met:

- A conditional stabilization of the patient must be possible under massive transfusion and intensive medical treatment.
- The personnel requirements must be met in the form of physicians on site who are experienced in angiography.
- Supplies of the required embolization materials and stents must be available.

Before carrying out a radiologic intervention, which generally lasts between 30 and 60 minutes including transport to the angiography unit, it is essential to clarify whether the patient can be stabilized with transfusions up to the time of the intervention and for the period of the intervention, whether the bleeding is located in an area that is typically accessible for embolization, and whether other sources of bleeding (e.g., extensive craniofacial injuries with massive diffuse bleeding), which are responsible for the blood loss, have been excluded.

Materials and techniques for interventional control of bleeding

In interventional radiology, the following materials are available for interventional control of bleeding:

- non-covered and covered stents
- metal coils
- detachable balloons
- solid particles
  - polyvinyl alcohol (Contour®)
  - gelatin foam (gel type)
  - microspheres (Embospheres®)
- liquid embolization materials
  - ethanol
  - tissue adhesives (Bucrylat®)
  - occlusion gel (Ethiblock®)

The coils are available in different diameters, shapes, and lengths. They are particularly suitable for the precise embolization of severely bleeding vessels of larger diameter. The positioning of the coils can be very precise and dislocations are very rare.

Contour particles are also available in different sizes between 100 and 500 µm and are particularly suitable for the treatment of diffuse bleeding from fracture zones. Which of the above-mentioned materials are to be used depends on the bleeding and the experience of the interventional radiologist and requires an individual decision adapted to the situation.

The goal of every embolization must be to carry out treatment without damaging the tissue if possible. In so doing, attention should be given to maintaining residual perfusion in the downstream organs and keeping damage to downstream tissue to the minimum.

The main indication for implanting a non-covered stent in trauma management is the presence of an intimal dissection. There is an indication to implant a stent coated with polytetrafluroethylene (PTFE), dacron or polyester in vessel tears, AV fistulas, pseudoaneurysms or traumatic aortic ruptures in order to cover the vessel leak.

Temporary balloon occlusion is available as a last resort. This can take the form of an occlusion of the infrarenal abdominal aorta for 30-60 minutes either under DSA or CT monitoring or a more selective occlusion in the internal iliac artery. However, if there is severe bleeding from the proximal internal iliac artery, preference should be given to coils for primary embolization. The goal of temporary balloon occlusion is to permit restoration of central circulation in patients with maximum circulation instability and thus to extend the timeframe until surgical or interventional care.

Planning interventional control of bleeding

A full-body MSCT scan is routinely performed before carrying out a radiologic intervention for controlling bleeding. There is a proven standardized examination protocol for this. Besides the plain examination of head and spine, the MSCT examination consists of a contrast-enhanced examination of thorax, abdomen, and pelvis. The primary contrast-enhanced examination after intravenous administration of 120 ml contrast agent at an injection rate of 2 ml/sec has been proven for the examination of thorax, abdomen, and pelvis. The examination should be carried out 85 seconds after contrast agent administration has started. This process ensures that, firstly, there is good, homogeneous contrasting of the parenchymatous organs but, secondly, sufficiently good contrasting of the great vessels is still ensured. In children and in a body weight less than 60 kg, the quantity of contrast agent and the flow rate should be adjusted appropriately (e.g., child weighing 30 kg: 60 ml contrast agent, flow rate 1 ml/s, child weighing 15 kg: 30 ml contrast agent, flow rate 0.5 ml/s). The start delay for the scan should remain at 80-85 seconds. The MSCT is able to visualize minimal density gradients reliably. Thus, the MSCT allows differentiation between already coagulated blood (density values between 40 and 70 HU) and active bleeding (density values between 25 and 370 HU, mean value 132 HU) [7].

Discussion

Embolization of the pelvis

Overall, the embolization of pelvic fractures is only seldom indicated as most patients with pelvic fractures are hemodynamically stable. According to a study by Agolini et al. [8], only 15 patients (1.9%) required embolization out of 806 patients with pelvic fractures. Other authors give the rate of necessary embolizations at 3% [9].

The management of patients with significant bleeding from pelvic fractures is very challenging. In addition to arterial bleeding, venous bleeding also represents a big problem. Arterial bleeding can be stopped by arterial embolization. The resulting hematoma then acts as a tamponade and also contributes towards arresting the venous bleeding. It is surgical hemostasis in arterial bleeding that frequently fails [10, 11] as the tamponade effect of the hematoma is removed during access to the iliac arteries, and massive, uncontrollable venous bleeding can occur. Even if definite evidence is still lacking, there are clear signs from clinical experience that arterial embolization can help even in diffuse venous bleeding as the arterial forward flow is cut off. According to our experience, the evidence here of active contrast agent extravasation in the MSCT greatly assists the decision-making process. If the personnel and logistic requirements are in place, embolization should be considered if there is evidence of active, relevant contrast agent extravasation in the presence of a critical circulation situation. If the examination technique is appropriate, the quantity of contrast agent sufficient, and the start delay 80-85 seconds after contrast agent administration has started, the lack of evidence of contrast agent extravasation in the MSCT is generally a reliable indication that arterial embolization could not promise success.

The studies by Agolini et al. [8] also showed that early embolization leads to a more favorable result with regard to mortality. Thus, in this study with an admittedly relatively small patient collective which was embolized, there was an advantage for mortality in the group that was embolized within 3 hours (mortality 14%) compared to the group embolized later (mortality 75%).

Embolization of the spleen

Arterial embolizations in splenic injuries are carried out only in isolated cases, usually as an alternative to surgical interventions to preserve the spleen [12]. Selective embolization without subsequent surgery is successful in 87-95% of cases [3, 13]. Proximal embolizations of the lienal artery should be avoided due to the risk of massive abdominal wall or pancreatic infarction. In addition, proximal embolization of the lienal artery is often not suited to achieving permanent hemostasis due to a reduction in pressure in the intrasplenic vessels.

Embolization of the liver

Embolization of the hepatic artery can be successfully used in the management of post-traumatic bleeding [14, 15, 16], involving overall relatively small series. Patients with sustained bleeding after primary surgical hemostasis to the liver in particular should undergo angiography and, if necessary, be embolized to avoid another operation [17].

If there is renewed bleeding after successful embolization, further treatment should also be carried out by angiography. In addition to the improved surgical results, arterial embolization has contributed particularly to improving the outcome after traumatic hepatic injuries [18].

Embolization of the kidneys

Many kidney injuries can be treated conservatively. Avulsions to the vascular pedicle must be surgically managed within the first few hours in order to preserve renal function. Angiography is indicated if, during the MSCT, contrast agent extravasation could be visualized in the kidney or around the kidney. Hemorrhagic-induced extravasation of contrast agent must not be confused with a dense contrast agent collection, e.g., in a urinoma. The success of renal embolization depends on this being carried out rapidly and as selectively as possible. A proximal occlusion of the renal artery is only indicated when a nephrectomy is indicated due to the organ being damaged but this must only be done later when the patient is more stable. In any case, the search for pole vessels is important for the angiographic work-up of the traumatic kidney injury as these might also require embolization. Studies have shown that kidney embolization is successful as primary treatment in 82-100% of cases.

Endovascular treatment of traumatic aortic rupture

Numerous studies have been carried out during recent years on the value of endovascular treatment of traumatic aortic rupture [19–26]. Practically all come to the conclusion that in an acute situation preference should be given to endovascular treatment as opposed to the open-surgical procedure. Thus, Ott et al. [24] found evidence that the mortality and paraplegia rates in endovascular treatment are markedly better at 0% than the results of open-surgical treatment with a mortality of 17% and a paraplegia rate of 16%.

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3 Emergency surgery phase

3.1 Introduction

How would you decide?

A 35-year-old cyclist has an accident. The patient is intubated and ventilated at the accident scene by the emergency physician. Volume replacement to support circulation is introduced. The patient is brought to you for primary management. After exclusion of relevant intraabdominal or intrathoracic bleeding and after a thorough diagnostic study, the following injury pattern manifests itself: traumatic brain injury II °, chest trauma with multiple rib fracture and pronounced left pulmonary contusion, I ° left open femoral shaft fracture, right distal lower leg fracture. The laboratory tests initially carried out show a hemoglobin value of 9.3 g/dl, INR of 77%, and a base excess of - 4.5 mmol/l.

You consider what care options exist in the first surgical phase for this patient and weigh up their advantages and disadvantages. The longer you think about it, the more questions arise: What is the first-line choice of surgery strategy for the femoral shaft fracture? Which care strategy is best for the distal lower leg fracture? Does the fibula have to be managed at the same time? Is primary definitive osteosynthesis sensible or is temporary osteosynthesis better? What role does the traumatic brain injury or the chest trauma play in the decision-making? You remember the management of similar cases in your department, the dogmatically repeated ideas of your "teacher" or other colleagues, the economic "restraints" of your hospital administration, and the perennial lack of time to deal properly for once with the almost limitless complex literature on polytrauma management. In the end, you opt once more to carry out the care based on your own experiences.

How would other providers in Germany decide?

By way of example, we will focus on the question of femoral shaft management. According to the available data in the trauma registry of the German Trauma Society, more than 65% of all multiple injuries involve injuries to the extremities and/or the pelvis (AIS $\geq$ 2). It is, therefore, all the more astonishing that contradictory surgical management strategies for femoral shaft fractures in polytrauma are practiced and published [1]. According to analyses of the trauma registry, the primary management of femoral shaft fractures in multiply injured patients in Germany is, almost dogmatically, always with an external fixator in some hospitals, always with a medullary nail in other hospitals, and finally in many hospitals, in every conceivable combination, sometimes with fixators and sometimes with nails [1].

The aim of this "emergency surgery phase" guideline section

Such depictions of "reality" refer to an alternative, often even contradictory range of decisions from different hospitals. They support the need for an overview of the evidence levels and grades of recommendation of differing management strategies. Thus, the aim of this section of the guideline is to gain an overview of the evidence levels of different management strategies in the emergency surgery phase after multiple injury, and from this either to derive clinical treatment algorithms (if there is sufficient evidence) or to document the need for scientific verification of the evidence (grade of recommendation).

Special notes:

In this guideline section, the assessment of core questions is often hampered by the lack of “hard”, scientifically based data or by only results on mono-injuries being available. In this regard, the corresponding locations are explicitly referred to and attempts are made, despite the partly contradictory information from the literature, to provide the clearest possible recommendations for clinical routine in individual key recommendations.

Moreover, in terms of fracture discussions, the initial assumption, if not explicitly mentioned elsewhere, is a closed fracture without vascular involvement and with no compartment syndrome. The open fracture, vascular involvement, and compartment syndrome are regarded as an indication for emergency surgery and require, if necessary, a different management strategy.

In addition, in many surgically demanding fractures (e.g., distal complex femur or humerus condyle fracture), particularly in polytrauma, it should be taken into account that primary definitive care can only be considered if: a) careful planning has been carried out (if appropriate, on the basis of 3D CT); b) the expected duration of surgery is not too long; c) an experienced surgeon is present; d) a suitable implant is in stock in the hospital. For this reason, in many German trauma centers, such surgically demanding fractures in the multiply injured patient ought first to receive primary temporary stabilization before subsequently undergoing secondary definitive reconstruction.

Finally, it is assumed hereafter that the patient has otherwise stable circulation with additional injuries of the extremities. The management strategy for a patient with multiple injuries and cardiopulmonary, metabolic, or coagulatory “instability” may be very different from this, depending on different priorities. Please refer to the relevant literature [1–7] for a risk assessment of the multiply injured patient as a decision aid in the management strategy. Damage control is a strategy for management of severely injured patients with the goal of minimizing secondary damage and maximizing the outcome for the patient. In the area of fracture treatment, for example, this would mean not carrying out primary definitive osteosynthesis but instead stabilizing the fracture temporarily with an external fixator. The smaller intervention and the shorter surgery time are intended to make it possible to limit the additional trauma burden to the maximum possible extent in terms of secondary damage. In precisely this respect, it must therefore be emphasized that individual biologic requirements (e.g., age), overall injury severity, but also additional severe injuries (e.g., severe traumatic brain injury), required surgery time, compensated dysfunctions in vital parameters (borderline patients), and the physiologic status of the patient (metabolism, coagulation, temperature, etc.) should also be included in the decision-making.

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3.2 Thorax

Surgical approach route

Key recommendation:

Depending on the injury location, an anterolateral thoracotomy, a posterolateral thoracotomy or a sternotomy can be selected. If the injury location is unclear, the clamshell approach may be selected.	**GoR 0**

Explanation:

The standard approach is the anterolateral or posterolateral thoracotomy on the injury side at the level of the 4th-6th intercostal space. If a bilateral chest injury is suspected, a bilateral anterolateral thoracotomy or a clamshell thoracotomy can be performed. If the injury can be located precisely, the appropriate approaches are used, e.g., posterolateral approach for interventions to the thoracic aorta or a higher intercostal approach for injuries to the subclavian vessels or to the intrathoracic trachea [8, 17, 51, 52].

The anterolateral thoracotomy appears to provide insufficient exposure of the injured organs in up to 20% of cases [25]. If required, this approach can thus be enlarged in the posterior direction or into a flap approach [51].

The median sternotomy is preferred for injuries to the heart, the ascending aorta, and the aortic arch as well as injuries to the great vessels [25, 50, 51].

In trauma surgery practice, the thoracoscopy is unsuitable in life-threatening emergencies. The video-based thoracoscopy can be used for the diagnostic work-up of diaphragm injuries or in the search for sources of bleeding but also for performing smaller interventions such as draining a hemothorax, etc. [17, 33, 51].

Penetrating chest injuries

Key recommendation:

If there are perforating chest injuries, embedded foreign bodies should only be removed during surgery under controlled conditions after opening up the chest.	**GoR B**

Explanation:

If it can be assumed that the chest has been perforated, foreign bodies penetrating the chest must not be removed due to a possible tamponade effect. Removal is always performed during surgery via an exploratory thoracotomy. The airtight closure or bandaging of puncture openings is also contraindicated because it prevents the pleural space from being decompressed. In complicated injuries, the goal should be a two-step closure of the chest wall after thorough lavage and generous wound debridement to avoid septic complications [51].

Indication for thoracotomy

Key recommendations:

A penetrating chest injury, which is the cause of hemodynamic instability in the patient, must undergo an immediate exploratory thoracotomy.	**GoR A**
A thoracotomy can be performed if there is an initial blood loss of > 1,500 ml from the chest drain or if there is persistent blood loss of > 250 ml/h over more than 4 hours.	**GoR 0**

Explanation:

The indication for immediate thoracotomy in penetrating injuries arises if the following are already present on admission to the emergency room: severe hemodynamic shock states, signs of pericardial tamponade, diffuse bleeding, absence of peripheral pulses, and cardiac arrest [2–4, 17, 25, 32, 51]. Hemodynamically stable patients can be monitored after insertion of a chest drain or can undergo further diagnostic tests such as helical CT.

Studies during the Vietnam War showed a reduction in mortality and the complication rate in predominantly penetrating injuries with a thoracotomy performed after a blood loss of initially > 1,500 ml or exceeding 500 ml in the first hour after drain insertion [32].

In a multicenter study, there was evidence also of the dependence of mortality on thoracic blood loss irrespective of the mechanism of injury (blunt versus penetrating). Mortality rose here by a factor of 3.2 in the group with a blood loss of more than 1,500 ml in the first 24 hours compared with a blood loss from the chest drain of 500 ml/24 h. The mean time for performing the thoracotomy was 2.4 ± 5.4 hours after admission [24]. Other authors agree with the strategy of performing a thoracotomy for blunt or penetrating injuries after an initial blood loss of 1,500 ml or with continuous bleeding of 250 ml/h over 4 hours [12, 24, 29, 32, 50]. If the drainage volume per time unit is used as an indication criterion for thoracotomy, this requires the drains to be correctly positioned and have reliable patency [51].

In the case of a combination thoracic injury with high blood loss and marked metabolic derangement, a temporary chest closure consistent with damage control surgery can be carried out after acute management with controlling of bleeding. After stabilization of the patient in intensive care, the definitive surgical management and chest closure is carried out later [12, 19, 22, 50].

Lung injuries

Key recommendation:

If an indication for surgery exists for lung injuries (persistent bleeding and/or air leak), the intervention should be parenchymal-sparing.	**GoR B**

Explanation:

Lung parenchymal injuries in a penetrating or blunt chest trauma with persistent bleeding and/or air leak require surgical management [16, 17, 51]. One of the main indicators for an exploratory thoracotomy is marked or persistent bleeding (1,500 ml initially or 500 ml/h) [24]. If necessary, appropriate surgical management of possible lung parenchymal injuries is then indicated for hemostasis. Compared to parenchymal-sparing surgical procedures such as oversewing, tractotomy, atypical resection or segment resection, the lobectomy and pneumonectomy carry a higher complication and mortality rate [12, 19, 22, 30, 50]. At the same time, blunt injuries appear to be associated with a worse prognosis with regard to number of days in situ, complications, and mortality [30].

Great vessel injuries

Key recommendations:

In the case of aortic ruptures, preference should be given over open revascularization procedures to implantation of an endostent graft if technically and anatomically possible.	**GoR B**
A systolic blood pressure of 90-120 mmHg should be set until reconstruction of the aorta or if under conservative management.	**GoR B**

Explanation:

The treatment for an aortic rupture traditionally consists of aortic reconstruction by direct suture with clamping of the aorta and using different bypass procedures to perfuse the lower body half and spinal cord during the clamping phase (left heart bypass, Gott shunt, heart-lung machine) [1, 11, 18, 28, 31, 35, 42, 50].

Current studies identify acute stenting for aortic ruptures as a minimally invasive, time-saving treatment option with minimal access damage [1, 36]. Complications such as cerebral or spinal hypoperfusion with corresponding late complications such as paraplegia occur less often. In the long term, anticoagulation as required in most bypass procedures can be dispensed with [6, 9, 14, 37, 47]. Also in a current meta-analysis which compares open aortic reconstruction with endovascular stenting, evidence was found of a significantly lower mortality rate and a significantly lower rate of post-operative neurologic deficits (paraplegia, strokes) with the same technical success rate for endovascular stenting [37]. However, there are to date no data on long-term survival after endovascular aortic reconstruction [21, 41]. Overall, according to the literature currently available, the implantation of an endostent graft appears to be preferable to the conventional procedure [15].

Complications such as paraplegia and acute kidney failure due to the open procedure are the result of operative-induced ischemia. The complication rate correlates with the aortic clamping time [23, 45].

If perfusion is maintained during bypass procedure surgery instead of clamping the aorta, the complication rate is reduced (paraplegia, kidney failure) [10, 11, 16, 35].

The hemodynamic status of the patient at the time of admission determines the timing for management of the aortic rupture. Patients in a hemodynamically unstable condition or in extremis must undergo surgery immediately [10]. In patients with concomitant traumatic brain injury, severe abdominal or skeletal injuries which require immediate surgery and in elderly patients with extensive cardiac and pulmonary comorbidities, the aortic injury can be managed with delayed urgency after treatment of additional life-threatening injuries and/or after stabilization [28, 50, 51]. In a series of 395 patients, Camp et al. showed that in hemodynamically stable patients the mortality was not significantly increased in non-urgent (> 4 hours) or delayed surgery (> 24 hours) compared to emergency surgery (< 4 hours) [10]. Other authors agree with this opinion [10, 15, 16, 45]. Delays of up to 2 months are tolerated in some cases [39].

If surgery is not carried out as an emergency, strict pharmacologic control of blood pressure (systolic blood pressure between 90 and 120 mmHg and heart rate < 100/min) is required with beta blockers and vasodilators [15, 16].

Cardiac injuries

Life-threatening cardiac injuries occur primarily due to penetrating trauma. Injuries to several chambers are particularly associated with high mortality [2, 3, 17, 51]. An intrathoracic injury to the inferior vena cava often causes a life-threatening pericardial tamponade. The surgical management of the vein is carried out after pericardial decompression via the right atrium by means of a direct suture or with a patch closure using extracorporeal circulation [49–52].

The approach is via a median sternotomy or, in the case of absolute urgency, by a left anterolateral thoracotomy. After decompression of the cardiac tamponade, which is present in more than 50% of cases, via a longitudinal incision of the pericardium, bleeding must be quickly controlled by staple or suture. After removal of the clamp from the bleeding atrial wall, this can be closed with a direct suture [34]. Ventricle lesions are closed by means of a pericardial patch or Teflon felt augmentation. Finally, the pericardial incision is adjusted by loosening to avoid a retamponade [2, 3, 17, 51]. Injuries that do not require an immediate thoracotomy are isolated septal defects, valve injuries or ventricle aneurysms [34].

Proximal lesions of the coronary vessels must be reconstructed or in an emergency managed with a coronary artery bypass using a heart-lung machine. Distal lesions of the coronaries can be ligated [17, 51].

The patient’s cardiac rhythm and cardiorespiratory function on arrival in the emergency room are important factors in prognosis [2, 3]. At all times, attempts must therefore be made to maintain cardiac pump function and treat cardiac arrhythmias as this lowers mortality [2, 3].

