Correction of deformities in children using the Taylor spatial frame

Mark Eidelman, Viktor Bialik and Alexander Katzman

The Taylor spatial frame is a unique external fixator. Despite its growing popularity, few reports on its use have been published. We evaluated the effectiveness of the Taylor spatial frame in the treatment of various deformities in 31 children and adolescents. All but one patient were anatomically corrected. Complications included superficial pin tract infection (45%), three fractures of the femoral regenerate, transient peroneal palsy, and injury to the genicular artery. Despite many challenging problems, our results compared favorably with the results achieved by others. We believe that the Taylor spatial frame is a very capable and accurate fixator for the precise correction of complex deformities. *J Pediatr Orthop B* **15:387–395 © 2006 Lippincott Williams & Wilkins.**

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Pediatric Orthopedics Unit, Meyer Children's Hospital, Rambam Medical Center, Haifa, Israel

Correspondence and requests for reprints to Dr Mark Eidelman, Pediatric Orthopedics Unit, Meyer Children's Hospital, Rambam Medical Center, POB 9602, Haifa 31096 Israel
Tel: +972 4 854 3181; fax: +972 4 854 2030; e-mail: markeid@yahoo.com

Introduction

The introduction of the Ilizarov method has been the main event in the field of deformity correction and limb lengthening in the last century [1–3], but correction of complex deformities (especially in multiple planes) remains difficult even with the Ilizarov external fixator. The Taylor spatial frame (TSF), a unique external fixation system introduced by Charles Taylor in 1994, dramatically changed our understanding and ability to correct deformities. Using computer software, TSF can correct the most difficult deformities and simultaneously correct six-axis deformities. This system is basically a circular external fixator, drawing on the foundation of the theory of projected geometry and the mechanical basis of the Stewart platform [4,5]. This very stable and accurate external fixation system has recently become popular throughout the world. In our opinion, the combination of a stable external fixation device and the accuracy of computer-based technology makes the TSF the treatment of choice in the precise correction of limb deformities.

The purpose of this study was to determine the effectiveness of the TSF for the treatment of various conditions in pediatric patients. In this paper, we review our early experience with the treatment of various conditions using the TSF in children and adolescents.

Basic principles of the Taylor spatial frame

The basic TSF construction consists of two full or partial rings connected by six telescopic struts attached at special universal joints. By adjusting strut lengths, one ring can be repositioned with respect to the other. TSF pre-planning includes calculation of three groups of parameters: deformity, mounting, and frame. Deformity parameters show the relationship between the origin and corresponding points. The origin is always located on the reference fragment (either proximal or distal). Corresponding points, therefore, are always located on the moving fragment. In most cases, deformity parameters can be calculated on the basis of the preoperative X-rays. Deformity parameters include anteroposterior and lateral views of angulation and translation, axial view angulation, and axial translation (which determines shortening or lengthening of the given case). Rotational deformity is determined by clinical examination. Mounting parameters reflect the relationship between the reference ring (the ring applied to the reference fragment) and the origin. Frame parameters define information on the diameters of the rings and lengths of the struts. Lastly, the surgeon chooses the structure-at-risk (the structure that will undergo the most risky elongation during deformity correction) and safe velocity correction (usually about 1 mm per day).

Patients, methods, and technique

From January 2003 until June 2005, we operated on 31 patients (22 boys, 11 girls), using 44 frames. TSF was applied on 27 tibiae, 13 femora, one radius and three feet. Mean age of patients at the time of the surgery was 12.2 years (range, 3.5–17 years). Eight patients had complicated fractures, four had malunions with subsequent growth arrest, four suffered from Blount disease, two had skeletal dysplasias, and two had a congenital short femur and tibia; there were three patients with knee flexion contractures, one with a clubfoot, and seven with various deformities of the lower limbs (Table 1). Before surgery, all patients had radiographic evaluation of mechanical axis deviation and deformity parameters.