Injuries of the tracheobronchial system

Key recommendations:

If there is clinical suspicion of an injury to the tracheobronchial system, a bronchoscopy should be carried out to confirm the diagnosis.	**GoR B**
Traumatic injuries to the tracheobronchial system should be surgically managed early following the diagnosis.	**GoR B**
In the case of localized injuries to the tracheobronchial system, conservative treatment can be attempted.	**GoR 0**

Explanation:

Injuries to the tracheobronchial system are rare and there is often a delay in making the diagnosis [5, 7, 26, 40, 44]. Occasionally, tracheobronchial injuries also occur as a complication in orotracheal intubation [43]. Penetrating injuries predominantly affect the cervical trachea whereas blunt injuries usually give rise to intrathoracic injuries. The right main bronchus in the immediate vicinity of the carina is affected more often [7, 26, 40]. If there are persistent pneumothoraces despite a functioning chest drain and despite the presence of soft tissue emphysema or atelectases, a tracheobronchoscopy should be performed to confirm the suspected diagnosis of a tracheobronchial injury [5, 7, 26, 27, 40]. Fiberoptic intubation with placement of the cuff distal to the defect can be directly connected to secure the airway. In a retrospective study, Kummer et al. established that a large number of patients require a definitive airway (tracheostomy) [27]. The emphasis here was on penetrating injuries. Surgical management of the tracheobronchial system should be carried out as soon as possible after making the diagnosis as delayed management is associated with an increased complication rate [7, 13, 26, 34, 40]. Surgical management of airway injuries is associated with a markedly lower mortality compared to conservative treatment [7, 26, 40]. Conservative treatment should be considered after bronchoscopic inspection only in patients with small bronchial tissue defects (defect smaller than 1/3 of the bronchial circumference) and well adapted bronchial margins [7, 13, 26, 34, 40]. In a retrospective study, Schneider and colleagues found no difference between the conservative and the surgical method in iatrogenic tracheal injuries without ventilation disorders and superficial or covered tracheal tears [43].

Cervical injuries are managed by a collar incision. A right-sided posterolateral thoracotomy should be performed in the 4th-5th ICS as an approach to intrathoracic tracheal injuries [5, 7, 26, 34, 40]. In simple transverse tears, tension-free end-to-end anastomosis of the bronchus is performed after its immobilization and, if necessary, resection of the cartilaginous bridge. If a direct suture is not possible, longitudinal tears with a defective formation of the membrane wall are closed with a patch to avoid bronchial stenoses developing [7, 26, 34, 40]. Managing the tracheobronchial injuries with a stent appears to have no role to play according to current literature.

Injuries to the bony thorax (excluding spine)

Key recommendation:

The majority of injuries to the bony thorax including flail chest should be conservatively treated.	**GoR B**

Explanation:

The vast majority of multiple rib fractures with an unstable thorax can be non-surgically treated by internal pneumatic splinting, CPAP (continuous positive airway pressure) ventilation, sensible bronchial toilet, and adequate pain therapy [38, 48]. Surgical treatment should be considered in patients with persistent respiratory insufficiency due to chest instability despite existing ventilation, in patients with extensive chest wall defects, and flail chest with threatening intrathoracic injury [38, 46, 48]. Voggenreiter et al. showed that primary surgical stabilization of multiple rib fractures with flail chest and respiratory insufficiency without pulmonary contusion has better results with a shorter ventilation period or a lower complication rate than conservative treatment. However, patients with a marked pulmonary contusion do not gain from surgical stabilization of the bony thorax [50].

In a prospective randomized study of surgically managed multiple rib fractures in patients with flail chest and respiratory insufficiency, Tanaka et al. found evidence of a shorter ventilation time, a shorter stay in the intensive care unit, and a lower complication rate in the group surgically stabilized with Judet clamps compared to the control group who received internal pneumatic splints [46].

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3.3 Diaphragm

Key recommendation:

When detected during the primary diagnostic study and/or intraoperative diagnosis, a traumatic diaphragmatic rupture should be quickly closed.	**GoR B**

Explanation:

A diaphragmatic rupture in up to 1.6% of cases due to blunt injuries is mainly caused by a lateral collision in road traffic accidents and predominantly affects the left diaphragm side [1–7].

There are no valid data available on the ideal time for surgery in the multiply injured patient. Only a pragmatic recommendation can be made that the rupture should be quickly closed if there is intrathoracic displacement of abdominal organs. This also applies to the intraoperative identification of a diaphragmatic rupture in the case of a cavity opening due to other injuries.

There is currently no clear evidence that a deferred closure increases the case fatality rate. With an all-cause mortality of 17%, the random effects meta-regression of 22 studies (n = 980) from 1976-1992 [7] showed no correlation between the frequency of deferred management and the case fatality rate (beta -0.013, 95% CI: - 0.67– - 0.240). In a current analysis of 4,153 patients on the National Trauma Database, pleural empyema was also not associated with the timing of the surgical intervention [8].

In the acute situation in patients with unstable circulation and if there are no thoracic lesions, surgical access is ideally via a transabdominal approach [9]. A thoraco-abdominal approach is used in confirmed combination injuries or if the suture is technically difficult to carry out. If management is delayed for 7-10 days, a thoracotomy is recommended due to intrathoracic adhesions [7, 10].

The diaphragm defect can usually be closed using a direct suture; defect grafting is only rarely necessary [1, 6, 10]. On the basis of the available data, no conclusions can be drawn on the success rates of specific suturing techniques (continuous versus single knot) or suturing materials (monofilament versus braided, absorbable versus non-absorbable). There are numerous reports in the literature on endoscopic techniques for closing post-traumatic diaphragmatic hernias [11, 12]; at present, however, no importance can be ascribed to these in the emergency surgery phase.

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3.4 Abdomen

Surgical approach path

Key recommendation:

In the trauma situation, preference should be given to the midline laparotomy over other approach paths.	**GoR B**

Explanation:

The midline laparotomy represents an anatomically justified universal surgical approach path to the traumatized abdomen. It can be performed quickly causing little bleeding and permits a good overview of all 4 quadrants [9, 10].

There is only one quasi-randomized study, which is over 25 years old (treatment group allocation according to even or odd admission number), in which the midline laparotomy was compared with a transverse upper abdominal laparotomy in patients with abdominal trauma [11]. The wound infection rates in patients with negative and positive laparotomy were 2% and 11% irrespective of the selected approach path. The mean period under anesthesia was 25 minutes shorter after positive midline laparotomy than after the transverse upper abdominal laparotomy (Table 14). This difference was statistically significant according to the published data ($p = 0.02$). However, there were no standard deviations reported nor was a further breakdown of surgery times undertaken. The study cannot serve as proof in favor of a specific type of incision but supports the possibility of surgical preferences (“Adequacy of organ exposure is still a matter of personal preference”).

Indirect evidence comes from randomized studies of elective abdominal interventions. A Cochrane Review suggests an advantage of the transverse incision with regard to the postoperative requirement for morphine equivalents, lung function, and the rate of incisional hernias [12]. A difference in the rate of pulmonary complications or in wound infections could not be detected. The multicenter randomized POVATI (Postsurgical Pain Outcome of Vertical and Transverse Abdominal Incision) Study published in 2009 showed an equivalence in the primary endpoint of postoperative analgesia requirement and lack of differences in secondary endpoints such as pulmonary complications, mortality, and incisional hernias after 1 year [13]. The authors also stress here the possibility of a situation-dependent approach to the abdomen (“The decision about the incision should be driven by surgeon preference with respect to the patient’s disease and anatomy”).

Table 14: Midline laparotomy versus transverse upper abdominal laparotomy in abdominal trauma

Study	LoE	Patients	Results	
Stone et al. 1983 [11]	2b	339 patients with blunt or penetrating abdominal trauma	Midline laparotomy (n = 177)	Transverse upper abdominal laparotomy (n = 162)
			Mean period under anesthesia: positive laparotomy (n = 66) 215 min, negative laparotomy (n = 111) 126 min	Mean period under anesthesia: positive laparotomy (n = 61) 240 min, negative laparotomy (n = 101) 132 min

Indications for a diagnostic laparoscopy are dealt with in the subsection "Emergency room: diagnostic study of the abdomen". The recommendations updated in 2007 of the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) also apply [14]. Reference is made to the evidence-based guideline of the European Association for Endoscopic Surgery (EAES) for therapeutic laparoscopy in abdominal trauma [15]. Numerous authors report on laparoscopic and hand-assisted laparoscopic abdominal surgery interventions performed on blunt and penetrating abdominal trauma (e.g., hemostasis, oversewing, and resection of hollow organs) [16–20]. There are no clinical studies in which laparoscopy was compared with a laparotomy or used in the particular case of polytrauma. The consensus of the EAES should be followed, namely that the currently available data prohibits a clear recommendation in favor of therapeutic laparoscopic interventions for abdominal trauma ("Nevertheless, the scarceness of clinical data prohibits a clear recommendation in favor of therapeutic laparoscopy for trauma").

Damage control: General principles

Key recommendation:

In patients with unstable circulation and complex intraabdominal damage, priority should be given to the damage control principle (hemostasis, packing/wrapping, temporary abdominal wall closure) over attempted definitive treatment.	**GoR B**

Explanation:

The term "damage control" (DC) was coined by the US navy and originally referred to the capacity of a ship to absorb damage yet maintain mission integrity [21]. The basis and indication for DC or an abbreviated/truncated laparotomy is the AHC triad consisting of acidosis (pH < 7.2), hypothermia (< 34 °C), and coagulopathy (International Normalized Ratio [INR] > 1.6 or transfusion requirement during surgery > 4 l) [22]. There is currently no standardized or uniform DC algorithm. Major accepted elements are 1) rapid hemostasis in injuries to the parenchymatous upper abdominal organs and avoiding peritoneal contamination through the simple repair of hollow organ injuries, if necessary also discontinuance of resection, 2) temporary closure of the abdomen, 3) intensive medical stabilization of body temperature, hemodynamics, and coagulation, 4) planned re-surgery to repair and reconstruct organ injuries, and 5) definitive abdominal wall closure [22–25].

An important element in bleeding from the liver is the perihepatic packing. The liver should be completely mobilized from its suspensory ligaments and the packing inserted around the posterior paracaval surface and subhepatic between liver and hepatic flexure in order to achieve compression against the diaphragm without hindering the venous outflow from the hepatic veins [26–30].

Despite the existence of an AHC triad, a survival advantage for patients after DC compared to one-step, definitive surgical treatment (definitive laparotomy, DL) was confirmed in 3 small retrospective cohort studies [31–33]. On the other hand, another retrospective cohort study showed a survival advantage in the DL group [34] (Table 15). The pooled relative risk (random effects) is 0.79 (95% CI: 0.48–1.33) in favor of DC. If only the maximum injured in the study by Rotondo are considered [32], the pooled relative risk is 0.60 (95% CI: 0.30–1.19). There was no multivariate adjustment in any of these studies for differences in injury severity or other confounders; the results are thus subject to bias.

In a current Cochrane Review, the authors could not identify any randomized studies despite a comprehensive search strategy in 9 databases (including congress abstracts and “gray” literature) and a hand search [35].

Individual reports suggest survival rates of 90% after DC even in a prognostically unfavorable baseline situation [36]. In the majority of larger case series, on the other hand, the case fatality rate of the injured who required a DC laparotomy is 25-50% [37–39].

Table 15: Damage Control versus definitive management

Study	LoE	Patients	Result	
Stone et al. 1983 [31]	2b	31 patients with penetrating or blunt abdominal injuries and intra-operative development of a coagulopathy	Definitive management (n = 14) Overall survival rate: 1/14 (7%)	Damage control (n = 17)[a] Overall survival rate: 11/17 (65%)
			RR 0.11 (95% confidence interval: 0.02–0.75)	
Rotondo et al. 1993 [32]	2b	46 patients with penetrating abdominal injuries	Definitive management (n = 22) Overall survival rate: 12/22 (55%)	Damage Control (n = 24)[b] Overall survival rate: 14/24 (58%)
			RR 0.94 (95% confidence interval: 0.56–1.56)	
			Survival rate for max. injury: 1/9 (11%)[c]	Survival rate for max. injury: 10/13 (77%)[c]
			RR 0.14 (95% confidence interval: 0.02–0.94)	
MacKenzie et al. 2007 [33]	2b	37 patients with penetrating or blunt hepatic injuries, grade 4/5	Definitive management (n = 30) Overall survival rate: 19/30 (63%)	Damage control (n = 7)¶ Overall survival rate: 7 /7 (100%)
			RR 0.63 (95% confidence interval: 0.48–0.83)	
Nicholas et al. 2003 [34]	2b	250 patients with penetrating abdominal injuries	Definitive management (n = 205) Overall survival rate: 184/205 (90%)	Damage control (n = 45) Overall survival rate: 33/45 (73%)
			RR 1.22 (95% confidence interval: 1.02–1.47, p = 0.0032)	

a: Immediate arrest, packing, abdominal closure under tension, mean time until second look: 27h

b: four-quadrant packing, hemostasis, ligature or simple (clamp) suture for hollow organ injuries, temporary abdominal wall closure, mean time until second look: 32h

c: Injury to great vessels + ≥ 2 visceral injuries; packing + angioembolization

The Pringle maneuver with clamping of the portal vein and common hepatic artery is possibly one of the oldest DC techniques for the temporary hemostasis of severe hepatic injuries [40]. Although an ischemia time of 45-60 minutes through the hepatic parenchyma is tolerated in patients with no preoperative shock event without serious postoperative function deficit, the full utilization of this ischemia period would seem to increase noticeably the risk of postoperative liver failure in the multiply injured patient [41]. In a Chinese case series, 5 out of 7 patients who had undergone a Pringle maneuver died because of a retrohepatic caval tear [42].

Damage control: Temporary abdominal wall closure

Key recommendations:

After DC laparotomy, the abdomen should be closed only temporarily and not using a fascial suture.	**GoR B**
The temporary abdominal wall closure in DC laparotomy should be performed using synthetic material which enables a stepwise convergence of the fascial edges.	**GoR B**

Explanation:

Primary fascial closure after DC laparotomy increases the risk of abdominal compartment syndrome (ACS). After primary fascial suture, a 6-fold increased risk for ACS was reported compared to only skin closure and insertion of a 3-liter irrigation bag for cystoscopies (Bogotá bag) [43]. Against the reduced risk for ACS by using a temporary closure, there is fluid loss and disturbed temperature regulation due to the large exchange surface and the difficulty of reconstructing the abdominal wall. Bogotá bag equivalents or commercial products with zip or hook-and-loop closure (Wittmann patch or Artificial Burr) have established themselves as temporary materials [44]. In addition, there is widespread use of vacuum sealing. The results of case series were summarized in a current systematic review paper [45]. According to this, the Wittmann patch is associated with the highest success rate for an abdominal wall closure. A retrospective cohort study comes to similar results [46]. In a small randomized study, no difference between a temporary closure using a vacuum dressing and polyglactin-910 mesh could be detected [47].

Table 16: Methods for abdominal wall closure

Study	LoE	Patients	Method	Result	
van Hensbroek et al. 2009 [45]	4	Systematic review of case series	Wittmann patch	Survival rate: 146/180 (81%)	Abdominal wall closure: 127/146 (88%)
			KCI-VACTM	Survival rate: 19/251 (78%)	Abdominal wall closure 118/195 (60%)
			Vacuum dressing[a]	Survival rate: 846/1,186 (71%)	Abdominal wall closure 444/846 (53%)
			Skin closure	Survival rate: 62/101 (61%)	Abdominal wall closure 27/62 (43%)
			Zip closure	Survival rate: 89/135 (66%)	Abdominal wall closure 32/89 (36%)
			Silo (Bogotá bag)	Survival rate: 61/109 (56%)	Abdominal wall closure 21/61 (34%)
			Net or sheet	Survival rate: 844/1,176 (72%)	Abdominal wall closure 214/844 (25%)
Weinberg et al. 2008 [46]	2b	59 patients with blunt or penetrating abdominal trauma	"Pre-Wittmann patch" (n = 23)		Fascial closure: 7/23 (30%)
			"Wittmann patch" (n = 36)		Fascial closure: 28/36 (78%)
Bee et al. 2008 [47]	1b	59 patients with blunt or penetrating abdominal trauma	Polyglactin-910 mesh (n = 20)	Case fatality rate: 5/20 (25%) Abscess: 9/15 (60%)	Fascial closure: 4/15 (27%)
			Vacuum dressing (n = 26)[a] KCI-VACTM (n = 5)	Case fatality rate: 8/31 (26%) Abscess: 12/23 (52%)	Fascial closure: 7/23 (30%)

a: using foil, abdominal sheets and Redon drains

Damage control: Second look after packing

Key recommendation:

After packing intraabdominal bleeding, a second look should be undertaken and the tamponade replaced between 24 and 48 hours after the first intervention.	**GoR B**

Explanation:

After packing and intensive medical stabilization as part of the damage control sequence, a re-laparotomy is necessary to replace the abdominal sheets and also for definitive injury management, if applicable. A balance must be maintained here between the risk of fresh bleeding and the possible complications (infections, fistula, restricted pulmonary function, abdominal compartment syndrome) from the foreign material.

The available data from retrospective cohort studies show that unpacking after 24-36 hours is associated with an increased risk of bleeding (pooled relative risk, fixed effects: 3.51, 95% confidence interval: 1.39–8.90) [48, 49]. There is no clear evidence that leaving the abdominal sheets for a period of 48 hours increases the risk of septic complications (pooled relative risk, fixed effects: 1.01; 95% CI: 0.59–1.70) [48–51]. In the study by Abikhaled, however, leaving the tamponades > 72 hours was associated with an almost 7-fold increase in the relative risk for intraabdominal abscesses (6.77; 95% CI: 0.84–54.25) [50]. From a pragmatic viewpoint, therefore, the re-laparotomy should be planned for not sooner than 24 hours and not later than 48 hours after the first intervention.

Table 17: Second look after packing

Study	LoE	Patients	Result		
Nicol et al. 2007 [48]	2b	93 patients with penetrating or blunt hepatic trauma	Second look 24h: (n = 25): Subsequent bleeding: 8/25 (32%) Packing in situ 24 h (n = 8): Complications: 5/8 (63%)	Second look 48h: (n = 44): Subsequent bleeding 5/44 (11%) Packing in situ 48 h (n = 44): Complications: 6/44 (14%)	Second look 72 h (n = 3): Subsequent bleeding: 0/3 Packing in situ 72 h (n = 20): Complications: 3/20 (15%)
Cué et al. 1990 [51]	2b	21 patients with penetrating or blunt hepatic trauma	Packing in situ 24 h (n = 7): Abscess: 2/7 (29%)	Packing in situ 48 h (n = 6): Abscess: 2/6 (33%)	Packing in situ 72 h (n = 8): Abscess: 3/8 (38%)
Caruso et al. 1999 [49]	2b	93 patients with penetrating or blunt hepatic trauma	Second look < 36 h (n = 39): Subsequent bleeding: 8/39 (21%) Complications: 13/39 (33%) Case fatality rate: 7/39 (18%)	Second look 36-72 h (n = 24): Subsequent bleeding: 1/24 (4%) Complications: 7/29 (29%) Case fatality rate: 7/24 (29%)	
Sharp et al. 1992 [52]	2b	22 patients with penetrating or blunt hepatic trauma	6 patients with septic complications: Packing in situ 2.2 ± 0.4 (2–3) days	6 patients without septic complications: Packing in situ 2.0 ± 1.0 (1–7) days	
Abikhaled et al. 1997 [50]	2b	35 patients with penetrating or blunt abdominal trauma	Packing in ≤ 72 h (n = 22): Abscess 1/22 (5%) Sepsis 11/22 (50%) Case fatality rate 1/22 (5%)	Packing in situ > 72 h (n = 13): Abscess 4/13 (31%) Sepsis 10/13 (77%) Case fatality rate 6/13 (46%)	

Definitive abdominal wall closure

Key recommendation:

Definitive fascial closure should be continuous using slow absorbable or non-absorbable suture material.	**GoR B**

Explanation:

The technique of fascial closure after a laparotomy is well-known to be controversial and is often determined by the surgeon’s preference. The best available evidence on decision-making is obtained from randomized studies of elective abdominal interventions. It appears pragmatic and expedient to transfer any clear trends in favor of a specific method to the trauma scenario.

There are 2 meta-analyses of randomized studies for which the data pool only partially overlaps. Both show a significant reduction in risk for incisional hernias through non-absorbable suture material and continuous sutures [53, 54]. The results of the multicenter INSECT (Interrupted or Continuous Slowly Absorbable Sutures – Evaluation of Abdominal Closure Techniques) trial published in 2009 show a similar though not significantly statistical trend [55].

The updated common Peto odds ratio from all available randomized studies on the comparison of continuous slowly absorbable and rapidly absorbable single knot sutures is 0.79 for incisional hernias (95% CI: 0.61–1.01) and for wound infections 1.49 (95% CI: 1.15–1.94).

Angioembolization

Key recommendations:

If, in the case of a patient with hepatic injury who can be hemodynamically stabilized, there is evidence of arterial bleeding in a contrast agent CT, selective angioembolization or a laparotomy should be performed.	**GoR B**
In the case of splenic injuries grade 1-3 which require intervention, selective angioembolization can be performed instead of surgical hemostasis.	**GoR 0**
In the case of retroperitoneal bleeding which requires intervention, selective angioembolization can be performed instead of or in addition to surgical hemostasis.	**GoR 0**

Explanation:

Interventional radiology has an established value in polytrauma management and is used both in primary non-surgical treatment of organ injuries and as a neo-adjuvant and adjuvant intervention [56, 57]. If there is evidence of active bleeding from the contrast agent enhanced CT scan which cannot or must not be addressed operatively and if there is a good response to fluid and blood replacement in the emergency room, angioembolization can contribute towards sustained stabilization of the circulation [58, 59].

There are no randomized studies. The currently best available evidence is on blunt and penetrating hepatic injuries and suggests a reduction in case fatality rate through additional angioembolization during DC management compared to operative treatment only (common RR [fixed effects] 0.47, 95% CI: 0.28–0.78) [60–65]. The bias due to lack of multivariate adjustment must be taken into consideration. Currently, there is no answer to the question as to whether angioembolization in hepatic injuries should be performed before or after the DC laparotomy. Two studies support early neoadjuvant angioembolization based on the lower complication rates [63, 65]. In 2 other studies, on the other hand, mortality was lowered if angioembolization was performed after a DC laparotomy [64, 66].

Decision-making must be on an individual case basis on the availability and presence of an experienced interventional radiologist, the success of circulation-stabilizing measures in the emergency room, the intraoperative finding, and the postoperative hemodynamics.

The same applies to angioembolization in the case of bleeding from the spleen, where more up-to-date data now seems to call for caution [67–70]. Compared to nonoperative treatment, angioembolization did not lead to a reduction in either the treatment failure rate (common RR [random effects] 1.13; 95% CI: 0.86-1.48) or mortality (common RR [fixed effects] 1.19; 95% CI: 0.66–1.15).

Table 18: Angioembolization

Study	LoE	Patients	Result			
Asensio et al. 2007 [61]	2b	75 patients with penetrating or blunt hepatic trauma grade 4/5	Angioembolization directly after DC laparotomy (n = 17) Case fatality rate 2/17 (12%)	DC laparotomy without angioembolization (n = 58) Case fatality rate 21/58 (36%)		
Johnson et al. 2002 [62]	2b	19 patients with penetrating or blunt hepatic trauma grade 1–5	Angioembolization directly after DC laparotomy (n = 8) Case fatality rate 1/8 (13%)	DC laparotomy without angioembolization (n = 11) Case fatality rate 4/11 (36%)		
Asensio et al. 2003 [60]	2b	103 patients with penetrating or blunt hepatic trauma grade 4/5	Angioembolization directly after DC laparotomy (n = 23) Case fatality rate 7/23 (30%) (grade 4: 4/14 [28%], grade 5: 3/9 [33%]) RR 0.51 (95% confidence interval 0.27-0.98) OR (multivariate adjusted for RTS, direct surgical access to hepatic veins and packing): 0.20 (95% confidence interval 0.05-0.72)	DC laparotomy without angioembolization (n = 80) Case fatality rate 52/80 (65%) (grade 4: 15/37 [39%], grade 5: 37/43 [86%])		
Wahl et al. 2002 [65]	2b	126 patients with blunt hepatic trauma grade 1–6	Early AE before/instead of DC laparotomy (n = 6) Case fatality rate 0/6 (0%), complications 3/6 (50%)	Late AE after DC laparotomy (n = 6) Case fatality rate 3/6 (50%), complications 6/6 (100%)	DC laparotomy (n = 20) Case fatality rate 7/20 (35%), complications 9/20 (45%)	Nonoperative treatment (n = 94) Case fatality rate 2/94 (2%), complications 2/94 (2%)

(continued)

Table 18: Angioembolization - (continued)

Study	LoE	Patients	Result	
Mohr et al. 2003 [63]	2b	26 patients with penetrating or blunt hepatic trauma grade 3–5	Early AE before/instead of DC laparotomy (n = 11) Case fatality rate 2/11 (18%), complications 5/11 (45%)	Late AE after DC laparotomy (n = 15) Case fatality rate 5/15 (33%), complications 6/15 (40%)
Monnin et al. 2008 [64]	2b	14 patients with blunt hepatic trauma grade 3–5	Early AE before/instead of DC laparotomy (n = 10) Case fatality rate 1/10 (10%)	Late AE after DC laparotomy (n = 4) Case fatality rate 0/4 (0%)

Table 19: Angiography

Study	LoE	Patients	Result			
Velmahos et al. 2000 [66]	2b	137 patients with blunt or penetrating abdominal trauma (36 hepatic injuries)	Emergency room angiography (n = 49) Case fatality rate: 14/49 (29%)	Emergency room ICU angiography (n = 15) Case fatality rate: 3/15 (20%)	Operating room angiography (n = 32) Case fatality rate: 7/32 (22%)	Operating room ICU angiography (n = 21) Case fatality rate: 2/21 (10%)

Table 20: Interventions after blunt splenic injuries

Study	LoE	Patients	Result		
Cooney et al. 2005 [69]	2b	194 patients with blunt splenic injuries grade 1–5	Angioembolization (n = 9) Success rate: 6/9 (67%) Case fatality rate: 0/9 (0%)	Nonoperative treatment (n = 137) Success rate: 126/137 (92%) Case fatality rate: 9/137 (7%)	Splenectomy (n = 48) Success rate: 48/48 (100%) Case fatality rate: 9/48 (19%)
Harbrecht et al. 2007 [67]	2b	349 patients with blunt splenic injuries grade 1–5	Angioembolization (n = 46) Case fatality rate: 2/46 (4%) Success rates: grade 2: 16/17 (94%), grade 3: 76%, grade 4: 88% [a, b]	Nonoperative treatment (n = 303) Case fatality rate: 12/303 (4%) Success rates: grade 2: 225/236 (95%), grade 3: 86%, grade 4: 63% [a]	Splenectomy (n = 221) Case fatality rate 42/221 (19%)
Smith et al. 2006 [68]	2b	221 patients with blunt splenic injuries grade 1–5	Angioembolization (n = 41) Success rate: 30/41 (73%)	Nonoperative treatment (n = 303) Success rate: 114/124 (92%)	Splenectomy (n = 56) Success rate: 56/56 (100%)
Duchesne et al. 2008 [70]	2b	154 patients with blunt splenic injuries grade 1–5	Before carrying out angioembolization (n = 78) Case fatality rate: 14/78 (18%) Sepsis: 4/78 (5%) ARDS: 4/78 (5%)	After carrying out angioembolization (n = 76) Case fatality rate: 11/76 (14%) Sepsis: 9/76 (9%) ARDS: 17/76 (22%)	
Wei et al. 2008 [71]	2b	87 patients with blunt splenic injuries grade 1–5	Angioembolization (n = 55) Case fatality rate: 4/55 (7%) abdominal complications: 2/55 (5%)	Splenectomy (n = 37) Case fatality rate: 2/37 (5%) abdominal complications: 13/37 (35%)	
a: No. of patients unclear			b: No effect of angioembolization on success rates after multivariate adjustment for age, AIS and abdominal concomitant injuries		

Spleen-salvaging operations

Key recommendations:

The goal can be spleen-salvaging surgery in the case of splenic injuries of severity grade 1-3 according to AAST/Moore that require surgery.	**GoR 0**
Preference should be given to splenectomy over a salvage attempt in patients with splenic injuries of severity grade 4-5 according to AAST/Moore that require surgery.	**GoR B**

Explanation:

The risk of an “overwhelming postsplenectomy syndrome (OPSI)” after a splenectomy is estimated at 2.5% [72]. In patients with stable circulation, splenic injuries only rarely represent an indication for laparotomy. Thus, only when surgery becomes necessary (e.g., in the case of unstable circulation or high transfusion requirement) does the question arise for the surgeon as to the possibility and the certainty of salvaging an organ. Complete mobilization of the spleen after separating the lienorenal and phrenicolienal ligaments is definitive for operative success [73].

Unsurprisingly, due to different patient populations and injury severity scores, it is difficult to conduct a direct comparison between the results after splenectomy and salvage procedures. With stable splenorrhaphy frequency between 1988 and 1993, an analysis of the North Carolina Trauma Registry showed a trend in favor of primary nonoperative management and a rejection of the splenectomy. The comparison between the methods yielded, not surprisingly, a lower mortality after splenorrhaphy compared to splenectomy (RR 0.36, 95% CI: 0.18-0.73) at higher mean ISS in the splenectomy group (25 ± 12 versus 19 ± 11, p < 0001) [74]. In this cohort there were also 10 patients with a mean ISS of 33 ± 15 where the salvage attempt failed. After the splenectomy, 2 patients died. In another study with comparable injury severity, considerably fewer infections occurred after splenorrhaphy (RR 0.30, 95% CI: 0.13–0.70) [75]. A non-significant trend to overall higher complication rates after splenorrhaphy (RR 1.81; 95% CI: 0.36-9.02) despite lower injury severity was observed in another study [76].

In a series of 326 patients from the early 1980s, the rates of spleen-salvaging operations for Moore I/II, III and IV/V injuries were 88.5%, 61.5%, and 7.7% [77]. A similar trend in relation to the ISS was also demonstrated in a more recent study with inclusion of 2,258 adult patients [78]. The failure quota (subsequent bleeding, secondary splenectomy) after a spleen salvage attempt was 7 out of 240 (2.9%; 95% CI: 1.2–5.9%). A splenectomy was necessary in 66.4% of all patients with an ISS ≥ 15. In a multivariate analysis of 546 patients from a 17-year period, Carlin derived injuries of grade 4 and 5 as independent predictive variables for a splenectomy [79]. However, whether this depicts the actual necessity of removing a spleen or merely the surgeon’s strong feelings cannot be conclusively evaluated. In the special case of 25 multiply injured patients with a mean ISS of 32.0 (95% CI: 28.2-35.8), Aidonopoulos and colleagues observed subsequent bleeding requiring a splenectomy in 2 patients with injury grade 3 after suturing with a ‘figure of eight’ (0-0 chromic cat gut) [80].

Table 21: Interventions after blunt or penetrating splenic injuries

Study	**LoE**	**Patients**	**Result**		
Clancy et al. 1997 [81]	2b	1,255 patients with blunt or penetrating splenic injuries grade 1–5	Splenorrhaphy (n = 150) Shock: 26/150 (17%) mean ISS: 19 ± 11 Case fatality rate: 8/150 (5%)	Splenectomy after splenorrhaphy (n = 10) Shock: 2/10 (20%) mean ISS: 33 ± 15 Case fatality rate: 2/10 (20%)	Splenectomy (n = 596) Shock: 149/596 (25%) mean ISS: 25 ± 12 Case fatality rate: 88/596 (15%)
Gauer et al. 2008 [82]	2b	91 patients with blunt splenic injuries requiring surgery	Splenorrhaphy (n = 34) Mean ISS: 31 Infections (total): 5/34 (15%) Pneumonias: 3/34 (9%)	Splenectomy (n = 57) Mean ISS: 33 Infections (total): 28/57 (49%) Pneumonias: 19/57 (33%)	
Kaseje et al. 2008 [83]	2b	91 patients with blunt and penetrating splenic injuries requiring surgery	Splenorrhaphy (n = 16) Mean ISS: 21 Complications: 2/16 (13%) [a]	Splenectomy (n = 58) Mean ISS: 28 Complications: 4/58 (7%) [b]	
a: Subsequent bleeding: b: Pancreas leaks and fistulas					

Hollow organ injuries

Key recommendation:

In the case of penetrating colon injuries, if technically possible, preference must be given over a two-step procedure with temporary stoma to oversewing only or to primary anastomosis in order to reduce the risk of intraabdominal infections.	**GoR A**

Explanation:

Due to the contamination of the sterile abdominal cavity with mixed anaerobic flora, penetrating colon injuries represent a potentially life-threatening clinical picture. Thus, patients with abdominal gunshot wounds who must undergo immediate surgical treatment have a 100-fold higher relative risk of dying compared to patients with injuries that can be treated non-surgically or during secondary surgery [84].

Since 1979, 6 randomized trials (RCTs) have been published in which the results after primary operative management to maintain continuity were compared with those after temporary insertion of an ileostomy [85–90]. These studies were summarized in a Cochrane Review updated in 2009 [91]. The observed trends were also reproduced in the multicenter study of the American Association for the Surgery of Trauma (AAST) [92].

Based on the best available evidence, there is a non-significant trend in mortality in favor of primary anastomosis (RR 0.67; 95% CI: 0.31-1.45) with a marked reduction in complication rates (RR 0.73; 95% CI: 0.52-1.02). The risk of intraabdominal infections could possibly be reduced by 23% through primary anastomosis (RR 0.77; 95% CI: 0.55-1.06) even though clear scientific proof from an appropriately designed randomized study is unavailable. Current data from the US Iraq operations support the trends in favor of primary anastomosis [93]. It is unclear whether the available data can be transferred to blunt injuries. In this situation, however, biologic and clinical considerations argue more in favor of maintaining continuity.

Stapling instruments represent a major valuable addition to the equipment for elective gastrointestinal interventions. Deep colorectal anastomoses were first made possible through the availability of circular staplers; laparoscopic intestinal surgery also gained from the option of stapled anastomoses.

In a meta-analysis of 9 randomized studies (1,233 patients), however, there was no evidence of advantage from staplers compared to a hand suture in the endpoints mortality, anastomosis failure, wound infection, re-operation, and length of stay in hospital [94]. On the other hand, there was a significantly increased risk of strictures after stapled anastomosis (Peto OR 3.59; 95% CI: 2.02–6.35). The multicenter studies of the Western Trauma Association and AAST have produced evidence of a possible disadvantage from stapled colon anastomoses in the trauma situation [95, 96]. The weighted relative risk for all complications after hand suture compared to stapled anastomosis from both studies is 0.72 (95% CI: 0.45-1.15). For anastomosis failures and intraabdominal abscesses, the common RR can be estimated at 0.90 (95% CI: 0.36-2.28) and 0.74 (95% CI: 0.42-1.28).

Two multicenter studies yielded similar, again non-significant trends for small intestine anastomoses [95, 97]. The hand suture is possibly associated with a reduction in all complications (RR 0.75; 95% CI: 0.31-1.82). Anastomosis failures and intraabdominal abscesses were also observed less frequently after hand suturing (RR 0.43; 95% CI: 0.08–2.42 and RR 0.54; 95% CI: 0.18–1.64).

The results of a randomized trial conducted under elective conditions suggest that a single-layer, continuous hand suture can be carried out without risk. In this study [98], no difference could be detected in the failure rates between a single-layer (2/65) and a two-layer/Lembert suture (1/67). The observed frequency of abscesses was also identical between the two treatment arms (2/65 and 2/67). Nineteen and 12 trauma patients were also included in the study.

Table 22: Primary anastomosis versus ileostomy after penetrating colon injury

Study	LoE	Patients	Result	
Nelson et al. 2009 [91]	1a	Meta-analysis of 6 RCTs (n = 707)	Primary anastomosis (n = 361) Case fatality rate: 7/361 (2%) All complications: 135/361 (37%) Infections: 120/361 (33%)	Ileostomy (n = 344) Case fatality rate: 6/344 (2%) All complications: 173/346 (50%) Infections: 144/346 (42%)
Demetriades et al. 2001 [92]	2b	297 patients with penetrating colon injuries	Primary anastomosis (n = 197) Case fatality rate: 8/197 (4%) All complications: 44/197 (22%) Infections: 33/197 (17%)	Ileostomy (n = 100) Case fatality rate: 10/100 (10%) All complications: 27/100 (27%) Infections: 21/100 (21%)
Vertrees et al. 2009 [93]	2b	65 wounded (Enduring Freedom/ Iraqi Freedom) with penetrating colon injuries	Primary anastomosis (n = 38) Case fatality rate: 1/38 (2%) all colon-associated complications: 11/38 (29%) Infections: 5/38 (13%)	Ileostomy (n = 27) Case fatality rate: 0/27 (0%) all colon-associated complications: 10/27 (37%) Infections: 9/27 (33%)

Table 23: Hand suture versus stapler after penetrating colon injury

Study	LoE	Patients	Result	
Brundage et al. 2001 [95]	2b	29 patients with blunt and penetrating colon injuries	Hand suture (n = 12) All complications: 2/12 (16%) Anastomosis failure: 0/12 (0%) Abscess: 2/12 (17%)	Stapler (n = 17) All complications: 6/17 (35%) Anastomosis failure: 3/17 (18%) Abscess: 5/17 (29%)
Demetriades et al. 2002 [96]	2b	207 patients with penetrating colon injuries	Hand suture: (n = 128) All complications: 26/128 (20%) Anastomosis failure: 10/128 (8%) Abscess: 20/128 (16%)	Stapler: (n = 79) All complications: 21/79 (27%) Anastomosis failure: 5/79 (6%) Abscess: 16/79 (20%)

Table 24: Hand suture versus stapler after penetrating colon injury

Study	LoE	Patients	Result	
Brundage et al. 1999 [95]	2b	117 patients with blunt and penetrating small intestine injuries	Hand suture (n = 44) All complications: 2/44 (5%) Anastomosis failure: 0/44 (0%) Abscess: 0/44 (0%)	Stapler (n = 70) All complications: 8/70 (11%) Anastomosis failure: 3/70 (4%) Abscess: 6/70 (9%)
Kirkpatrick AW et al. 2003 [97]	2b	232 patients with blunt and penetrating small intestine injuries	Hand suture (n = 25) All complications: 4/25 (16%) Anastomosis failure: 1/25 (4%) Abscess: 3/25 (12%)	Stapler (n = 55) All complications: 7/55 (13%) Anastomosis failure: 3/55 (6%) Abscess: 6/55 (11%)

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3.5 Traumatic brain injury

Surgical management

Emergency surgical management

Key recommendation:

Compressive intracranial injuries must be surgically managed as an emergency.	**GoR A**

Explanation:

The goal of the treatment after a TBI is to limit the extent of secondary brain damage and to provide the brain cells whose function is impaired but not destroyed with the best conditions for functional regeneration. Injury sequelae requiring surgery must be treated in a timely manner.

The indication for surgical decompression of traumatic intracranial compression has never been tested in prospective randomized controlled trials. There are several retrospective analyses [3-9, 13] from which the benefit of surgical decompression can be derived. Due to the decades of consensual experience, the need for a surgical procedure can be regarded as a basic incontrovertible assumption of good clinical practice.

Compressive intracranial injuries represent an absolute urgent indication for surgery. This applies both to traumatic intracranial bleeding (epidural hematoma, subdural hematoma, intracerebral hematoma/contusion) and to compressive impression fractures. The definition of compression refers to the shift of cerebral structures, particularly the 3rd ventricle normally located at the midline. In addition to the finding in the computed tomography (layer thickness, volume, and location of hematoma, extent of midline shift), the clinical finding is key to establishing the indication and the speed with which surgical management should be carried out. If there are signs of a transtentorial herniation, every minute can make a difference to the clinical outcome. It is not considered meaningful to indicate the volumes at which an intervention should be performed as the individual situation of the patient (age, possible pre-existing brain atrophy inter alia) must be taken into account in establishing the indication.

Operations with deferred urgency

Open or closed impression fractures without shift of midline structures, penetrating injuries or basal fractures with liquorrhea constitute operations with deferred urgency. Their surgical conduct requires neurosurgical competence. The timing of the surgical intervention depends on many factors and must be decided on an individual basis.

Decompressive craniectomy

An effective option for lowering elevated intracranial pressure is surgical decompression by craniectomy and, if necessary, expansive duraplasty. The necessity mainly arises from the development of marked (secondary) brain edema and thus frequently has several days' latency. According to a prospective randomized controlled trial, the method shows good treatment success despite an increased complication rate [23]. Further prospective studies [10, 18] are ongoing so that no final recommendation can yet be made [26].

Nonoperative treatment of intracranial bleeding

In noncompressive bleeding and stable neurologic finding, a nonoperative procedure can be justified in individual cases [5, 7]. However, these patients must undergo close clinical and computed tomography follow-up observation. In the event of clinical deterioration or increase in compression, it must be possible to carry out immediate surgical decompression.

Measuring intracranial pressure

Key recommendation:

Intracranial pressure can be measured in unconscious brain-damaged patients.	**GoR 0**

Explanation:

Internationally in recent decades, the measurement of intracranial pressure has found its way into the acute management of unconscious brain-damaged patients and has meanwhile been adopted in several international guidelines [2, 21, 30]. For pathophysiologic reasons, this seems sensible as clinical monitoring of many cerebral functions is only possible to a limited extent. As a monitoring instrument in sedated patients, it can indicate imminent midbrain incarceration due to progressive brain swelling or compressive intracranial hematomas and thus permits early counter-measures to be taken. Even if there is currently no prospective randomized controlled trial that compares the clinical outcome with carrying out ICP monitoring [15], several cohort studies in recent years as well as clinical practice indicate its value in neurosurgical intensive medicine [1, 17, 20, 22]. The introduction of guidelines which, inter alia, stipulate this type of ICP monitoring has also led to an increase in favorable courses in TBI patients [24, 11]. Intracranial measurement is used for monitoring and treatment control of unconscious patients while taking into account the clinical course and morphologic image findings after TBI. However, it is not required in every unconscious patient.