Table 1 Patients' characteristics

Patient	Age (years)	Diagnosis	Site	Bilateral	Operation/osteotomy	Angular deformity	Rotational correction	Lengthening	Time in frame (weeks)	Complications
1. S.I.	14	Blount disease	Tibia		Proximal tibial osteotomy without fibular osteotomy	Proximal tibial varus 20°	5° internal tibial torsion (ITT)	10 mm	12	Bleeding after injury of genicular artery by half-pin; superficial pin tract infection
2. K.L.	17	Blount disease	Tibia	Yes	Proximal tibial osteotomy without fibular osteotomy	Proximal tibial varus 15°/18°			14	Superficial pin tract infection
3. K.M.	13	Blount disease	Tibia		Proximal tibial osteotomy without fibular osteotomy	Proximal tibial varus 18°	10° ITT	10 mm	12	Superficial pin tract infection
4. M.A.	14	Blount disease	Tibia	Yes	Proximal tibial osteotomy without fibular osteotomy	Proximal tibial varus 20°/16°	10° ITT		12	
5. J.B.	8	Growth arrest of ankle + most foot joints; 40 mm shortening, severe valgus	Tibia		Supramalleolar osteotomy of distal tibia, lengthening	38° distal tibial valgus; 20° recurvatum		40 mm	12	
6. A.L.	15	Congenital short femur + fibular hemimelia	Femur + tibia	Femur + tibia	Distal femoral osteotomy and proximal tibial osteotomy	8° distal femoral varus; 6° proximal tibial valgus		40 mm femur; 40 mm tibia	20	Delayed union of femoral site
7. N.E.	12	Spondyloepiphyseo-metaphyseal dysplasia	Femurs + tibia	Bilateral femurs + tibia	Bilateral distal femoral + proximal tibial osteotomy	20° right distal femoral varus; 30° left distal femoral varus;10° tibial recurvatum	30° ITT (internal tibial torsion)	50 mm bilateral	20	Fracture of regenerate of right femur after removal of fixator
8. H.U.	16	DDH; Distal femoral valgus and shortening	Femur		Distal femoral osteotomy	11° distal femoral valgus		25 mm	9	
9. K.B.	16	Growth arrest of tibia + 8 cm shortening	Tibia	3 rings construction	Double level osteotomy of the tibia	21° proximal tibial varus + 9° distal tibial varus		80 mm	24	Superficial pin tract infection
10. H.S.	6	Congenital short femur + fibular hemimelia	Femur		Distal femoral osteotomy			50 mm	20	Fracture of femur after fall
11. M.O.	7	Fibrous dysplasia; Distal femoral varus shortening	Femur		Distal femoral osteotomy			25 mm	12	Pin tract infection
12. K.S.	10	Displaced tibial fracture	Tibia		Application of TSF	5° tibial varus correction + 7 mm translation			7	
13. H.R.	8	Nonunion of midshaft of tibia (tibial displacement)	Tibia		Application of TSF	6° tibial varus + 11° procurvatum			12	Delayed union, additional 2 months in cast
14. G.O.	9	Distal femoral fracture, SP ORIF by plate, break of the plate	Femur		Removal of plate, application of TSF, gradual reduction	3° distal femoral varus + 18° procurvatum			8	Superficial pin tract infection
15. H.M.	14	Displaced distal tibial fracture, compartment syndrome; malalignment in Ilizarov frame	Tibia		Application TSF to the Ilizarov + gradual reduction of fracture	6° of distal tibial valgus; 4 mm translation			8	Superficial pin tract infection
16. A.T.	6	Open displaced distal tibial fracture	Tibia		Application of TSF	10° tibial varus + 11 mm translation			8	
17. B.Y.	14	Open displaced distal tibial fracture	Tibia		Application of TSF	12° distal tibial varus			14	Delayed union
18. H.S.	13	Open displaced midshaft fracture; delayed union (8 weeks after fracture)	Tibia		Application of TSF + fibular osteotomy	9° tibial varus + 9 mm translation		10 mm	14	Transient peroneal nerve palsy
19. N.N.	16	Rickets	Femur		Distal femoral osteotomy	14° varus; 33° procurvatum		10 mm		