The prerequisite for adequate brain perfusion is adequate cerebral perfusion pressure (CPP), which can be calculated simply from the difference between the mean arterial blood pressure and the mean ICP. The literature contains divergent opinions on whether lowering the ICP or maintaining the CPP should be the focus of the treatment in the case of elevated ICP. The currently available evidence argues in favor that,

- on the one hand, the CPP should not fall below 50 mmHg if possible [30].
- on the other hand, the CPP should not be raised to above 70 mmHg by aggressive treatment [30].

Invasive ICP measurement is necessary for continuous determination of the CPP. Provided the ventricles are not completely compressed, ICP monitoring via a ventricle drain offers the possibility of lowering elevated ICP through draining cerebrospinal fluid.

Determining the individual optimum CPP requires simultaneous knowledge of brain blood supply, oxygen supply and demand and/or brain metabolism. Regional measurements (using brain tissue probes, transcranial Doppler examinations or perfusion-weighted imaging) for estimating this value are currently the subject of scientific studies [19, 27].

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3.6 Genitourinary tract

Key recommendations:

Critical renal injuries (grade 5 according to the AAST classification) should be surgically explored.	**GoR B**
In the case of renal injuries < grade 5, a primary conservative procedure should be introduced in stable circulation conditions.	**GoR B**
If other injuries necessitate a laparotomy, renal injuries of average severity grade 3 or 4 can be surgically explored.	**GoR 0**

Explanation:

The indication to operate on renal injuries is now regarded with more restraint than a few years ago. In most cases, the decision to perform a laparotomy is already dictated by the intraabdominal concomitant injuries. However, life-threatening renal bleeding also represents an absolute indication for surgery [116]. The injury severity score according to AAST (American Association for the Surgery of Trauma) [117] has established itself as the basis of decision-making as this classification is closely correlated to the need for surgery and the possibility of salvaging the kidney [118]. Grade 5 renal injuries represent an indication for surgery because of the blood loss and/or threatening loss of renal function. In contrast, it is usually the case that grade 2 to grade 4 injuries can definitely be managed conservatively unless the patient has unstable circulation due to their renal injury; then the kidney should be surgically freed [119–133]. In the meantime, there are even individual reports by authors who have successfully treated grade 5 injuries conservatively [134, 135]. Provided pelvic or abdominal injuries require a laparotomy anyway, non-trivial renal injuries (> grade 2) can be surgically explored as this increases therapeutic certainty and may even make second interventions superfluous.

In particular, controversy has long surrounded the procedure for severe renal injuries with urine discharge and devitalized fragments. However, individual smaller studies have shown that even here non-surgical management is possible [136–138] even if the complication and revision rate here turns out to be markedly higher [139].

Pathologic pyelogram findings with additional evidence of a pulsating or expanding retroperitoneal hematoma should be surgically explored in cases where only i.v. pyelography can be carried out because of prioritizing. The evidence of hematuria and ideally also the ultrasound finding should be used here in the evaluation. Ichigi et al. showed that the size of the perirenal hematoma is closely linked to the severity of the renal injury [140] so that this criterion can also be used in the decision between a surgical or conservative procedure [4, 6, 9].

Table 25: Grading classification of renal trauma according to the American Association for the Surgery of Trauma (AAST) [117]

Grade	Properties
1	Renal contusion, perirenal or subcapsular hematoma, no other lesion in the imaging
2	Grade I lesion and laceration of the parenchyma up to 1 cm, collecting system not involved
3	Laceration > 1 cm without urine extravasation
4	Penetrating parenchymal lesion involving collecting system and/or hilar vessels
5	Shattered kidney and/or renal vascular pedicle avulsion, bleeding/sequestration

Key recommendation:

Selective angiographic embolization of a renal artery injury can be attempted as a therapeutic option in the patient with stable circulation.	**GoR 0**

Explanation:

Up till now, the importance of angiographic embolization has been documented in a few case series and case reports [95, 141, 142] but which also partly include non-traumatic bleeding of the renal arteries [143–145]). These studies also refer partly not only to the primary phase of polytrauma management but also describe the treatment of pseudoaneurysms or arteriovenous fistulas in the secondary phase [94, 146, 147]. According to these case series, bleeding is successfully arrested in about 82% [94] to 94% [95] of patients. In more recent review papers as well, the angiographic embolization of renal injuries in patients with stable circulation is increasingly accepted as the first intervention step albeit with reference to the monotrauma situation [9, 41, 47]. Usually, it involved branches of the renal artery which required embolization. It is undisputed that the selection of patients, the technical equipment, and the individual medical experience have a decisive influence on the success rate. Primarily because of the considerable amount of time required for embolization, selective angiographic embolization can only be successfully incorporated into the overall management in individual cases of multiply injured patients.

Key recommendations:

Depending on the type and severity of injury and concomitant injuries, a renal injury can be surgically managed by oversewing or, if necessary, by partial renal resection and other procedures to salvage the organ.	**GoR 0**
Primary nephrectomy should be reserved for grade 5 injuries.	**GoR B**

Explanation:

In the multiply injured patient with renal injury, the surgical approach is usually determined by the overall injury pattern and then normally consists of a midline laparotomy. In order to control renal bleeding, the renal pedicle is generally prepared before opening Gerota's fascia. Individual zig-zag sutures and continuous sutures are then used to arrest the bleeding [116]. Fibrin adhesives can be advantageous here [148]. The surgical procedure for the multiply injured patient is largely identical to that for the monotrauma patient and there is no need to go into detail here.

The effort expended in reconstruction attempts should be based on the overall situation of the patient. Primary nephrectomy should be reserved for grade 5 injuries [9]. No long-term reconstruction attempts should be undertaken unless both kidneys are at risk. For reasons of time and the fewer complication possibilities, the indication for nephrectomy in the multiply injured patient should be made sooner than for the monotrauma patient [9, 41].

Ureter injuries

As ureter injuries are difficult to diagnose, if a laparotomy is being performed for another reason, it should be used for examining the ureters if such an injury is suspected [7]. Although macroscopic evaluation is also unreliable [102], it presents a huge advantage in that it allows a ureter injury to be treated early. Untreated ureter injuries lead to urine fistulas, urinomas, and infections so that the goal here should also be surgical management at the earliest opportunity [101]. The lesions are most frequently located in the proximal ureter [149]. A wide range of surgical procedures can be used [7].

Bladder injuries

Key recommendations:

Intraperitoneal bladder ruptures should be surgically explored.	**GoR B**
Extraperitoneal bladder ruptures without involvement of the neck of the bladder can be conservatively treated through suprapubic urinary diversion.	**GoR 0**

Explanation:

In most cases, the management of frequently numerous concomitant injuries should be given priority over a bladder injury. Numerically, extraperitoneal bladder ruptures are roughly twice common as intraperitoneal bladder ruptures [11, 60]. Combined extraperitoneal and intraperitoneal ruptures are markedly less frequently observed. Even taken on their own, intraperitoneal bladder ruptures represent a surgical indication since large tears are often found which can then lead to peritonitis and urinomas [150, 151]. The bladder should be closed and any urinomas drained.

The majority of extraperitoneal bladder injuries can be treated conservatively by means of a catheter drain, even if large retroperitoneal or scrotal extravasates are present [150]. Based on a series of 30 extraperitoneal ruptures, Cass and Luxemberg report on a 93% success rate with this non-surgical method [152]. In another series of 41 patients, almost all extraperitoneal bladder ruptures healed successfully within 3 weeks [153]. However, if the bladder neck is injured [11], bony fragments lie in the bladder or the bladder is clamped between bony pelvic fragments, a primary surgical procedure is necessary [1]. In the sequence of operations, osteosynthesis of the pelvis comes first followed by urological management [38]. Routt et al. also emphasize that good cooperation between the trauma surgeon and the urologist is essential here [38].

Urethral injuries

Key recommendation:

Complete ruptures of the urethra should be treated in the emergency surgery phase by suprapubic urinary diversion.	**GoR B**
Urinary diversion can be supplemented by urethral re-alignment.	**GoR 0**
Provided a pelvic fracture or another intraabdominal injury necessitates surgery anyway, urethral ruptures should be managed in the same session.	**GoR B**

Explanation:

It should be particularly mentioned in the management of urethral injuries that the method described here refers explicitly only to the emergency surgery phase as other principles also apply in the further management.

To date, there has been insufficient evidence as to whether primary, delayed or secondary re-anastomosing should be preferred in complete ruptures of the posterior urethra. In addition, primary and delayed urethral re-alignment is proposed [8]. The main problems in the post-traumatic course are urethral strictures, incontinence, and impotence so the treatment goal is to avoid them.

In a literature review summarizing several case series and comparative studies [20, 154–163] on the treatment of the urethral rupture, Koraitim [31, 164] describes the following rates of stricture, incontinence, and impotence: suprapubic diversion on its own 97%, 4% and 19%; primary re-alignment 53%, 5% and 36%; primary suture 49%, 21% and 56%. Accordingly, in the case of a complete urethral rupture in the male, he recommends suprapubic diversion on its own or re-alignment if there is a large gap between the ends of the urethra. However, as this literature review spans back more than 50 years, more recent studies on urethral re-alignment with better results are perhaps not sufficiently taken into account. Nevertheless, even current studies find both treatment options of equal value [165]. Accordingly, the EAST Guideline also comes to the conclusion that both primary re-alignment and also suprapubic diversion with secondary surgery are equally worthy of recommendation [10].

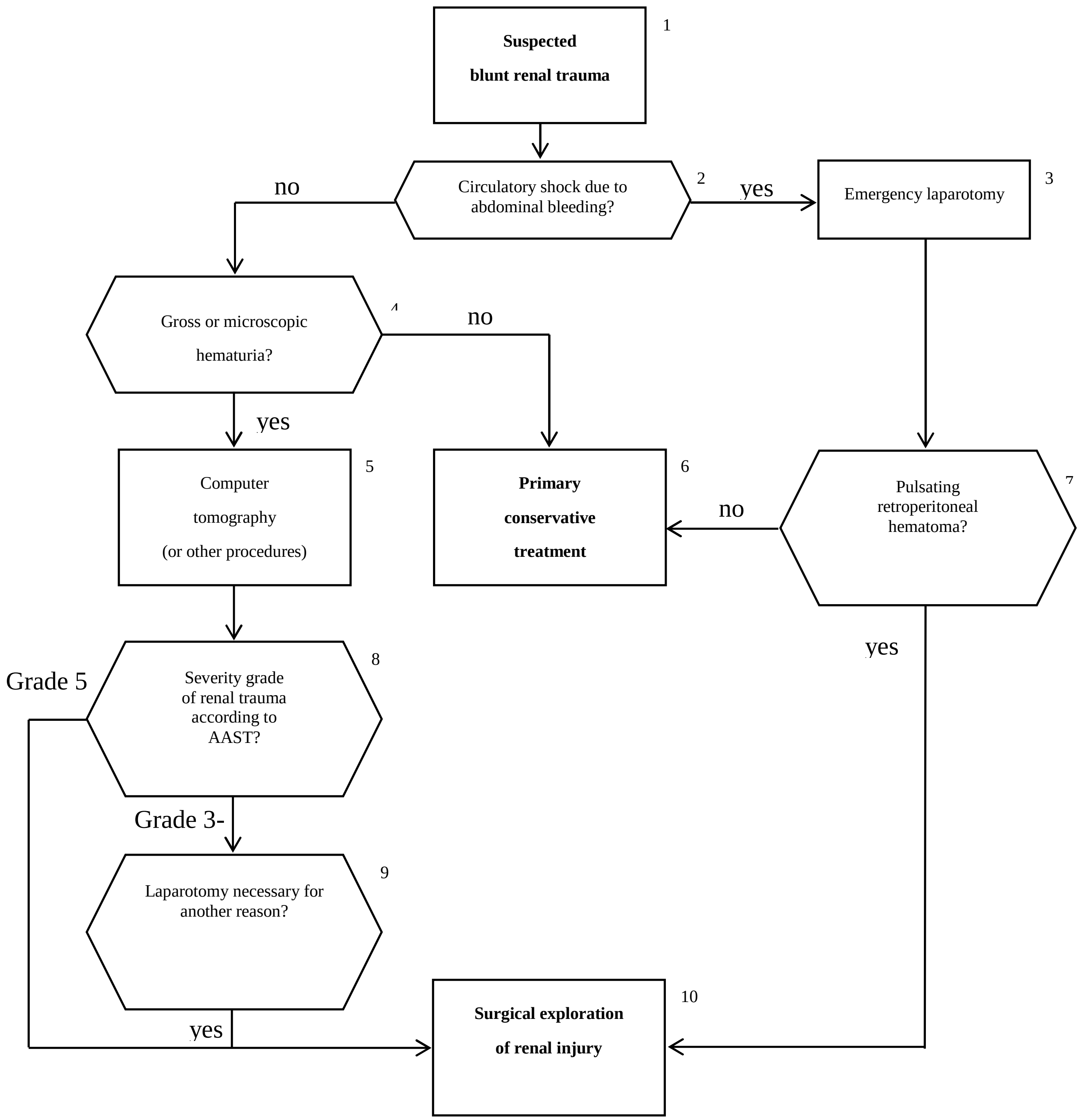
In the cases where surgery is necessary anyway due to other adjacent lesions, it appears expedient to manage the urethral rupture at the same time to avoid two-step management [166]. Particularly if the abdominal cavity is contaminated by large intestine injuries, primary suture of the urethra over a splinting catheter appears advisable to avoid complicating infections. Even if a conservative procedure actually appears to be possible, urethral injuries should be managed by primary surgery if the definitive osteosynthesis of the bony pelvis cannot otherwise be carried out [167].

Ruptures of the anterior urethra in the male are somewhat rarer than those of the posterior urethra. Primary surgical reconstruction may be necessary in open injuries. In the majority of cases, however, preference should also be given here to suprapubic urinary diversion followed by later reconstruction as reconstruction of the anterior urethra and the external male genitals, which are often injured as well, is usually difficult and time-consuming. However, in the case of a penile fracture with injury to the corpus spongiosum, it is recommended that the urethral injury also undergoes primary surgery [8, 168, 169]. The severity of the urological injury [170] and the overall severity of all injuries are crucial in deciding between primary surgery and conservative treatment.

Urethral injuries occur markedly less frequently in women than in men. However, when they occur, they are mostly very pronounced and associated with bladder injuries. For this reason, primary treatment should consist only of suprapubic urinary diversion if the patient has unstable circulation and/or other injuries require more urgent surgical management [67]. On the other hand, in women with less severe polytrauma, ruptures in the proximal urethra can undergo primary reconstruction via retropubic approach [69, 70, 171].

These recommendations apply similarly to children as well, whereby again a distinction should be made between the sexes. In a series of 35 boys with posterior urethra tears, Podestá et al. (1997) compared suprapubic diversion (with later urethroplasty), suprapubic diversion with urethral catheter alignment, and primary anastomosis [172]. As the continence rate after primary anastomosis only reached 50%, and in the group with catheter alignment all 10 patients still required urethroplasty later, the authors recommend suprapubic urinary diversion on its own followed by secondary urethroplasty. In a study on urethral injuries in girls with pelvic fracture and other concomitant injuries, the same authors found deferred management to be advantageous as good results could be observed despite vesical and vaginal concomitant injuries.

Figure 5: Algorithm on the diagnostic and therapeutic procedure for suspected renal injuries



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3.7 Spine

Indication for surgery

Key recommendation:

Unstable spinal injuries with confirmed or assumed neurologic deficits, with malpositions in which neurologic deficits can probably be prevented or improved by reduction, decompression, and stabilization, should be operated on as early as possible (“day 1 surgery”).	**GoR B**

Explanation:

After life-threatening injuries to the body cavities and the head, and the long bones, spinal injuries occupy third place, or second place if there is a spinal cord injury, in management priority [1].

Surgical indications are atlanto-occipital dislocation, translatory atlanto-axial dislocation, unstable Jefferson fracture, unstable Dens fracture (particularly type II), Hangman fracture (rib fracture C2 and invertebral disc injury C2/C3), C3 to C7 fractures (A3, B and C types) also in terms of dislocation, and T1 to L5 fractures (A3, B and C types) also in terms of dislocation. According to prevailing opinion, an absolute primary surgical indication exists even if there is an open spinal injury [2, 3].

In addition, the indication for primary management of a spinal injury in polytrauma is assisted by the classification according to Blauth et al. (1998) into a) complex spinal injuries with an injury to essential neural pathways and organs such as the spinal cord, lung, great vessels and abdominal organs, b) unstable spinal injuries (type A3, B and C - in this case, functional treatment can lead to severe malpositions and neurologic damage), and c) stable spinal injuries. If a complex spinal injury or an unstable spinal injury is involved, the goal should be surgical stabilization at the earliest possible opportunity - in other words, on the day of the accident if none of the contraindications mentioned below are present [4].

According to Blauth et al. (1998), a complex spinal injury is a multi-level spinal injury or one accompanied by intrathoracic or intraabdominal injury or polytrauma. The fact that polytrauma makes a spinal injury a “complex” injury is substantiated inter alia by studies by Hebert and Burnham [5] which established that the length of stay in hospital was extended and the number of surgical interventions increased in these patients and that the combination of spinal injury/polytrauma is associated with an increased morbidity and mortality and an increased degree of disability. Nevertheless, according to a survey in North America by Tator et al. (1999), 1/3 of spinal injuries with neurologic injuries were still conservatively treated and of those operated on only 60% received surgery before the 5th day and 40% after [6].

The goal of primary surgical management in unstable spinal injuries with confirmed or assumed neurologic deficits or with malpositions is firstly early spinal decompression and the avoidance of neurologic secondary damage and secondly to achieve positioning stability for the intensive treatment [1].

The indication for surgery to avoid neurologic damage is relatively clear in unstable fractures without spinal cord lesion. If there are spinal injuries which are unstable and which could be displaced by necessary positioning measures such as in chest trauma, the indication for primary spinal stabilization should be made [4, 7-9]. However, controversy surrounds the issue of whether early or later fracture management is advantageous in fractures where spinal cord injury has already occurred. As far as neurologic symptoms are concerned, animal experiments show advantages in spinal stabilization being carried out as early as possible [10, 11]. However, in the field of clinical research, several large systematic reviews (some with meta-analysis) could detect no clear correlation between the timing of surgery and the neurologic outcome [12-15].

Only the most recent meta-analysis by La Rosa et al. [12] revealed that early surgical decompression has advantages compared to late decompression or conservative treatment. In the early group (17 studies), an improvement in neurology could be found in 42% of patients with complete deficit, and in 90% with incomplete deficit. In the late group, the improvement quotas were 8% and 59%, in the conservative group 25% and 59%. However, as the results from the studies differ greatly, La Rosa et al. also describe early surgery only as a “practical option”.

The only randomized controlled trial on this was conducted on 62 patients with cervical spinal injury only [16]. Although the authors found no difference between early (< 72 hours) versus late stabilization (> 5 days) in the neurologic outcome, they still recommended early stabilization. Levi et al. also found indifferent results concerning the early (< 24 hours) and late (> 24 hours) stabilization in the cervical spine injury but ultimately also recommend early surgery [17]. After Wagner and Chehrazi also found no correlation between the timing of surgery and neurologic outcome in cervical spine injuries, they concluded [18] that primary medullary damage determines the prognosis. McKinley et al. draw a similar conclusion [19]. In contrast, Papadopoulos et al. observed improved neurologic outcomes after early surgery [20]. Mirz et al. also described in 1999 [21] that early stabilization (< 72 hours) of a cervical spine injury is more favorable for the neurologic outcome than later stabilization (> 72 hours). However, all these are data from studies that did not study exclusively multiply injured patients.

In addition to these studies focusing primarily on the neurologic outcome, there is a series of studies which have concentrated mainly on the non-neurologic effects of early stabilization. A study by Croce et al. found evidence in 2001 [7] that, in contrast to late stabilization (> 3 days after trauma), early stabilization (< 3 days after trauma) of the spinal injury offers advantages, especially in polytrauma (mean ISS 24) with thoracic spine injury, as the intensive care period, pneumonia rate, costs, and ventilation time can be reduced. The studies by Johnson et al. [8] also argue in favor of primary stabilization of unstable spinal fractures as this can lower the ARDS rate especially in multiply injured patients. Dai et al. also observed a reduction in pulmonary complications after early management [22]. According to results by Aebi et al. [23], the immediate surgical management of a cervical spine injury is more important for neurologic outcome than improved surgical techniques. In a study published in 2005, Kerwin et al. [24]

found that primary stabilization of the spine in critically injured patients (ISS > 25) shortened the length of hospital stay from 29 to 20 days.

The above-mentioned indications presume that a diagnostic study which adequately balances the injury could be performed in the emergency room phase. The patient should have stable cardiopulmonary parameters, and surgical bleeding sources should be excluded. Additional vital parameters such as intracranial pressure, core body temperature, and coagulatory function should lie within the normal range. If there is a substantiated risk that the condition of the casualty will worsen in a significantly (life-) threatening way by primary reduction, decompression, and stabilization of the spine, then spine stabilization is relatively contraindicated.

If the patient has stable intracranial pressure, pulmonary, cardiac, and circulatory function, this multiply injured patient benefits especially from early management of the spinal injury: positioning stability is achieved, thereby avoiding second hits through subsequent surgery and also reducing the antigenic load through the instability of a fracture in proximity to the trunk. On the other hand, critical conditions with hypothermia, massive transfusion, coagulation derangement, lung failure, and high catecholamine dependency constitute relative contraindications for immediate spine stabilization.

In this context, McLain and Benson (1999) [25] ascertained that immediate (< 24 hours after trauma) stabilization had the same outcomes as early stabilization (24-72 hours after trauma) of an unstable spinal fracture if the patients had multiple injuries, neurologic symptoms, and a concomitant thoracic-abdominal injury. Nevertheless, the authors recommend that stabilization is carried out as early as possible. Schlegel et al. [26] and Chipman et al. [27] also ascertained that surgical stabilization of unstable spinal fractures within 72 hours especially in polytrauma was associated with lower morbidity (fewer lung complications, fewer urinary tract infections, shorter hospitalization and intensive care stay). If there is an abdominal injury, which leads to laparotomy in up to 38% of patients with a spinal fracture [28], it must be weighed up after surgical management of the abdomen whether the unstable spinal fracture must or can be stabilized during the same session.

In contrast, in the case of a hemothorax, the condition of bleeding in the ribcage alone supports early stabilization of a thoracic spine injury [29]. The results from the study by Petitjean et al. [30] also argue in favor of early stabilization of the thoracic spine fracture inter alia secondary to simultaneous chest trauma with pulmonary contusion. If there is a primary transverse lesion or irreducible dislocation, surgery can be postponed until organ functions are stabilized during intensive care treatment.

In conclusion, therefore, there is an advantage in early surgery for the multiply injured patient particularly against the background of the publications in recent years between 2006 and 2008 [31–45] Although the neurologic outcomes appear relatively unaffected by the timing of surgery, early fracture stabilization helps to minimize general complications and the length of hospital stay. As general complications, particularly lung-related, are common in the multiply injured patient, the result is the above recommendation for surgery at the earliest possible opportunity.

Key recommendations:

Unstable thoracolumbar spine injuries without neurologic deficit should be surgically managed.	**GoR B**
Surgery should be performed on the day of the accident or alternatively later during the course.	**GoR B**

Explanation:

Apart from the B and C injuries, this applies particularly to A2 and A3 fractures of the thoracolumbar spine which are not displaced by positioning measures during intensive care. There is no reason here for urgently stabilizing such an injury on the day of the accident. However, according to results from Jacobs et al. [46], it generally applies that the successes of surgical treatment on unstable thoracic and lumbar spine fractures are better than those of conservative treatment in respect of reduction, neurology, mobilization, rehabilitation period, and incidence of complications [47].

Key recommendation:

Stable spinal injuries without neurologic deficit should be treated conservatively.	**GoR B**

Explanation:

The fracture type A1, if applicable also A2, which does not benefit from surgical stabilization, is regarded as stable [48, 49], particularly if the adjacent vertebral discs remain intact. Surgical stabilizationis notindicated in polytrauma [50].

Surgery technique

Key recommendation:

For injuries to the cervical spine, primary surgical methods that can be used are: 1) halo fixator, 2) ventral stabilization procedure.	**GoR 0**

Explanation:

The halo fixator is indicated if there are contraindications to definitive internal osteosynthesis, which is actually necessary, and a soft cervical collar is insufficient for temporary stabilization [51, 52, 53, 54].

Ventral spondylodesis is indicated particularly in C3-C7 dislocation fractures. Generally, the first-line choice is corpectomy - removal of the invertebral disc, replacement with iliac crest bone graft, if necessary, a cage, and stabilization using a plate, if necessary, a fixed-angle one [55]. In polytrauma, preference should be given to the ventral management of unstable cervical spine fractures over the dorsal stabilizing procedure particularly on the day of the accident [56].

According to Brodke et al. [57], there are no significant differences in the knitting, in the success of reduction, in neurology, and in the long-term symptoms for ventral versus dorsal cervical spine procedures but the latter requires much more effort and time, which is why it should not be recommended in polytrauma. If there is an unstable Dens fracture, ventral screwing is generally indicated; if there is an unstable Jefferson fracture, dorsal screwing or occipitocervical fusion can be indicated. However, the latter procedure does not represent a good indication for Day 1 Surgery and should be performed as an electively planned procedure.

Key recommendation:

For injuries to the thoracolumbar spine, the dorsal internal fixator should be used as the primary surgical method.	**GoR B**

Explanation:

Only the dorsal internal fixator can be recommended for the primary management of fractures to the thoracolumbar spine [59-61]. This procedure can achieve good reduction, decompression, and stabilization, sufficient for all positioning measures in intensive care. According to Kossmann et al., this measure is understood as damage control for the spine in polytrauma [62]. Ventral fusions are recommended only electively and then in the secondary surgery phase if they are necessary. Moreover, according to Been and Bouma, dorsal stabilization on its own can be sufficient in burst fractures of the thoracic/lumbar spine [63]. The logistic and technical effort plus surgery time must be taken into account for the various surgical methods on the spine.

Laminectomy increases instability [23, 65–68] and at best can serve as access for dorsal decompression to push forward posterior edge fragments. There is dispute over whether removing bone fragments from the spinal canal (spinal clearance) is really clinically advantageous [69-71]. Insofar as there is an indication for laminectomy, it should be made very narrowly and only considered if there is neurologic deficit and compression caused by bone and invertebral disc fragments which cannot be removed ventrally.

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3.8 Upper extremity

Key recommendation:

Surgical management of fractures to the long bones in the upper extremities should be carried out early.	**GoR B**

Explanation:

There are no prospective comparative studies on the determination of the optimum timing for the surgical management of fractures of the long bones in the upper extremity in multiply injured patients. The data is based on studies which either focus on primary shaft fractures of the lower extremity in polytrauma or analyze multiply injured patients in the total collective with single fractures of the long bones of the upper extremity.

Shaft fractures of the upper extremity must be surgically managed early, if possible directly after cardio-respiratory stabilization [1].

If concerns exist over primary internal fixation, the alternative option is provided by the external fixator or, in exceptional cases, even primary plaster cast and later change in procedure [2].

After initial stabilization by external fixator, plaster cast or re-applied dressing, even fractures close to the joint can be managed well by secondary surgery if planned, if the acute problems of other injuries make this necessary [3].

Open fractures are best operated on within the first 6 hours, if necessary with temporary stabilizing measures.

In the hierarchy of urgency, however, there is also a correlation with the location of other fractures. In multiply injured patients, therefore, the priority of fractures in the upper extremity follows management of tibia, femur, pelvis, and spine but precedes complex joint reconstructions, definitive treatment of maxillofacial injuries, and soft tissue reconstructions [4].

There are no comparative studies that deal specifically with the most suitable procedure in fractures of the upper extremity in multiply injured patients. The multiply injured patient is always included in heterogeneous groups as an important indication for the surgical procedure. Thus, the conclusion by analogy is generally drawn from the totality of the patients with fractures of the long bones of the upper extremity.

However, there are no large studies here either that reflect a high level of evidence. The AO multicenter study on the humerus shaft fracture also no longer represents all current procedures [5].

In the management of fractures of the upper extremity in multiply injured patients, the focus lies on the rapid but safe stabilization of the fracture to the upper extremity. Within this context, controversy surrounds the ranking between medullary nailing and plate osteosynthesis as the competence of the surgeon in one or the other procedure appears to be more important than the procedure itself [3, 6–12].

In metaphyseal fractures to the humerus, radius, and ulna, specific intramedullary procedures are now also used; studies with informative value on their use in multiply injured patients are not available.

Key recommendations:

The decision to amputate or to salvage the extremity in the critical injury to the upper extremity should be made on an individual basis. The local and general condition of the patient plays a crucial role here.	**GoR B**
In rare cases and in extremely severe injuries, an amputation can be recommended.	**GoR 0**

Explanation:

In subtotal amputation injuries, fracture stabilization and reconstruction of nerves, vessels, and soft tissues should be carried out immediately after the resuscitation phase and management of vital sign injuries, if necessary also while shortening the extremity.

In the case of total amputation injuries, the availability and condition of the lost extremity are key to deciding whether it makes sense to replant or definitively amputate to create a vital stump.

Even extremely contaminated, severe open fractures do not represent per se an indication for primary amputation in multiply injured patients. Stabilization and debridement are important in this instance [15]. The literature contains mainly case histories on this subject [16].

The Mangled Extremity Severity Score (MESS) developed for the lower extremities [17] cannot be simply transferred to the upper extremity.

Key recommendation:

Provided the severity of the overall injury permits, the surgical management of vascular injuries should be carried out at the earliest possible opportunity, i.e. directly after treating the injuries threatening the vital functions.	**GoR B**

Explanation:

Due to the rapid onset and poor prognosis associated with ischemic sequelae, vascular reconstruction must be carried out rapidly in polytrauma as well [18–20].

Absent pulses in the pendant parts of the extremity affected can give information about an additional vascular injury or even a vascular injury without a fracture; Doppler and duplex supplement the diagnostic study [18, 19].

Schlickewei et al. recommend the generous use of preoperative angiography in injuries to the upper extremity and the urgent surgical restoration of perfusion to the extremities to reduce the period of ischemia [20]. In the case of those injuries that required secondary amputation in conjunction with the vascular injury, the period of ischemia exceeded 6 hours in 51.8% of cases, there was severe soft tissue damage in 81.4%, and a grade III open fracture in 85.2%. However, reconstructive interventions are put to one side if vital functions are at risk. Due to low case numbers, there are only isolated case series on this [18–20].

Key recommendation:

Depending on the type of nerve damage, injuries with nerve involvement should be managed together with stabilization.	**GoR B**

Explanation:

The majority of multiply injured patients are ventilated and intubated on admission to hospital but the sensitivity and motor functions of the fractured upper extremity often cannot be clearly examined at the accident scene. The rate of primary non-discovered concomitant nerve damage is unclear. Provided it is not simply a question of decompression as part of the fracture management, the correct reconstruction of peripheral nerve lesions in the long bone region of the upper extremity is time-consuming and complex and should be planned and carried out in a stable environment. Thus, this should only be integrated into the primary management of multiply injured patients in exceptional cases. This does not only apply to the injury to isolated peripheral nerves but also to brachial plexus injuries [21–25].

Due to low case numbers, there are only isolated case series which are not exclusively limited to polytrauma.

Compartment syndromes associated with fractures of long bones in the upper extremity are rare. Due to deleterious sequelae occurring within a few hours, however, they require rapid decompression during fracture stabilization. This applies equally to multiply injured and to non-multiply injured patients and should take place within the first few hours after trauma and compartment syndrome development. Wippermann et al. [26] showed for the upper arm and Schmidt et al. [27] showed for the forearm that the prognosis depends on the totality of the injuries and is most favorable in the case of isolated compartment syndrome without fracture. Nevertheless, the conclusion of rapid action is based less on specific studies on compartment syndrome in the upper extremity in polytrauma but rather much more on the experiences with the lower extremity (Evidence Level 5). Open fractures and those with vascular injuries should thus undergo rapid surgical revision after restoration of cardiopulmonary stability. In closed fractures, those with impairment of the epiphyseal gaps represent an urgent surgical indication after stabilization of the vital functions. For logical reasons, shaft fractures in the long bone in multiply injured children are fixed outside the epiphyseal gaps by means of elastic intramedullary splinting[28]; alternatively, the external fixator can be used. Bennek [29] envisages its use particularly in open and long-segment fractures. As with Schranz [30], the case numbers are very small in this respect. Nevertheless, the procedure should be adapted to the age of the child as well as to his concomitant injuries [31, 32]. Due to low case numbers, there are only isolated case series which are not exclusively limited to polytrauma.

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3.9 Hand

Fractures and dislocations of the distal forearm, the carpals, metacarpals, and phalanges

Key recommendations:

Closed fractures and dislocations should be conservatively treated in the emergency surgery phase.	**GoR B**
Dislocations must be reduced and stabilized in the emergency surgery phase.	**GoR A**

Explanation:

In polytrauma, 75% of hand injuries are closed fractures [2, 91]. In principle, closed fractures and dislocations can be reduced according to clinical criteria without too much effort and immobilized by simple means (plaster, splints). However, in unstable, extremely dislocated fractures of the distal radius, metacarpals, and phalanges, primary stabilization via an external fixator and Kirschner wires is indicated after closed reduction.

In the secondary phase (5th-12th day), the following injuries should be definitively operated on: unstable fractures and those remaining in intolerable malpositions, ligament injuries temporarily managed during the emergency surgery phase, and fractures.

Dislocations of the finger joints represent important injuries in the prognosis of hand function. In principle, reduction must be carried out immediately [23, 69]. If closed reduction is not possible, then open reduction must be carried out in the emergency surgery phase. After primary successful reduction, a stable closed finger joint dislocation without articular fracture can be treated conservatively [4, 23, 45, 64, 66, 99, 105, 126, 134].

Key recommendation:

In the case of open fractures and dislocations, primary debridement and stabilization by wires or external fixator should be carried out.	**GoR B**

Explanation:

Open fractures and dislocations should be managed in the emergency surgery phase. Here, the main procedure corresponds to the usual procedure for open bony injuries (dressing kept on until in surgery, wound cleaning, debridement, irrigation, fracture stabilization, soft tissue reconstruction). Fracture stabilization using the external fixator or Kirschner wires should be given preference over time-consuming primary definitive osteosynthesis (plates, screws) [5, 16, 17, 38, 81, 101]. Wound irrigation and careful debridement make a crucial contribution to infection prevention [49, 112]. Carrying out a second look after 2-3 days depends on the primary local injury pattern and the clinical situation [49]. See the section on “Drug Treatment” for administration of antibiotics.

Key recommendation:

In the case of perilunar dislocation/perilunar dislocation fractures, reduction, if necessary open, must be undertaken in the emergency surgery phase.	**GoR A**

Explanation:

The long-term outcomes after perilunar dislocations/dislocations of the lunate bone depend on early diagnosis and correct treatment. Reduction of the dislocated carpals is undertaken early in the emergency surgery phase either closed or, if this is not possible, open. After primary closed or open reduction, stabilization must be undertaken using Kirschner wires and/or an external fixator [40, 53, 83, 95].

Definitive open reduction, internal fixation using drill wires and/or reconstruction of the torn ligaments should be undertaken in the secondary phase. Fractures as part of perilunar dislocation injuries should be managed osteosynthetically with screws or drill wires [39, 53, 56]. Whereas the injury morphology (course of fracture and dislocation line, extent of dislocation) is not important for the clinical and radiologic long-term outcome, the time until diagnosis and the accuracy and immobilization of the reduction represent relevant prognosis factors [40, 53].

Amputation injuries

Key recommendations:

Establishing the indication for replantation must be based on the overall injury severity according to the “life before limb” principle.	**GoR A**
In establishing the indication, the local finding and patient-related factors should be taken into account.	**GoR B**

Explanation:

Replantations in the hand region are possible and advisable in the multiply injured provided the severity score is 1-2 (polytrauma score [PTS]) [15, 111]. However, the indication for replantation should be kept very narrow for all those with life-threatening injuries as the surgery time is considerably extended and morbidity increased [13, 82].

Negative predictors are Crush or avulsion injuries, severe contamination, warm ischemia over 12 hours or cold ischemia over 24 hours, arteriosclerosis, and smoking [3, 8, 13, 24, 32, 37, 48, 82, 92, 120, 121]. In the case of replantations at the level of the wrist and proximal thereto, the serum potassium concentration measured 30 minutes after reperfusion in the amputated part can be used as a prognosis indicator (critical value 6.5 mmol/l) [129].

Key recommendation:

As with isolated hand injuries, the goal should be replantation particularly in the case of loss of thumb or several fingers, amputation at the level of metacarpals/carpals/wrist, and all amputation injuries in children.	**GoR B**

Explanation:

Replantations for amputations of the thumb, several fingers, metacarpals, and wrist are priority indications [13, 32, 46, 48, 82, 92, 130, 135]. Revascularizations have a somewhat more favorable prognosis as tissue bridges still in place often improve the venous outflow [90, 100].

Provided the general condition allows it, the indication for replantation should also be made in children since good functional results can be expected [28, 48, 90, 116, 136]. Positive predictors here are smooth-edged separations and a body weight exceeding 11 kg [7]. Children's fingers tolerate markedly longer ischemic periods than those of adults [22].

Key recommendation:

Individual fingers should not be replanted if amputations are proximal of the superficial tendon insertion (middle phalanx base).	**GoR B**

Explanation:

The amputation level of a finger is crucial in establishing the indication for replantation. In amputations of an individual finger proximal of the superficial tendon insertion, no replantation is indicated because of the poor functional result expected as a consequence of the severe mobility restriction [24, 120, 135]. In contrast, replantations are expedient in amputations that are distally further away provided the dorsal veins can be reconstructed. Good results can be achieved on the distal phalanx even without venous reconstruction [21, 37, 47, 48, 60, 68, 113].

Complex hand injury

Key recommendation:

Carrying out time-consuming salvage attempts on the hand is an individual decision. It must take into account the overall injury severity and the severity of the hand injury.	**GoR A**

Explanation:

If there are complex hand injuries with involvement of bones, tendons, nerves, and skin, the additional strains on the patient caused by the reconstruction must be weighed up against the outlook for success and the functional gain that can be expected. Time-consuming salvage attempts in the hand region are indicated only in PTS severity grades 1 and 2 [111]. Establishing the indication for or against salvaging the hand must always take into account the individual circumstances of each patient. MESS (Mangled Extremity Severity Score), which was originally developed for the lower extremity, can serve as an additional decision aid. In prospective and retrospective studies, a positive predictor value of 100% for an amputation was also obtained for the upper extremity with a MESS value of at least 7 points [31, 52, 96].

Key recommendation:

Debridement and bony stabilization should be carried out in the emergency surgery phase.	**GoR B**

Explanation:

Debridement and stabilization of the hand skeleton have priority in an open injury whereas nerve, tendon, and skin reconstruction can be carried out at a later time [17, 34, 81, 102, 114]. Time-consuming definitive reconstructions of soft tissue structures should be carried out in the secondary phase. The advantages and disadvantages (time required, operative traumatization, mobilization) of drill wire osteosyntheses should be weighed up against those of stable osteosyntheses by plates and screws [19, 20, 34].

Skin/soft tissue injury including thermal/chemical damage

Key recommendation:

The initial treatment of circumferential skin-soft tissue damage should comprise thorough debridement followed by keeping moist the wound surfaces that cannot be closed in primary management.	**GoR B**

Explanation:

During the emergency surgery phase, debridement of devitalized and contaminated tissue parts should be carried out [20, 101]. Keeping the wound surfaces and deeper structures moist by means of suitable dressing techniques is more important than attempting a soft tissue graft during the initial management [17].

If the wounds are clean and free of infection, the definitive defect covering should be carried out during the secondary phase (5th-12th day). In so doing, the procedure selected should always be the least technically demanding one with a good outlook for success, i.e. free flaps are always the last treatment option [43, 72].

Key recommendations:

Thermally/chemically damaged, fully devitalized skin areas should initially be debrided.	**GoR B**
In the case of deep-reaching and circumferential thermal/chemical damage, an escharotomy should be carried out similar to the procedure for compartment syndrome.	**GoR B**
For the conservative wound treatment of superficial burns (1-2a degree), preference should be given to sulfadiazine silver ointments or synthetic dressing materials and for the temporary treatment of deep burns (2b-3 degree) preference should be given to hydrocolloid dressings or vacuum sealing.	**GoR B**

Explanation:

Burns require initial debridement by removing all definitely devitalized areas to prevent circulatory disorders and infections. If full skin loss is subsequently present, a primary meshed graft covering should be given preference over secondary skin grafting. The primary grafting shortens the treatment period and reduces the frequency of secondary reconstructive operations [14, 67]. In the case of deep burns, the indication for escharotomy must be monitored within the first 36 hours by regularly monitoring local perfusion [1] (see section on Compartment Syndrome for indication and technique).

Silver sulfadiazine cream is suitable for treating superficial areas not requiring debridement; it should be re-applied each time after daily wound cleaning. Alternatively, synthetic dressings can be used. In the case of deeper burns, preference should be given to hydrocolloid dressings or vacuum seals as these lead to shorter healing courses and a reduction in pain [6, 93, 94, 98, 117]. In a controlled trial, faster healing of partial burns could be achieved through the use of collagenase with local antibiotics than through conventional treatment with sulfadiazine [50]. If secondary demarcated necroses occur under this treatment, they must also be removed. If healing is uncertain after 3 weeks, a skin graft, possibly after debridement again, should be carried out to avoid hypertrophic scarring and contractures [14, 67].

Tendon injuries (flexor tendons, extensor tendons)

Key recommendation:

Time-consuming tendon sutures should not be carried out as a primary procedure.	**GoR B**

Explanation:

Whether a severed flexor tendon should be managed by primary or delayed primary suture is surrounded by controversy [61, 62, 65, 106–110]. However, time-consuming tendon sutures can be carried out in multiply injured patients in the secondary phase (5th-7th day) without disadvantages being expected [20, 101, 102, 104, 107, 109, 131]. On the other hand, secondary flexor tendon reconstructions are disadvantageous (after weeks) [125].