20. G.R.	16	Tibial malunion (recurvatum and varus)	Tibia		Osteotomy and gradual reduction	7° varus + 16° recurvatum		8 mm	11	Superficial pin tract infection
21. B.N.	13	Proximal tibial valgus (Cozen phenomena)	Tibia		Proximal tibial osteotomy and distal fibular osteotomy	14° valgus			9	Superficial pin tract infection
22. T.T.	16	Osteogenesis imperfecta; excessive external tibial torsion	Tibia		Supramalleolar tibial osteotomy and gradual derotation		70° external tibial torsion		12	Superficial pin tract infection
23. H.D.	14	Severe bilateral genu valgum	Femurs + tibia	Bilateral femurs + tibia	Bilateral distal femoral + proximal tibial osteotomy	14° valgus of right femur; 13° valgus of left femur; 8° valgus of right tibia			14	Fracture of right femur after removal of frame
24. B.A.	14	Proximal tibial valgus	Tibia		Proximal tibial osteotomy of the tibia	13° valgus			9	Superficial pin tract infection
25. S.I.	13	Malunion + growth arrest of radius	Radius		Distal radius osteotomy + gradual correction of deformity	12° radial inclination + 7° volar tilt		15 mm lengthening	9	Superficial pin tract infection
26. H.I.	16	Schmid-type skeletal dysplasia	Femurs + tibia	2 rings on femur	Double osteotomy of femur + mid-tibia osteotomy	Acute correction of proximal femur; 20° distal femoral valgus + 9° procurvatum; 15° tibial valgus + 8° procurvatum	15° ITT		13	Residual deformity on the femur
27. A.O.	13	Unilateral internal tibial torsion + genu varum	Tibia		Proximal tibial osteotomy of tibia	45° ITT			12	Pin tract infection
28. A.Y.	3.5	Arthrogryposis; Flexion contracture knee	Knees and feet	4 rings contrac-tures	Full popliteal release + gradual correction of knee flexion contracture and clubfeet				13	Intraoperative femoral fracture over half pin
29. R.B.	4	Myelomeningocele; paralytic knee flexion contracture + clubfoot	Knee + foot	2 rings construc-tion	Full popliteal release + gradual correction of knee flexion contracture and clubfoot				12	Superficial pin tract infection
30. H.O.	5	Clubfoot; equinus + internal tibial torsion	Foot		Foot derotation and equinus correction	25° ITT			16	Talus subluxation
31. A.I.	12	Post-lengthening knee flexion contracture	Knee		Gradual distraction				8	

TFS, Taylor spatial frame.

We always applied the reference ring first. We tried to put this ring perfectly orthogonal to the reference fragment. The center of the reference ring is marked by two long bolts on the anteroposterior and lateral views for easier determination of mounting parameters. Osteotomy was performed after completion of fixation and application of all six struts. When using a Gigli saw osteotomy, only two anterior struts are removed; otherwise all struts should be removed and reapplied after completion of the osteotomy. All deformities were analyzed using a total residual program; in one patient with a fracture, the first ring method was employed.

The patients received a program schedule and usually started with strut adjustment after the sixth post-operative day (if an osteotomy was performed). In all other cases (correction of fractures, flexion contractures, etc.), correction was initiated the day after surgery.

Results

All frames were removed by the time of manuscript preparation. Mean follow-up after removal of the frame was 9 months. Mean time in the frame was 12.5 weeks (range, 8–20 weeks). All patients were re-examined and long X-ray views were obtained. We performed 11 distal femoral osteotomies and 20 tibial osteotomies (two supramalleolar, two mid-diaphyseal, and 16 proximal tibia osteotomies). Three fractures of the femoral regenerate were noted. Two patients underwent nailing of the femora and one was treated by application of a spica cast.

Superficial pin tract infections occurred in 14 (45%) patients. One patient had undercorrection of the deformity; two patients had problems related to half-pin insertions (neuropraxia of deep peroneal nerve and genicular artery bleeding). These patients had pin relocations and recovered fully. The patient with under-correction of the deformity will undergo further surgery at the time of correction of the second limb.

We divided all the patients into five groups: Blount disease, angular deformity with shortening, deformity group, fractures and nonunions, and miscellaneous.