The same recommendations apply in principle to the timetable for reconstruction of extensor tendon injuries as for flexor tendon injuries. However, the extent of damage to the soft tissue sheath and open joint injuries can necessitate primary definitive management [30, 124].

The choice of flexor tendon suture technique to be used depends on the preference of the surgeon as individual experience and execution are more important than the choice of suturing technique [109].

In the case of both flexor tendons being severed, reconstruction of both tendons is favored [61, 62, 71, 102, 106–110]. However, various authors prefer the sole reconstruction of the deep tendon in zone 2 because of better functional results [25, 57, 65]. In addition, there was evidence in a prospective randomized study that preference should be given to resection of the superficial flexor tendon and reconstruction only of the deep flexor tendon within zone 2 (Tang's subdivision 2C), particularly in delayed primary management [115]. For this reason, only the deep tendon is to be reconstructed within zone 2 particularly in delayed primary flexor tendon suture.
Routine administration of antibiotics is also not indicated in delayed primary flexor tendon suture. In a retrospective cohort study, Stone and Davidson [104] showed that not giving

antibiotics in primary or delayed primary flexor tendon reconstruction does not increase the risk of infections occurring [104]. The administration of antibiotics to the multiply injured patient depends much more on the presence of other injuries or the occurrence of infectious complications.

Nerve injuries of the hand

Key recommendation:

In assumed closed nerve injuries, time-consuming diagnostic procedures or surgical release can be dispensed with in the primary phase.	**GoR 0**

Explanation:

Closed nerve damage to the hand is the result of the effect of pressure or extension forces. A continuity disruption to the nerves is not to be expected. For this reason, primary surgical revision is not indicated here. The only exceptions are nerve lesions due to fractures or dislocations, where the nerve can be located and decompressed during surgical management of the skeletal injury. Thus, there is also no necessity to carry out time-consuming diagnostic measures to reveal assumed lesions while the patient is still unconscious [20]. The development of clinical symptoms and neurophysiologic parameters should be awaited.

Key recommendation:

Surgical reconstruction of open nerve injuries should be carried out as a delayed primary suture.	**GoR B**

Explanation:

Open nerve injuries require time-consuming microsurgical reconstruction. The best possible outcome must be achieved by initial nerve restoration [27]. For this reason, these interventions should be undertaken as delayed primary surgery in the secondary phase on 5th-7th day [18, 101, 131]. Later secondary reconstruction leads to poorer outcomes [9, 58, 59, 70, 122]. It is helpful to identify the nerve stumps and mark as atraumatic during emergency surgery [20].

Compartment syndrome

Key recommendation:

If there is clinical suspicion of compartment syndrome in the hand, a pressure measurement device can be used to take a measurement.	**GoR 0**

Explanation:

If there is compartment syndrome, it is crucial to establish an early diagnosis because irreversible damage is done to musculature and nerves after 8 hours at the latest [133]. The diagnosis is made in the primary phase according to clinical criteria [54, 55]. Normal pallor and temperature in the fingers and the presence of distal pulses [10, 33, 51, 54, 77, 133] do not exclude compartment syndrome. The cardinal symptom of pain and pain-provoking muscle extension and sensitivity tests cannot be used in the multiply injured patient who is generally unconscious or analgesic sedated. Provided compartment syndrome has not already been clinically diagnosed, the definitive diagnosis can be established using a pressure measurement device [79, 89]. Compartment pressures exceeding 30 mmHg or, in the case of hypotension, exceeding the difference $p_{diastolic}$ - 30 mmHg are classed as critical values and indication for a fasciotomy in the unconscious patient [51, 73, 77, 133].

Key recommendation:

If manifest compartment syndrome is present in the hand, fasciotomy must be performed immediately.	**GoR A**

Explanation:

If the diagnosis of compartment syndrome has been established, an immediate fasciotomy is indicated. An early adequate dermatofasciotomy prevents ischemic contractures and represents an emergency intervention [33, 51, 54, 77, 133].

If compartment syndrome has been detected clinically or by using a device, all 10 compartments in the hand should be decompressed via 4 incisions whereas in the forearm a palmar fasciotomy is generally sufficient. In the forearm, the palmar fasciotomy is started as a parathenar carpal tunnel incision and continued up to the elbow by dividing the bicipital aponeurosis, whereby a median arch-shaped and a palmar-ulnar incision line are both equally effective [42, 133]. If this does not lead to a sufficient lowering in pressure in the dorsal compartment, additional decompression via a straight median incision line is required in the dorsal forearm [42, 89]. The 10 compartments in the hand must be decompressed via several incisions. The dorsal and palmar interosseous compartments can be accessed by dorsal incisions over metacarpals 2 and 4. The incision line for the thenar and hypothenar compartments is on the radial side of metacarpal 1 and the ulnar side of metacarpal 5, respectively [89].

The indication for fasciotomy on the fingers is made according to clinical criteria. As a pressure measurement device is not expedient for the fingers, the degree of swelling is used for establishing the indication for fasciotomy. The incision is made unilaterally, radial for the thumb and little finger and ulnar for the other fingers. Preference should be given to a mid-lateral incision line from the fingertip to the interdigital crease. While protecting the neurovascular bundle, the Cleland ligaments should be divided on both sides in the palmar flexor tendon canal [89].

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3.10 Lower extremity

Key recommendations:

In polytrauma among adults, isolated and multiple shaft fractures of long bones in the lower extremity can be managed both with primary definitive as well as primary temporary and secondary definitive osteosynthesis.	**GoR 0**
As an exception, isolated closed shaft fractures of the tibia can also receive primary temporary stabilization with a plaster cast.	**GoR 0**

Explanation:

There are 2 contradictory treatment strategies for isolated shaft fractures of the long bones in the lower extremities: a) primary definitive osteosynthesis and b) the two-step osteosynthesis with secondary definitive management. Out of 65 controlled studies published on the femoral shaft fracture in polytrauma (from 1964 through 2008; with n = 18 to n = 1582 documented patients), there were 10 studies with prospective or randomized study design. However, the majority of papers were based on retrospective-clinical data. In addition to the main endpoint of case fatality rate, there were numerous subsidiary endpoints: complication rates (from pseudarthrosis rate to incidence of sepsis and organ failure), number of days in situ in the intensive care unit, ventilation parameters, cardiopulmonary changes, and length of stay in hospital. Only a few authors substantiated their treatment regimens with prospectively collected laboratory chemical findings. No paper focused on the later quality of life of the patient in the decision criteria. A late management of long bones was preferred in 20 papers whereas 37 publications regarded early management as better. Eight authors were undecided. In addition, many authors emphasized that there are certain patient groups (patients with chest and/or brain injuries) in which a method is specifically indicated or contraindicated. Specific controlled studies on the isolated lower leg fracture management strategy in polytrauma were not identified. In summary, it must be stated that the results of the literature analysis on isolated upper and lower leg shaft fractures are contradictory and do not permit any generally valid conclusion.

To date, there have been few scientific studies on the management strategy for multiple femur and lower leg shaft fractures in multiply injured patients. Although the alleged incidence of multiple femur and lower leg shaft fractures of 2-7% is suggestive of its clinical importance, there are few references to this in the literature. There was only 1 study with a prospective design (8 patients) out of 72 papers listed in the databases (MEDLINE, The Cochrane Library, and Knowledge Finder, as at 1/2004) on the research question of the surgical strategy for bilateral fracture of the lower extremity. The majority of papers were based on retrospective-clinical data (n = 42, 4–222 patients) and also case reports (n = 29). In addition to the main endpoint of case fatality rate, there were numerous subsidiary endpoints such as complication rates, number of days in situ, and concomitant injuries. The vast majority of authors see the advantages of early stabilization of fractures but the procedure and timing still remain under dispute. The high proportion of pulmonary complications in the group of multiple medullary nailing (8.2% versus

62.5%) was noticeable in the only prospective study to date [206]. As a consequence of the results of this paper, the author recommends a multi-step management strategy. In their retrospectively collected data, other authors were unable to document any increased pulmonary risk such as that of (fat) lung embolism following multiple medullary nailings. On the other hand, others revealed a shortened convalescence and lower complication rate in surgically stabilized (pediatric) patients and advocate primary definitive stabilization. In summary, surgical stabilization is increasingly favored in the literature but the type and timing of surgical stabilization still remains a matter of controversy; a generally-valid conclusion cannot be made.

Within the context of polytrauma management, both isolated and multiple fractures of long bones of the lower extremity involve a clinically relevant research question which often has to be decided in everyday practice. Thus, there is an urgent necessity for additional prospective studies with appropriate study design to clarify the treatment strategy.

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendations:

Proximal femoral fractures in polytrauma can be stabilized by primary osteosynthesis.	**GoR 0**
In justified cases, a temporary joint-bridging external fixator can be indicated.	**GoR 0**

Explanation:

There are no controlled studies on the treatment of the proximal femoral fracture specifically in multiply injured patients. Studies cited below contain both patients with isolated femoral fracture and multiply injured patients with proximal femoral fracture [37, 103, 104]. Proximal femoral fractures are subdivided according to their location into intracapsular, extracapsular (trochanteric), and subtrochanteric fractures.

Femoral head fractures (Pipkin fractures) are rare and often associated with hip dislocations and/or acetabular fractures. Surgical management ranges from removal of small osteochondral fragments to refixation and reconstruction of the femoral head. Although femoral neck fractures are common in elderly people after relatively trivial trauma, in young people they are mostly caused by a high energy trauma which is often associated with additional multiple injuries. The favored head salvage procedure is (cannulated) screw osteosynthesis [12, 93, 131, 133–135]. Prosthetic management is listed as equivalent [86, 133-135, 140, 152, 188]. In the meta-analyses conducted by Bhandari et al. [13] and Parker et al. [132, 136, 137], the osteosynthetic management of the isolated femoral neck fracture led to a considerably higher revision rate but the infection rate, blood loss, operating time, and trend in mortality [13] were higher in the group with joint replacement. To date, no advantage has been found for the bipolar prosthesis compared to total hip replacement [34, 39, 132, 136, 137].

The extracapsular fracture can be managed with extramedullary, fixed plate sliding hip screw (dynamic hip screw, Medoff sliding plate, etc.) or intramedullary procedure (proximal femur nail, gamma nail, etc.) [9, 29, 30, 38, 52, 65, 72, 73, 89, 99, 100, 102, 122, 130, 132–137, 139, 144, 194]. In general, surgical management of the proximal femoral fracture is regarded as the standard treatment [9, 24, 43, 54, 64, 101, 132, 136–138, 199].

There is no evidence in randomized studies on the timing of fracture management, and observational studies lead to differing conclusions [23, 45, 71, 138, 191]. Early surgical management (within 24-36 hours) after physiologic stabilization is recommended for most patients. The unnecessary delay in operating can increase the complication rate (decubitus rate, pneumonia). Emergency indications for surgery are: open fracture; fracture with vascular injury; fracture with compartment syndrome. If surgery has to be significantly delayed (> 48 hours), a joint-bridging external fixator can be temporarily (or, if applicable, permanently) attached. Complication possibilities: bleeding, infection, wound healing disorder, avascular necrosis in the femoral head, pseudarthrosis, rotational malposition, mobility restriction, prosthesis dislocation, thrombosis, embolism [128].

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendations:

For definitive management of a femoral shaft fracture in multiply injured patients, the first-line choice of surgical procedure should be locking medullary nailing.	**GoR B**

Explanation:

Surgical stabilization of the femoral shaft fracture is regarded as the standard treatment (see Key Recommendation 1). Emergency indications for surgery are: open fracture; fracture with vascular injury; fracture with compartment syndrome. In a hemodynamically stable situation (see “Emergency room management”), the focus is on early definitive osteosynthesis with the intramedullary nail being preferred by most authors as the gold standard [27, 33, 96, 198]. The central argument of the proponents of the medullary nail is the early weight-bearing capacity.

Nevertheless, in a retrospective study on 255 multiply injured patients with femoral fracture, Neudeck et al. [119] showed that, taking account of injury severity, injury pattern, and clinical course, only 29% of these patients could benefit from the advantage of early weight-bearing capacity after primary medullary nailing. Thus, the choice of primary surgical procedure (nailing versus plate osteosynthesis) in the multiply injured patient is also treated as a matter for debate by a few authors [6, 18, 20, 83, 90, 126, 159, 168, 174]. Bone et al. [18] showed that the incidence of pulmonary complications does not depend on the type of stabilization (nail/plate) of the femoral fracture but is solely caused by the lung injury. In a retrospective study on 217 patients with drilled femur nailing and 206 patients with plate osteosynthesis, Bosse et al. [20]

likewise found no differences in the incidence of lung failure (ARDS) in multiply injured patients with and without chest trauma. In a retrospective study for primary plate osteosynthesis, Auf´m Kolk et al. [6] also found evidence of no increase in case fatality rate and morbidity in patients with and without chest trauma (AIS thorax ≥ 3). In support of this, several animal models, including one by Wozasek et al. [200], found evidence of no significant pulmonary-hemodynamic effect between medullary nailing and plate osteosynthesis. There is no dispute surrounding the issue of fat embolization due to elevated intramedullary pressure as a result of medullary nailing, and there is evidence of this, particularly by echocardiography, in many clinical and animal experimental studies [145]. Ultimately, the question of clinical relevance still remains unclarified and thus also the question whether preference should be given to (non)drilled medullary nailing. Accordingly, several prospective randomized studies comparing drilled and nondrilled medullary nailing found evidence of no differences in the ARDS rate, pulmonary complications, and the survival rate [5, 35].

Open grade 3 femoral fractures with vascular involvement are regarded as contraindications of primary medullary nailing in hemodynamically stable patients [51, 119, 182]. In these cases, alternative procedures such as the external fixator are used as a type of stabilization [166].

Femoral shaft fractures are characterized by good callus formation and a low complication rate [26]. Ten to twenty percent of femoral shaft fractures are associated with ligamentous injuries in the knee joint. Complication possibilities are: bleeding, infection, wound healing disorder, avascular necrosis in the femoral head, pseudarthrosis, rotational malposition, mobility restriction, thrombosis, embolism.

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendation:

Unstable distal femoral fractures in polytrauma can be stabilized by primary surgery.	**GoR 0**

Explanation:

There are no controlled studies on the treatment of the distal femoral fracture specifically in polytrauma. Studies cited below contain both patients with isolated femoral fracture and multiply injured patients with distal femoral fracture. Surgical management of the distal femoral fracture is regarded as the standard treatment. Emergency indications for surgery are: open fracture; fracture with vascular injury; fracture with compartment syndrome. In a hemodynamically stable situation, the focus is on early definitive osteosynthesis. Depending on the fracture type, both intra-articular fractures and fractures without intra-articular involvement of the distal femur can be managed by open or closed reduction and osteosynthesis by means of a plate (Less Invasive Stabilization System [LISS], angled plate, etc.) or retrograde nailing [67, 79, 88, 125, 169, 179, 207]. A joint-bridging external fixator can be temporarily attached in a hemodynamically unstable situation or as part of a damage control strategy.

Complication possibilities: bleeding, infection, wound healing disorder, pseudarthrosis, rotational malposition, mobility restriction, thrombosis, embolism, early arthrosis.

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendations:

Knee dislocations must be reduced at the earliest possible opportunity.	**GoR A**
Knee dislocations must be stabilized at the earliest possible opportunity.	**GoR B**

Explanation:

There are no controlled studies on the treatment of knee dislocation specifically in polytrauma. Studies cited below contain both patients with isolated knee dislocation and multiply injured patients with knee dislocation. The highest management priority is given to any vascular injury (popliteal artery), which must be treated. The study by Green and Allen [56] with 245 patients with knee dislocation showed a vascular injury in 32% of cases. In 86% of patients who received vascular reconstruction beyond the 8-hour period, an amputation had to be performed; 2/3 of the remaining patients retained an ischemic contracture. Compartment release is recommended if the ischemia period exceeds the 6-hour limit and if there is a threat of compartment syndrome.

In the hemodynamically stable and unstable multiply injured patient, the knee dislocation should be reduced at the earliest possible opportunity. If closed reduction is not successful, the dislocated joint is open reduced [77]. In planned conservative treatment and in planned early cruciate ligament reconstruction, the stabilization of the reduction result can be carried out by means of external fixator and transfixation with Steinmann nail or with brace/plaster. According to expert opinion, the external fixator reveals advantages over other methods [91].

Ligamentous injuries after knee dislocation can be treated by surgery or conservatively. The meta-analysis by Dedmond and Almekinders [40] studied the results from 12 retrospective and 3 prospective studies on 132 surgically treated and 74 conservatively treated knee dislocations with respect to the clinical outcome. The surgically managed patients showed significantly better results in range of motion (123 ° versus 108 °), in the Lysholm score (85.2 versus 66.5), and a reduced flexion contracture (0.5 ° versus 3.5 °). Randomization of the treatment groups did not take place and the indication for surgical or conservative procedure is not substantiated. Two more retrospective studies also showed superiority in surgical compared to non-surgical treatment [113, 158].

Direct suture or cruciate ligament replacement is available for the surgical management of cruciate ligaments after knee dislocation. Regarding stability and range of motion, the retrospective study by Mariani et al. [105] with a small number of cases of knee dislocations showed superiority in anterior and posterior cruciate ligament reconstruction with patellar tendon or semitendinosus tendon compared to direct suture [105].

Key recommendation:

Unstable proximal tibial fractures and tibial head fractures can undergo primary stabilization.	**GoR 0**

Explanation:

There are no controlled studies on the treatment of proximal tibial fracture specifically in polytrauma. Studies cited below contain both patients with isolated proximal tibial fracture and multiply injured patients with proximal tibial fracture.

Primary management can be carried out by splint immobilization. Non-dislocated fractures are conservatively treated by decompression and functional treatment. If necessary, surgical fixation can be performed to prevent secondary dislocation. Surgical management of the dislocated proximal tibial fracture is regarded as the standard treatment [75, 114]. Rival procedures are plate systems (conventional, fixed-angle Less Invasive Stabilization System – LISS, etc.), tibia nails, screws, and fixator systems [10, 84, 121, 153], which are used depending on the complexity and joint surface involvement of the fracture. Requirements of osteosynthesis are the option for joint surface reconstruction and permanent fracture stabilization along with mobilization treatment while minimizing the perioperative soft tissue damage. In the case of minor dislocation, arthroscopically assisted, radiologically controlled reduction and percutaneous screw fixing can be carried out [58]. Emergency indications for surgery are: open fracture;

fracture with vascular injury; fracture with compartment syndrome. If necessary, an external fixator can be attached until the soft tissue conditions permit definitive management. In the hemodynamically stable situation, the focus is on early definitive elective osteosynthesis after initial subsidence in swelling (e.g., after 3-5 days). Tibial plateau fractures are associated with meniscus injuries in up to 50% of cases and with ligamentous injuries in up to 25% of cases [11].

Complication possibilities [205]: bleeding, infection, wound healing disorder, pseudarthrosis, rotational malalignment, mobility restriction, thrombosis, embolism, early arthrosis.

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendation:

Tibial shaft fractures should undergo surgical stabilization.	**GoR B**

Explanation:

There are no controlled studies on the best management procedure specifically for a tibial shaft fracture occurring in polytrauma. The core requirement is adapted management in relation to the overall condition. Due to the marginal soft tissue situation in the distal half of the tibia, the treatment strategy is often not dictated by the fracture per se but by the existing soft tissue situation.

Stable fractures with minimum dislocation can be conservatively treated with plaster immobilization [164]. Surgical management of the unstable tibial shaft fracture is regarded as the standard treatment, usually by intramedullary nailing [159, 197, 201]. Emergency indications for surgery are: open fracture; fracture with vascular injury; fracture with compartment syndrome. In a hemodynamically stable situation, the focus is on early definitive osteosynthesis. If surgery has to be significantly delayed (> 48 hours) or there is an extensive open injury with severe contamination, an external fixator can be temporarily (or if necessary permanently) attached [80].

In a meta-analysis by Bhandari et al. [15], the treatment of open tibial shaft fractures was studied. The results showed that, compared to the external fixator, non-drilled medullary nails reduced the risk of re-operation, pseudarthrosis, and superficial infection. A smaller re-operation risk was revealed with drilled nails in comparison with non-drilled nails. In a prospective randomized study, evidence was also found in closed fractures of a lower rate of secondary operations and pseudarthroses after a drilled medullary nail compared to a non-drilled medullary nail [94]. Tibial shaft fractures are associated with ligamentous injuries in up to 22% of cases. Complication possibilities: bleeding, infection, wound healing disorder, soft tissue necrosis with the necessity of a skin graft (dermatoplasty), pseudarthrosis, rotational malalignment, mobility restriction, thrombosis, embolism. Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendation:

Distal lower leg fractures including articular distal tibial fractures should undergo surgical stabilization.	**GoR B**

Explanation:

There are no controlled studies on the isolated treatment of the distal tibial fracture specifically in polytrauma. Studies cited below contain both patients with isolated distal tibial fracture and multiply injured patients with distal tibial fracture.