Blount disease

This group consisted of four patients (six limbs), all boys, with adolescent Blount disease (patients 1–4; Table 1). Mean age at surgery was 14.5 years (range, 13–17 years). Mean time in the frame was 12.5 weeks (range, 12–14 weeks). The fibula was not osteotomized in any of these patients, as the origin was chosen at the level of the proximal tibial fibular joint. Internal tibial torsion was corrected in three patients, and two patients had correction of mild procurvatum deformity of the proximal tibia. Three patients had symptoms of superficial pin tract infection and one patient had postoperative bleeding from around the half-pin in the proximal tibia. Angiography revealed penetration of the genicular artery and bleeding stopped after the half-pin was removed. The aim of surgery was restoration of the mechanical axis of the lower limb to normal parameters. This was achieved in all patients, and the mean medial proximal tibial angle at the last follow-up was 88° (range, 87–90°).

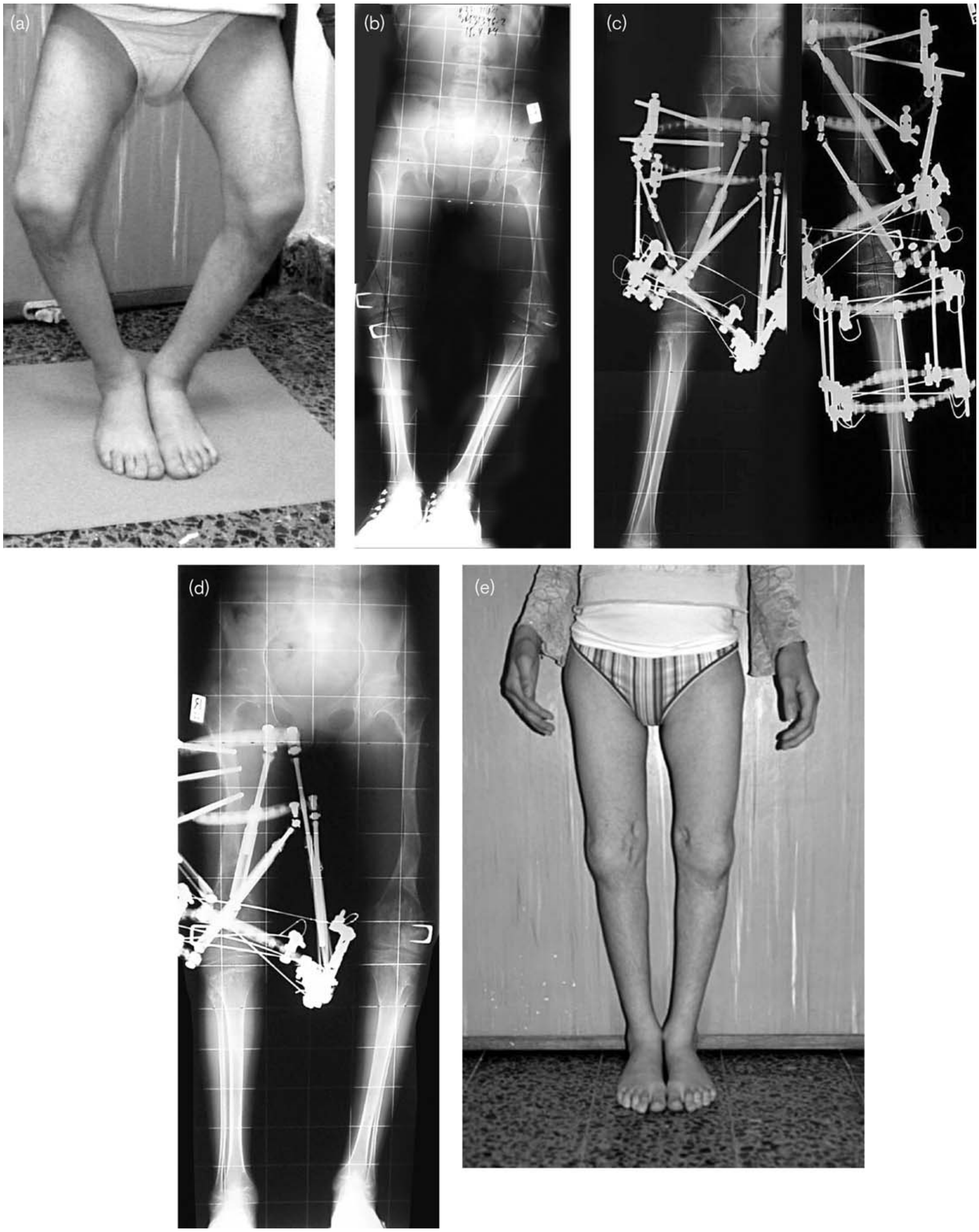
Angular deformity with shortening

Lengthening with deformity correction was performed in seven patients (four boys, three girls) with 10 affected limbs (four tibiae and six femurs, patients 5–11, Table 1). Mean age at surgery was 11.4 years (range, 6–16 years). Mean external fixation time was 14.1 weeks (range, 9–24 weeks). This group consisted of two patients with congenital short femur and fibular hemimelia, two patients with post-traumatic growth arrest of the tibia and severe deformity, one patient with fibrous dysplasia of the femur, and one patient with femoral deformity and shortening secondary to developmental dysplasia of the hip. All the patients had various deformities that needed to be corrected. Mean lengthening was 40 mm (range, 25–80 