Surgical management of the distal tibial fracture is regarded as the standard treatment. Due to the marginal soft tissue situation in the distal tibia (and in the pilon), the treatment strategy is often not dictated by the fracture per se but by the existing soft tissue situation. Emergency indications for surgery are: open fracture; fracture with vascular injury; fracture with compartment syndrome. In a hemodynamically stable situation, the focus is on early definitive osteosynthesis. Distal tibial fractures without pilon involvement can be managed by medullary nail osteosynthesis. In addition to medullary nailing, fixed-angle plate osteosynthesis should be mentioned as a procedure option, particularly as an inserted plate. In the case of a distal fibular fracture as well, additional plate osteosynthesis of the fibula is recommended (in order to build a frame and to prevent distal axial deviation) [19, 41, 63, 97, 151, 155, 176, 186, 195]. In the case of pilon involvement, open reduction and osteosynthesis are regarded as the standard treatment [26, 69, 184, 202]. If the operation has to be significantly delayed (> 48 hours) (e.g., if there is severe swelling or open contamination), a joint-bridging external fixator can also be attached temporarily (or if necessary permanently), if necessary with percutaneous fixation of the joint surface (screws, K wires). Complication possibilities are: bleeding, infection, wound healing disorder, soft tissue necrosis with the necessity of a skin graft (dermatoplasty), pseudarthrosis, rotational malalignment, mobility restriction, thrombosis, embolism, early arthrosis. Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendation:

Ankle fractures should undergo primary stabilization.	**GoR B**

Explanation:

There are no controlled studies on the isolated treatment of ankle fractures specifically in polytrauma. Studies cited below contain both patients with isolated ankle fracture and multiply injured patients with ankle fracture.

Surgical management in general and the type of osteosynthetic management of the fibula fracture depend not least on the rest of the injury pattern in the multiply injured patient. Thus, some authors prefer external fixation at an injury severity of ISS > 25 or 29 points and/or with a chest trauma of AIS > 3 [4, 118, 164]. In addition, the type of fracture determines the choice of osteosynthesis material.

Proximal fibula: In Maisonneuve injuries, the distal fibula should be surgically fixed to the tibia in the upper ankle [47]. Here, 2 syndesmotic screws should be attached as, being tricortical, these screws have 5-fold greater tear and rotational strength than the sole suture of the syndesmosis [55, 203].

Fibula shaft: High fibula fractures in terms of a pronation-eversion injury according to Lauge-Hansen type III or IV should be surgically managed (plate osteosynthesis). The complex dislocation mechanism may have additionally led to other bony (medial malleolus fractures) and ligamentous injuries (syndesmoses, medial/lateral capsular ligament apparatus) [157].

Distal fibula: “Stable” and “unstable” fractures must be differentiated between in isolated lateral malleolus fractures. “Stable” fractures are those at the level of the syndesmosis (Weber B1) and supination-eversion fractures type SE II according to Lauge-Hansen [25, 44, 156, 204]. A stable lateral malleolus fracture exists if there is no fibula shortening, no fracture dislocation > 2 mm, no axis deflection, and an intact posterior syndesmosis [44, 156]. Stable lateral malleolus fractures can be conservatively immobilized, e.g., in a plaster cast or orthotic device manufactured from synthetic material. Types of fracture that deviate from this must be surgically managed.

The type of osteosynthesis also depends on the concomitant soft tissue injury (contusion, swelling, compartment syndrome) [146]. In the case of relatively severe soft tissue damage or more complex types of fracture (e.g., dislocation fractures), the first goal must be external fixation irrespective of the extent of the remaining injuries in order to prevent imminent neurovascular damage [22]. In the case of stable lateral malleolus fractures and lateral malleolus fractures that have been made stable by osteosynthesis, a follow-up treatment strategy that provides early functionality and early weight-bearing capacity shows a significant improvement in the ankle’s range of motion and requires a shorter rehabilitation phase [148].

Please refer to the introductory section of the emergency surgery phase for the risk assessment (damage control) of a multiply injured patient as a decision aid in the fracture management strategy.

Key recommendation:

Perioperative antibiotic prophylaxis must be carried out in the surgical management of both close and open fractures of the lower extremity.	**GoR A**

Explanation:

In open fractures, there is preoperative bacterial contamination in 48-60% of all wounds and in 100% of all severe wounds [98].

Antibiotic administration in closed fractures:

In the surgical management of closed fractures, the administration of antimicrobial prophylaxis (normally a single shot of a long-acting first-generation cephalosporin) is generally recommended when implanting foreign material [3, 78]. There is EL 1 data on the management of femoral neck fractures which confirm a significant reduction in postoperative wound infections through perioperative antibiotic treatment [21, 31, 32, 78]. The Cochrane Review of 2003, which analyzes data from 8,307 patients from 22 studies, reveals a significant reduction in postoperative wound infections as well as also in infections of the genitourinary and respiratory tracts by preoperative single shot antibiosis during the surgical management of fractures to the long bones. Both in the Cochrane Review by Gillespie et al. [53] and in the meta-analysis by Slobogean et al. [173], no evidence could be found of further advantages from multi-dose compared to single shot antibiosis.

Antibiotic administration in open fractures:

The presence of open fractures provides sufficient evidence that antimicrobial prophylaxis should be carried out. According to the guideline of EAST (Eastern Association for the Surgery of Trauma), in addition to careful wound debridement - if possible within 6 hours of the trauma - it is recommended that coverage of gram-positive organisms is also started as early as possible. For fractures of grade 3 according to Gustilo, additional treatment for gram-negative triggers and also high-dose penicillin should be administered for farm-related injuries as a prophylaxis against clostridial infections. The treatment should be continued up to 24 hours after primary defect covering. With grade 3 fractures, the antibiotic treatment should be continued up to 72 hours after the trauma and not more than 24 hours after soft tissue has been covered [98]. As with a series of other studies [68], Dellinger et al. [42] could not show any significant difference in infection rate in 248 patients in relation to the period of antibiotic prophylaxis (1 versus 5 days).

Although some authors recommend the administration of antibiotic-impregnated beads for local infection prophylaxis in addition to i.v. antibiosis, there is no supporting literature of EL 1 on this either [68, 70, 124, 170].

Key recommendation:

Provided the severity of the overall injury permits, the surgical management of vascular injuries in the lower extremity should be carried out at the earliest possible opportunity, i.e. directly after treating the injuries threatening the vital functions.	**GoR B**

Explanation:

There are only few confirmed data on the incidence of arterial and venous vascular injuries of the lower extremity in multiply injured patients. There is wide variation worldwide among the individual collectives in degree of severity, the mechanism of generation, the location of the vascular injury (and of the other injuries), and the quality of the preoperative diagnostic study and management [147, 177, 181, 185, 190]. The morphologic damage to the vessels in relation to the mechanism of generation is accurately described in its importance for the type of management [192].

The management recommendations listed here are based predominantly on the experiences and recommendations of experts who have published their results and conclusions from individual collectives. Only one publication is based on a controlled randomized trial [193]. However, the published recommendations from different subdivisions of trauma surgery and vascular surgery permit only qualified conclusions on the treatment of severe injuries in the lower extremity with vascular involvement in multiply injured patients. Ultimately, therefore, it is an individual decision for the individual patient.

Provided the severity of the overall injury permits, the surgical management of arterial and venous injuries in the lower extremity should also be carried out in multiply injured patients at the earliest possible opportunity, i.e. directly after treating the injuries threatening the vital functions. There is no consensus in the literature on whether a fracture must be stabilized first followed by vascular reconstruction or whether the reverse sequence is advantageous. Discussion also surrounds interim solutions (primary shunt insertion to preserve blood supply, fracture stabilization and later definitive vascular reconstruction or in terms of damage control through to physiologic recompensation of the patient after severe trauma) [81, 108, 117, 120, 123, 127, 143, 180]. In complex trauma with a high prediction probability of vascular injury, primary vascular revision should be carried out with, if necessary, immediate vascular reconstruction [193]. The resources, principles of surgery, and operative techniques available correspond to those for non-trauma-induced management of arterial and venous reconstructions and partly exceed the indication range.

Arterial injuries of the iliac and femoral vessels should be reconstructed and are usually technically easily accessible. An isolated crural artery injury can be ligated if the openness of the other distal main arteries is confirmed. If at least 2 vessels are affected, there is almost always a critical vascular disorder which requires primary revascularization. The combination with venous injuries increases the amputation rate, which is why the indication for venous reconstruction should be made broadly in combination injuries [50, 177, 181]. Arterial injuries of the lower extremity should be managed (in descending order) by means of direct suture, insertion of a continuity-preserving anastomosis, patch angioplasty (autologous, synthetic material) or bypass reconstruction (autologous, synthetic material, composite) [46, 190]. Venous injuries of the lower extremity should be managed (in descending order) by means of patch graft, autologous vein interposition graft, PTFE (polytetrafluorethylene) interposition graft or primary ligature [1, 111, 129, 141, 142, 154, 183].

The indication for fasciotomy should be made early; if necessary it should be carried out even before vascular reconstruction [49, 177].

Endovascular treatment of arterial injuries represents another option for managing arterial injuries of the lower extremity even in the multiply injured patient. Established procedures applied proximal to the extremity (coiling, covered stents) can also be used peripherally in individual cases. The goal can even be temporary revascularizations until definitive surgical management [106, 116, 149, 167].

Key recommendation:

In the case of compartment syndrome in the lower extremity, immediate compartment decompression and fixation of a concomitant fracture must be carried out.	**GoR A**

Explanation:

Compartment syndromes in relation to fractures of long bones in the lower extremity and particularly in the tibia are not rare. Due to the deleterious sequelae within a few hours, however, they require rapid decompression (fasciotomy) during fracture stabilization. Van den Brand et al. [187] even support prophylactic versus therapeutic fasciotomy. Establishing an early diagnosis is essential if there is compartment syndrome because irreversible damage to musculature and nerves results after 8 hours at the latest [196]. The diagnosis is made in the primary phase according to clinical criteria [74]. Normal pallor and skin temperature and the presence of distal pulses [66, 74, 115, 196] do not exclude a compartment syndrome. The cardinal symptom of pain and pain-provoking muscle extension and sensitivity tests are not usable in the multiply injured patient who is generally unconscious or analgesic sedated. For this reason, according to Rowland et al. [162], the definitive diagnosis must be established using a pressure measurement device. Compartment pressures exceeding 30 mmHg or, in the case of hypotension, exceeding the difference $p_{diastolic}$ - 30 mmHg are classed as critical values and indication for fasciotomy [66, 92, 110, 115, 196]. If the diagnosis of compartment syndrome has been established, immediate fasciotomy (emergency intervention) is indicated [66, 74, 115, 196]. All 4 compartments in the lower leg should be opened. The prognosis depends on the totality of the injuries and is most favorable in the case of isolated compartment without fracture. If there is a concomitant fracture, stable osteosynthesis should be carried out in addition to the fasciotomy. The preferred stable osteosynthesis is intramedullary nailing [48, 189] as, compared to other procedures, it causes the least irritation to the soft tissue and avoids the necessity of pin transfixation of the tissue. In a meta-analysis by Bhandari et al. [14], the drilled medullary nail was compared to the non-drilled medullary nail with regard to the relative risk of compartment syndrome. Although not significant (relative risk 0.45; 95% CI: 0.13-1.56), the authors concluded that the drilling of the medullary nail appears to lower the risk of compartment syndrome. Nevertheless, the conclusion of rapid action is based less on specific studies on compartment syndrome in polytrauma but rather much more on experience.

Key recommendation:

The decision to amputate or to salvage the extremity in the critical injury to the lower extremity should be made on an individual basis. The local and general condition of the patient plays a crucial role here.	**GoR B**

Explanation:

The critical injury to the lower extremity can represent a complex problem in the treatment of polytrauma. The critical decision between amputation and salvaging the extremity can be necessary here. The literature shows that loss of neurologic function is correlated with delayed amputation and increased morbidity as well as mortality [2]. Early amputation should be considered if there is a loss of function and sensitivity in the foot/extremity. Conversely, if there is function and sensitivity in the foot/extremity, the goal should be to salvage [2]. Thus, the focus should be on amputation for all patients, for example, with a type III-C fracture and a completely severed sciatic or tibial nerve. In the case of significant nerve severance, no studies have shown an advantage in salvaging the extremity compared to early amputation [17, 109, 163].

Vascular integrity increases the probability of salvaging the extremity [161]. The vascular disorder should be remedied as quickly as possible. An ischemic period of > 6 hours was correlated with irreversible nerve damage and loss of function [95, 178]. For logical reasons, necrotic extremities (or parts thereof) should be amputated. A delay in amputation leads to a significant increase in sepsis, immobility, number of surgical interventions required, mortality, and costs [17, 109, 163].

Many reports have been published about objective criteria for the decision to amputate or salvage the extremity [36, 57, 76, 85]. However, to date, no study could define guaranteed prediction instruments for this decision. Scoring systems (e.g., Predictive Salvage Index, Mangled Extremity Severity Score [MESS], Limb Salvage Score, NISSSA [Nerve Injury, Ischemia, Soft Tissue injury, Skeletal injury, Shock and Age of Patient] Scoring Index) can be used to supplement the clinical assessment. Thus, it is absolutely essential that an individual decision is taken for each patient and for each injury. The decision to amputate or to salvage the extremity should never be taken solely on the basis of a protocol or algorithm [16].

In summary, the primary and secondary amputation rate in injuries of the lower extremity (without them being predictable, e.g.,, through scoring systems) thus depends on the number and location level of the simultaneously injured arterial and venous vessels, the injured nerves, the overall severity of the injuries, and the extent of the concomitant soft tissue damage [7, 49, 50, 82, 87, 107, 112, 123, 150, 171, 172, 175, 177, 181, 190].

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3.11 Foot

The affected patients often have residual pains and restricted function in the foot after polytrauma management requiring a high level of staff and material resources. The reasons for foot injuries in polytrauma being missed or underestimated are more eye-catching and life-threatening injuries, deficient radiography technique in the emergency situation, extremely variable clinical standards in the analgesic sedated patient, lack of experience on the part of the examiner in less common foot injuries, and breakdown in communication in the treatment of the multiply injured due to several teams working together [45, 60].

The number of studies with relatively high evidence on the topic of management of foot injuries in the multiply injured patient is remarkably small. This is all the more remarkable as the presence of foot injuries has a significant negative influence on the prognosis of multiply injured patients [84]. For the reasons cited, repeated attempts have been made to compile experience-based treatment guidelines for these patient groups [52, 60, 76, 77, 92, 93], which, in the absence of controlled studies, form the basis of the following draft. The aim of this guideline section is therefore to provide an aid based on the available study data for the timely and appropriate treatment of foot injuries which is adapted to the extent of injury in the multiply injured patient.

Emergency indications

The necessity of emergency management of open fractures, neurovascular injuries, compartment syndrome, and an extreme soft tissue hazard is no different from the emergency indication in the remaining skeletal sections [16, 76, 77]. Accordingly, reference is made to the appropriate guideline parts.

Topographic features in the foot arise from the danger of avascular necrosis even in closed dislocation fractures of the talus [15, 25, 34, 77], to a lesser degree also of the navicular bone [70], and in Lisfranc dislocation fractures and calcaneus fractures, which hold an increased danger of compartment syndrome [46, 51, 54, 64, 94]. In addition, the closed reduction of dislocation fractures of the talus and of the Chopart and Lisfranc joint is only possible in exceptional cases. The cited injuries should be managed immediately following the initial stabilization of the multiply injured patient.

Compartment syndrome in the foot

Key recommendations:

If a manifest compartment syndrome is present in the foot, a fasciotomy must be performed immediately.	**GoR A**
If there is clinical suspicion of compartment syndrome in the foot, a pressure measurement device can be used to take a measurement.	**GoR 0**

Explanation:

Calcaneus fractures, Lisfranc dislocation fractures, and in general severe crush injuries are particularly at risk from compartment syndrome [39, 46, 51, 54, 76]. Most authors recommend a fasciotomy from a threshold of 30 mmHg [47, 50, 51, 87]. In contrast to the lower leg, other authors recommend compartment splitting even from a threshold of 25 mmHg as blisters develop more rapidly on the foot and the tolerance of the small foot muscles and terminal branches of the nerves and vessels is less compared to comparable pressures in the lower leg [93, 94].

In compartment syndrome of the lower leg, attention should be paid to a concomitant foot compartment syndrome as established by Manoli et al. [40] in a series of 8 cases. There were multiple injuries in 7 out of 8 cases. In experimental and clinical studies, both the dorsomedial and the medial fasciotomy (modified Henry approach) permit sufficient decompression of all foot compartments [40, 50]. In addition, 2 parallel dorsal incisions and a “three-incision decompression” with additional plantar fasciotomy are described which, however, offer no obvious advantage.

Open injuries

Soft tissue damage in the foot has a crucial effect on the functional outcome [26, 27, 86]. Aggressive debridement of contaminated and hypoperfused tissue and early soft tissue covering are essential in the treatment of open fractures in the foot in order to prevent prolonged infection courses [12, 16, 27, 35, 74, 75, 96].

Bones, joint cartilage, and tendons are at risk even if there is primary vitality if they are not sufficiently covered by tissue. Artificial skin products can guarantee a temporary closure if a secondary skin closure is expected after swelling has subsided and consolidation of the soft tissues or an additional *second look* is necessary due to severe contamination (farm-related injuries) [29]. Secondary split thickness skin grafts are suitable for superficial defects in non-weight-bearing regions. These require a clean (not sterile) wound surface without exposed bones, joint cartilage or tendons. In children, the requirements for the wound surface are disproportionately less [1]. The problems of marginal hyperkeratosis in the border region between transplant and local foot skin are still unresolved [13]. In *degloving* injuries, the upper layer (approx. 0.3 mm) of the hypoperfused and potentially avitalized abraded skin can be detached with the dermatome and be used for covering adjacent sections with vitalized wound substrate (*split-thickness skin excision* [89]). In addition, the extent of bleeding after raising the transplant permits a reliable conclusion to be made on its viability.

Multi-layer defects require a local or free flap transfer [35, 44, 68]. The flap choice here depends on the size of defect and the blood supply pattern and takes into account the functional-anatomic foot zone divisions and the *like with like* principle [1, 28, 44]. Local pedicled flaps are suitable for covering smaller lateral, medial or plantar defects due to their limited action range [20]. Free flaps with microvascular anastomosis require an intact attachment point and attention must be paid to the type of shoe and cosmetic aspects in addition to technical feasibility [66]. Preoperative angiography (if necessary also phlebography) should generally be carried out [35]. More extensive defects on the flat dorsum of foot benefit from free fasciocutaneous flaps whereas deep, contaminated defect cavities need to be filled with muscle flaps covered with split thickness skin grafts (e.g., latissimus dorsi). The latter are less bulky than myocutaneous flaps [41]. The pedicle-rotated sural flap is a suitable *salvage procedure* in inadequate main vessels [6, 12, 38].

Even in successful extremity salvage, considerable functional deficits often remain after open pilon, talus, and calcaneus fractures [27, 68, 73]. This is partly explained by arthrogenous and tendogenic fibroses with corresponding mobility deficit after the necessary longer immobilization. In open grade 2 and grade 3 lower leg fractures, early defect covering with free flap transfer is a proven technique compared to delayed covering [11, 17, 19]. In this regard, reference is made to the section “Open and closed soft tissue damage to the extremities”.

The experiences with the foot are fewer due to smaller patient numbers. In initial series, patients with larger, contaminated defects due to open foot trauma achieved good functional outcomes through early flap coverage within 24-120 hours with primary stable osteosynthesis [12, 48]. However, this procedure is only possible in a patient in a stable general condition; in terms of an optimum functional outcome, all reconstructive options should then be exhausted for the multiply injured patient as well [56].

As with open fractures in other extremity sections, a single shot antibiotic prophylaxis is also recommended for open fracture in the foot to supplement the surgical debridement; depending on the expected, predominantly gram-positive bacteria range, first or second generation cephalosporins or an antibiotic with comparable effect range in terms of the calculated antibiosis are used [10, 14, 24, 27, 52, 53].

Complex trauma of the foot

Key recommendations:

The decision to amputate the foot should be made on an individual basis.	**GoR B**
Replantation of the foot generally cannot be recommended in polytrauma.	**GoR 0**

Explanation:

The definition of complex foot trauma is based both on the regional extent of the injury across the 5 anatomic-functional levels of the foot and on the extent of soft tissue damage [92]. According to Tscherne und Oestern [81], 1 point is awarded for each injured foot region and for each grade of soft tissue damage; the definition of a complex foot trauma is when 5 or more points are awarded. The absolute score simultaneously permits a prognostic statement [92].

If there is complex foot trauma, the criteria for amputation in relation to the overall injury severity in polytrauma are not defined precisely. Tscherne [81] recommends primary amputation with a PTS value (Hannover polytrauma key [65]) of 3-4, and an individual decision if the PTS is 2. Validated scores such as the Hannover fracture scale (HFS [83]), the MESS (Mangled Extremity Severity Score [32]) and the NISSSA Score (Nerve Injury, Ischemia, Soft Tissue Injury, Skeletal Injury, Shock and Age of Patient Score [43]), the Predictive Salvage Index (PSI) [30], and the Limb Salvage Index (LSI) [67] offer a certain amount of help in decision-making. In a prospective multicenter study on 601 patients with complex injuries of the lower extremity (Lower Extremity Assessment Project [LEAP]), a high specificity of all scores (HFS, MESS, NISSSA, PSI, LSI) was found but with low to moderate sensitivity [7]. This means that a low score can certainly reliably predict limb salvage but a high score is not predictive for an amputation. The authors therefore warn against an uncritical application of the scores in deciding in favor of amputation [7]. In addition, such scores cannot replace in particular individual consideration of the overall course in the polytrauma and the specific local injury pattern in the foot [94, 95].