mm). A girl with spondylo-epi-metaphyseal dysplasia underwent correction of severe bilateral femoral varus, 50 mm lengthening of both femora and gradual derotation of the proximal tibia (Fig. 1a–d). A patient with growth arrest of the proximal tibia underwent double lengthening of the tibia (80 mm) and correction of severe proximal tibia varus (Fig. 2a–d). One patient with a congenital short femur and fibular hemimelia underwent combined femoral and tibial lengthening of 80 mm. Lengthening of 50 mm was performed in a patient with a congenital short femur, 40 mm after growth arrest of the distal tibia (Fig. 3a and b), and lengthening of 30 mm was performed in two other patients. In this group, there were two fractures of the femoral regenerate after frame removal. Fractures were managed by nailing of the femurs by Rush pins and application of spica casts. Four patients had episodes of superficial pin tract infection, successfully treated by oral antibiotics.

Fractures and nonunions

This group consisted of seven patients, six boys and one girl (patients 12–18, Table 1). Mean age in this group was 10.6 years (range, 6–14 years). Mean external fixation time was 10.1 weeks (range, 8–14 weeks). Six patients with displaced fractures of the tibia (two open) were treated initially by external fixation or cast but, owing to persistent malalignment, were switched to TSF. One patient was treated by TSF after fatigue fracture of the metal fixation plate used to realign a displaced supra-condylar femoral fracture. Bony union and anatomic alignment were achieved in all patients. Three patients had episodes of pin tract infection. One patient had transient big toe drop due to injury of the deep peroneal nerve during half-pin insertion; this complication resolved spontaneously after 4 weeks.