In addition to general criteria such as age, concomitant diseases, and concomitant injuries, the following points regarding the foot are important in the decision to amputate: the loss of large parts of the sole of the foot with its unique chambered profile cannot be replaced by equivalent tissue and is potentially more serious than defects on the dorsum of foot. Vascular injuries endanger the vitality of distal foot sections and make the restoration of foot function considerably more difficult [8, 23, 72, 94]. The loss of the protective sensitivity of the sole of the foot due to a traumatic tibial nerve lesion involves a greater potential for soft tissue-induced late complications even if sensitivity can be regained within 2 years in about half the cases of blunt injury of the tibial nerve [9].

Severe comminutions of the bony foot skeleton and joint destruction which necessitate primary arthrodesis to support osteosynthesis potentially lead to a more rigid foot with non-physiologic pressure distribution on the sole of the foot, which is often compromised by the trauma anyway. The traumatic loss of the talus or its joint surfaces through the necessary tibiotalar, tibiotalocalcaneous or pantalar arthrodesis leads to a rigid foot with considerable functional impairment even if bones and wounds heal without problems [21, 68, 70]. In all cited cases, the indication for amputation should be verified early even if there are no life-threatening concomitant injuries [23, 52, 68]. In these cases, the Pirogoff amputation at least still permits the original sole of the foot to bear weight; it is also suitable in critical blood supply conditions [92].

In the LEAP Study on 8 North American Level I trauma centers, the most important amputation criteria in severe high-energy injuries of the lower leg and foot were severe muscle injury (OR 8.74), severe vein injury (OR 5.72), absence of plantar sensitivity (OR 5.26), open foot fracture (OR 3.12), and absence of foot pulses (OR 2.02). Patient-related factors that influenced the decision in favor of amputation were hemorrhagic shock and concomitant diseases whereas the general injury severity (ISS) had no significant influence in this series [78].

In contrast to the vascular-surgical principles of waiting until hypoperfused extremity sections are demarcated, an early decision on the final amputation level is recommended in fresh trauma for an early definitive soft tissue closure [92, 93]. In principle, there should be no blood arrest during surgery in order to assess correctly the vitality of bones and musculature [52, 63].

The experiences with replantation are disproportionately fewer in the foot than in the hand and are restricted to case reports and small case series [4, 5, 18, 88]. The outlook for successful replantation is markedly greater in children than in adults [3, 31]. Essentially, the attempt should only be undertaken if a plantigrade, stable foot with protective sensitivity of the sole of the foot can be regarded as a realistic endpoint of treatment without endangering the patient. Important criteria for successful replantation are an anoxia period of less than 6 hours and high patient compliance in the face of slow, difficult rehabilitation [18]. It is almost impossible to estimate these criteria in the multiply injured patient and replantation that lasts several hours within the critical ischemia period is generally not indicated due to the general condition of the patient [72].

Specific injuries

Key recommendation:

Dislocations and dislocated fractures of the tarsal bones and metatarsals should be reduced and stabilized as soon as possible.	**GoR B**

Explanation:

Central dislocation fractures of the talus (aviator's astragalus) are associated with a polytrauma with above-average frequency (according to the AO multicenter study in 52% of cases [34]). The relationship between the occurrence of avascular necrosis of the talus and initial dislocation extent has been confirmed in several large clinical series [15, 25, 34]. Closed reduction is only rarely possible in dislocated fractures of the talus, and repeated attempts damage the soft tissues which are compromised anyway. For this reason, the goal is immediate open reduction and (mostly minimally invasive) stabilization in dislocated fractures of the talus (if permitted by the general condition of the multiply injured patient) in order not to endanger further the vitality of the skin and the talus itself [15, 25, 62, 79]. The definitive management and osteosynthesis of minor dislocated talus fractures can be carried out later if the patient is in a stable general condition without there being an increased risk of avascular necrosis of the talus developing [36, 85, 86].

Calcaneus fractures with open wound, manifest compartment syndrome, and incarcerated soft tissues should be managed by emergency surgery. After the diagnostic study in the case of open injuries, initial debridement, if necessary artificial skin covering, temporary percutaneous Kirschner wire osteosynthesis or medial transfixation (each with a Schanz screw in the distal tibia, in the tuber calcanei and metatarsal I) are carried out to prevent soft tissue retraction [27, 63, 95]. In extensive, bony defects, insertion of PMMA (polymethyl methacrylate) beads is recommended. A second look operation must generally be carried out within 48-72 hours. The indication for early flap coverage should be made broadly [12, 48].

In closed grade 3 fractures with manifest compartment syndrome, the emergency dermatofasciotomy is performed in polytrauma via an extended dorsomedial approach with insertion of a triangular medial external fixator [63, 95]. The clinical relevance of the plantar calcaneal compartment, which has been presented in injection studies and in which an isolated increase in pressure can occur, is not finally clarified but the occurrence of hammer toe malalignments after isolated calcaneal fractures indicates this problem [39, 54, 96].

In the vast majority of fractures (closed soft tissue damage grade 1 and 2), osteosynthesis is recommended 6-10 days later after the swelling in the soft tissue has subsided [2, 58, 68, 71, 91, 95]. Elevating the extremity by more than 10 cm above the level of the heart is not recommended so as to prevent ischemia [16]. A good indicator for surgery time is the onset of skin creasing due to the subsiding edematous swelling [68]. A surgery time beyond the 14th day is associated with an increased risk of complications if no reduction and transfixing has been carried out initially [58, 80]. Local contraindications for osteosynthesis exist if there are critical soft tissue conditions with high risk of infection such as tension blisters and skin necroses and advanced arterial or venous vascular disorders; general contraindications are lack of compliance and a manifest immune weakness [58, 92, 95]. Conservative treatment is indicated in these cases due to the risk of wound healing disorders and deep infections.

Injuries at the level of the Chopart and Lisfranc joint are associated with multiple injuries with an above-average frequency (50-80%) [33, 64, 90]. They belong to the most commonly missed injuries of all, particularly in polytrauma [22, 33, 37, 57, 92].

The closed reduction of Chopart and Lisfranc dislocated fractures is generally not possible so that there is an indication for emergency surgery in most cases [37, 49]. Lisfranc dislocated fractures are also associated with an increased risk of compartment syndrome in the foot [51, 64]. If the general condition of the patient permits no definitive osteosynthesis, the goal is Kirschner wire transfixation and/or the insertion of a tibiometatarsal external fixator; definitive management should be carried out later [57, 61, 63, 93].

After stabilization of the general condition of the multiply injured patient, fractures of the metatarsals and toes can be managed later by osteosynthesis according to the general treatment principles; the above-cited general principles apply to open injuries of the forefoot [59].

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3.12 Mandible and midface

Securing the airways; bleeding

Key recommendation:

In mandible and maxillofacial injuries, primary securing of the airways and hemostasis in the oral and maxillofacial region must be carried out.	**GoR A**

Explanation:

The immediate securing of the airways and management of intense bleeding are vital to life [44]. There is often a danger of suffocation due to foreign bodies (e.g., dental prostheses, tooth and bone fragments, blood clots, mucus, vomit). This danger should be eliminated by manually cleaning the oral cavity and the throat and by suctioning the deeper airways [2]. If there is instability in the mandible as a result of comminutions or erosion of the middle piece, this can cause the tongue to fall back and displace the airways. The hazardous situation can be remedied by reduction and stabilization of the mandible with wire ligatures attached to available teeth [2]. If the airways in the craniocervical region are disabled by intense bleeding, tongue swelling and displacement, then intubation, a tracheotomy or coniotomy (cricothyroidotomy) is necessary depending on the urgency and feasibility [3, 28].

If larger vessels are affected (generally the origins of the external carotid artery), surgical hemostasis will be necessary. Open surgical hemostasis with vascular ligation and bipolar electrocoagulation or embolization with angiography is recommended [16, 18, 28]. The exact source of bleeding should be located for effective hemostasis [38]. Epistaxis is one of the commonest types of bleeding. Most bleeding can be arrested by primary compression using tamponades [26, 40]. In the case of persistent bleeding in the nasopharyngeal space, it is necessary to insert Bellocq packing or a balloon catheter [15]. In the case of bleeding from the maxillofacial region, particularly the maxillary artery, an attempt can be made to arrest the bleeding by compressing the maxilla dorsocranially against the base of the skull (e.g., spatula head bandage, dental impression tray with extraoral brace) [2]. In the case of sagittal maxillary fractures, compression can be necessary, e.g., by a transverse wire suture from the molars on one side to the molars on the contralateral side [2, 37]. Reduction and fixing of craniofacial fractures often represent the best causal treatment even for severe hemorrhages [15].

Soft tissue facial injuries

Key recommendation:

Soft tissue injuries should be managed during the emergency surgery phase.	**GoR B**

Explanation:

Injuries to the facial soft tissues occur either isolated in the form of abrasion, gash, cuts, crush, and defect wounds or in severe trauma in combination with craniofacial fractures. Gash and crush wounds are the commonest facial soft tissue injuries [43]. Soft tissue injuries, particularly those with exposed cartilage and/or bone surfaces, for example, should be managed at the earliest opportunity. Ideally, this can take place in the emergency room [20]. Rapid management of soft tissue injuries also contributes towards achievement of improved esthetic and functional outcomes [5, 17, 27, 31, 41, 45].

Appropriate hemostasis and cerebral decompression if there is intracranial pressure are the most important principles in the first hours after the trauma [24]. Craniofacial and soft tissue injuries are managed in the secondary phase [42]. In the case of combined soft tissue injuries with craniofacial fractures, definitive soft tissue management should be carried out after reconstruction of the bony structures if possible (“from inside to outside”) [22]. Functional structures such as eyelids, lips, the facial nerve, and the parotid gland should be reconstructed during primary wound management [39]. Gently cleansing the wound and removing foreign bodies should be carried out before reconstructive graft work so that good esthetic and functional results can be achieved later [21]. Bigger reconstructive measures or microvascular reconstructions are generally undertaken in two steps [32].

Tooth injuries, alveolar process fractures

Key recommendation:

The goal should be immediate management, if necessary rapid management of the tooth-alveolar process trauma.	**GoR B**

Explanation:

The treatment goal for tooth injuries and alveolar process fractures consists of restoring shape and function (esthetics, occlusion, articulation, phonation). This entails attempting to salvage both the tooth structure and the alveolar process.

The treatment depends on the general salvage worth and vitality of the teeth [1].

The prognosis for preserving a tooth long-term after avulsion depends on the length of time and storage of the tooth (e.g., cell culture medium/Dentosafe, cold milk, physiologic saline solution, oral cavity) until successful replantation [9, 10]. The most favorable replantation results can be achieved within the first 30 minutes [46]. Avulsed teeth, which have been preserved dry for several hours, have the most unfavorable prognosis although successful replantations have also been reported in individual case reports. For this reason, a replantation attempt after a longer interval can also be justified in individual cases [13].

Management of alveolar process fractures should also be undertaken at the earliest opportunity [6, 46].

Acute treatment should be carried out within a few hours for extrusion, lateral dislocation or avulsion of a tooth, an alveolar process fracture or a root fracture [1, 6]. Careful handling of the periodontal ligament and swift fixation via splints or splint bandaging protect from infections and permanent tooth loss [9, 10, 48].

Managing complicated crown fractures after 3 hours and uncomplicated crown fractures with exposed dentine after 48 hours worsen the prognosis of vital teeth [6].

Mandible and midface

Key recommendation:

Depending on the overall injury severity, maxillofacial and mandible fractures can be managed in the emergency surgery phase or secondary phase.	**GoR 0**

Explanation:

The treatment goal consists of restoring shape and function. Particular value is placed on restoring occlusion, articulation, joint function, esthetics, and motor and/or sensory nerve function. Treatment strategies, surgery techniques, and procedure are comparable with those for isolated fractures or combination fractures of the mandible and/or midface.

Ideally, maxillofacial and mandible fractures receive one-step early primary management [7, 36]. In maxillofacial fractures, early management with anatomic reduction and fixation led to a reduction in edema formation and better recontouring of the facial soft tissues [12, 23, 34]. However, the timing was very imprecisely stated by the authors with “immediately” or “within the first few days”. Bos et al. [4] require surgical management of maxillofacial fractures with open reduction and fixation within 48-72 hours in order to achieve a good esthetic and functional outcome and to avoid secondary corrections. Better reduction of bone fragments and faster healing and thus also more favorable esthetic results were observed in children with maxillofacial fractures who were operated on within a week after trauma [19].

With reference to a concomitant traumatic brain injury (TBI), the Glasgow Coma Scale (GCS) provides valuable information on the prognosis of the injured person. However, this does not mean that patients with a low GCS have to be automatically excluded from management of craniofacial fractures. Manson [23] reports that patients with head injuries can undergo surgery without increased complication rates provided that the intracranial pressure is kept below a value of 25 mmHg during the intervention. In a retrospective study on 49 patients with mandible and/or maxillofacial fractures with additional traumatic brain injury, Derdyn et al. [8] observed that patients with intracranial pressure below 15 mmHg after early surgical management (0-3 days after the accident) had comparable survival rates to comparison groups after medium-term (4-7 days) or later (> 7 days) surgical management. There were no significant differences in postoperative complications between the comparative patient collectives receiving early, medium-term, and late surgery. In contrast, craniofacially-injured patients with low GCS, intracranial bleeding, and shift in median brain structures after lateral and multisystem trauma had a significantly worse prognosis.

Due to improvements in functional and esthetic outcomes through the use of mini- and microplates and by less invasive surgical techniques [14], early management within 24-72 hours is becoming increasingly controversial.

If higher priority is given to the general condition or other injuries, then the definitive management of craniofacial injuries can be postponed by 7-10 days after the trauma event after management of soft tissue injuries and temporary stabilization (e.g., with splint bandaging, wire ligatures, splints) of fractures [7]. Ideally, soft tissue management and temporary stabilizations can take place in the emergency room [20].

In a retrospective study with comparable groups on a total of 82 multiply injured patients with mandible and/or maxillofacial fractures, Weider et al. [47] showed that delayed management (≥ 48 hours) did not lead to any extension in treatment time in the intensive care unit and in hospitalization. The infection rate was negligible and the complication rate comparable with that of patients who had been operated on within 48 hours. Schettler [35] did not observe any disadvantages in definitive management of maxillofacial fractures within 14 days. Neither infections nor residual disorders in eye motility were observed to a greater extent compared to immediate treatment. On the other hand, after the initial severe edema subsided, the complicated rejoining of even the smallest bone fragments was much easier to carry out. He regards the most favorable timing for definitive management as between the 5th and 10th day after the trauma. Kühne et al. [20] retrospectively analyzed a total of 78 patients with mandible and/or maxillofacial fractures who received surgery in the emergency room. There was a comparatively identical postoperative complication rate among the patients who received early primary (within 72 hours) or delayed (after 72 hours) surgery. The group of patients who received delayed surgery had a markedly higher overall injury severity than those who received early primary management.

Exceptions for delayed management are non-arrestable bleeding from fractures which require immediate reduction and osteosynthesis, and intraorbital or intracranial damage to the optic nerve, which necessitates therapeutic action within a few hours [7]. Retrobulbar hematomas, elevated eye pressure or direct compression on the optic nerve secondary to vision deterioration can necessitate the immediate introduction of a megadose of cortisone treatment over 48 hours (30 mg Urbason/kg BW i. v. as bolus and 5.4 mg Urbason/kg BW hourly over the following 47 hours) and/or immediate surgical decompression of the optic nerve [7, 11, 30, 46].

In injuries covering several disciplines, the appropriate specialist disciplines must be involved in the treatment planning and treatment [25]. Depending on the injury severity, the sequence of measures to be taken should be established on an interdisciplinary basis [20, 25, 47].

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3.13 Neck

Key recommendations:

Provided no intubation or tracheotomy has been carried out beforehand, all findings related to the airways must be examined and assessed before induction of intubation anesthesia.	**GoR A**
Intubation aids and a coniotomy set must be kept immediately available. Difficult airway algorithms must be heeded here.	**GoR A**
A coniotomy carried out previously must be surgically closed; if necessary, a tracheotomy must be carried out.	**GoR A**
Penetrating trauma to the esophagus should undergo primary reconstructive treatment within 24 hours.	**GoR B**

Explanation:

If the upper airways are involved in a polytrauma, intubation difficulties from swelling, displacement and/or secretion and blood are to be expected.

In the case of tracheal tears or avulsions or open tracheal injuries, surgical exploration with insertion of a tracheostoma or direct reconstruction is recommended [1]. The same applies to trauma in the region of the larynx.

There is controversy surrounding conservative treatment of tracheal tears. Conservative treatment can be considered for non-gaping, short-segment lesions that can be bridged by the tube [3]. The majority of studies argue in favor of surgical reconstruction at the earliest opportunity via transcervical approach, thoracotomy or, as an exception, a transcervical-transtracheal approach. The single-layer suture with absorbable material and single knot sutures is recommended [1, 2, 4–7]. The decision must be made on a case-by-case basis as to whether a tracheotomy in the conventional sense, in other words an epithelized tracheostoma, or a puncture tracheotomy is used. On the one hand, the exclusion criteria for a puncture tracheotomy must be heeded and, on the other hand, the risk of iatrogenic injury to adjacent structures [5]. The fact that cannula replacement is simpler is a particular advantage of the epithelized tracheostoma. In laryngeal trauma, attempts should be made to effectuate early reconstruction. There are no literature sources to be found which focus on a purely conservative treatment of laryngeal trauma [1, 2, 4–7], particularly against the background of preventing stenoses and voice disorders. In addition to removing stenoses and covering cartilage defects, the insertion of indwelling laryngeal stents for several weeks is recommended in order to prevent stenoses, strictures, and webbing [2, 4, 5].

An elective tracheotomy should be considered if ventilation treatment is expected to continue longer. Historical studies have shown that, even after 48 hours, orotracheal intubation can lead to irreversible damage to the larynx and tracheal cartilage with blood pressure, tube materials, and the use of vasoactive substances being important determinants. The main critical place is the cricoid cartilage; using modern cuffs (low-pressure high-volume), the risk of a tracheal stenosis can be lowered with simultaneous monitoring of the cuff pressure. Early tracheotomy thus serves primarily to prevent cricoid cartilage stenosis.

Damage to the recurrent laryngeal nerve or the vagus nerve can be most easily detected by evaluating vocal cord mobility using a laryngoscope (direct and indirect) or stroboscope. There is no evidence in the literature for emergency surgical treatment for a suspected recurrent paresis as part of polytrauma. Here, the focus is on confirming airway stenosis possibly caused by posttraumatic vocal cord paralysis. No studies have been found on traumatically induced laryngeal paralysis. The conclusions are based on postoperative pareses after struma surgery. Here, contradictory successes in surgical decompressions and reconstructions are reported. A noticeable improvement in the situation for the patient cannot be deduced from the literature. Following on from the endoscopic functional diagnostic study (laryngoscopy/stroboscopy), imaging procedures such as computed tomography can provide evidence on the location of the damage [9, 10].

As an alternative to surgery, conservative treatment using antibiotic protection can be considered for localized perforations lying in the cervical section of the esophagus [11]. According to case series, a direct suture of all layers within the first 24 hours offers the best prognosis for the clinical course [12, 13]. According to the literature, intrathoracic esophageal injuries should always undergo surgical treatment; no studies have been found which support conservative treatment. For esophageal perforations not accessible by direct suture, partial resections, if necessary with interposition grafts, are recommended [12-18]; alternatively, an endoluminal bond with fibrin adhesive can be considered. With all these recommendations, it should be noted that no clinical studies have been found, only case series and individual reports.

This should be carried out as surgical reconstruction, if necessary with interposition grafts of the arterial vessels. However, injuries not occluding the lumen can also be treated conservatively (e.g., dissections). A reconstruction of venous vessels must not be carried out/is not indicated.

Angiography, computed tomography and duplex or Doppler ultrasonography represent the first line choice of examination procedures for injuries to the neck vessels [21]; this applies without restriction in zones I and III according to Roon and Christensen [23]. Surgical exploration is additionally recommended for zone II. Although this is hotly debated in the literature, it is not in dispute that 100% of defects can be detected by this method and if necessary treated [21, 23]. The largest clinically controlled study is by Weaver et al. [24] and comes to the conclusion that reconstructions of arterial vessels offer the best outcome for penetrating injuries. The restoration of arterial vessels must be carried out within a timeframe of 120 minutes [20]. However, injuries not occluding the lumen can be treated conservatively with success by duplex ultrasonography monitoring [24].

In addition to a surgical intervention, there is also the possibility of neuroradiologic endovascular treatment for pseudoaneurysms or fistulas [19]. No studies have been found that support reconstruction of injured venous vessels [22].

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