Fig. 1

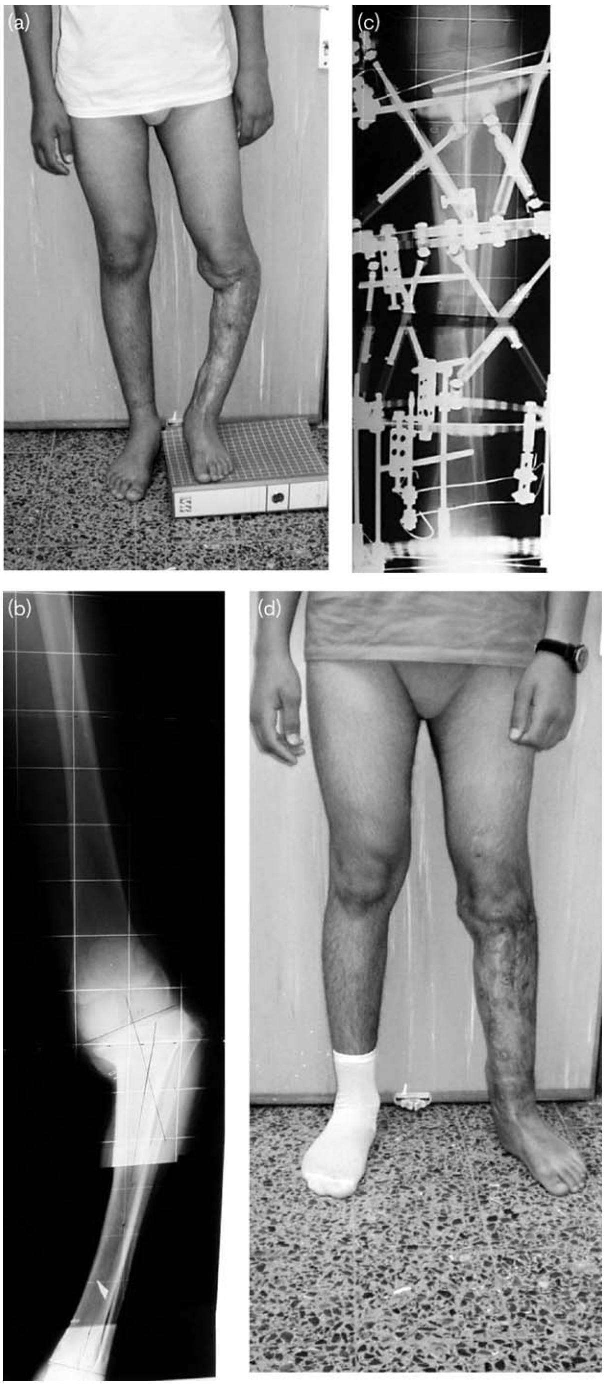


(a) A 12-year-old girl with spondylo-epi-metaphyseal dysplasia. (b) X-rays before correction. (c) Application of Taylor spatial frame (TSF) on both femurs and right tibia with 50 mm lengthening of both femurs and derotational osteotomy of proximal tibia. (d) X-rays before removal of TSF. (e) End of correction.

Deformity group

This group consisted of nine patients (13 limbs; patients 19–27, Table 1), three girls and six boys, with a mean age at surgery of 14.5 years (range, 13–16 years). External fixation time was 11.6 weeks (range, 9–16 weeks). Three patients in this group had severe genu valgum; one

Fig. 2



(a) A 16-year-old boy with growth arrest of proximal tibia, severe varus, and 80 mm shortening. (b) X-rays before operation. (c) X-rays before removal of frame. (d) Clinical picture after frame removal.

patient with vitamin D-resistant rickets underwent correction of varus; one patient with Schmid dysplasia underwent correction of tibial and femoral deformities; two patients underwent correction of unilateral internal tibial torsion and distal tibial varus; and two patients underwent correction of post-traumatic malunions (radius and tibia). In all but one patient, full restoration of normal mechanical axes was achieved. After double femoral and proximal tibial osteotomy, the 16-year-old boy with Schmid dysplasia still had a residual proximal femoral deformity that required further surgery. A 14-year-old girl who underwent bilateral femoral and proximal tibial osteotomy had a fracture of the femur at the site of the osteotomy after removal of the frame. She was managed by closed reduction and spica cast and finally achieved normal alignment with full range of motion (Fig. 4a–d). Four patients in this group had superficial pin tract infections.

Miscellaneous group

This group consisted of four patients (eight limbs; patients 27–31): two girls and two boys with a mean age of 6.1 years (range, 3.5–12 years). Mean external fixation time was 12.2 weeks (range, 8–16 weeks). In this group, three patients had knee flexion contractures and one child had idiopathic recurrent clubfoot. One girl with arthrogryposis had severe rigid bilateral knee flexion contracture and bilateral recurrent clubfeet (Fig. 5a–c). She was treated by popliteal release and gradual correction of knee and feet deformities. One girl with myelomeningocele and paralytic unilateral rigid knee flexion contracture and clubfoot underwent correction of both deformities. One girl who had knee flexion contracture 1 year after femoral lengthening was treated by gradual distraction of the knee. A 6-year-old boy with residual clubfoot and severe internal tibial torsion and rigid equinus was treated by tibial derotation and correction of the equinus. The arthrogryposis patient had an intraoperative proximal femoral fracture over a 4 mm half-pin. She was treated by immediate femoral nailing with a Rush rod. The clubfoot patient had mild talar subluxation and was treated by readjustment of the TSF schedule. All patients had full correction of their contractures, maintained after a mean follow-up of more than 13 months.

Discussion

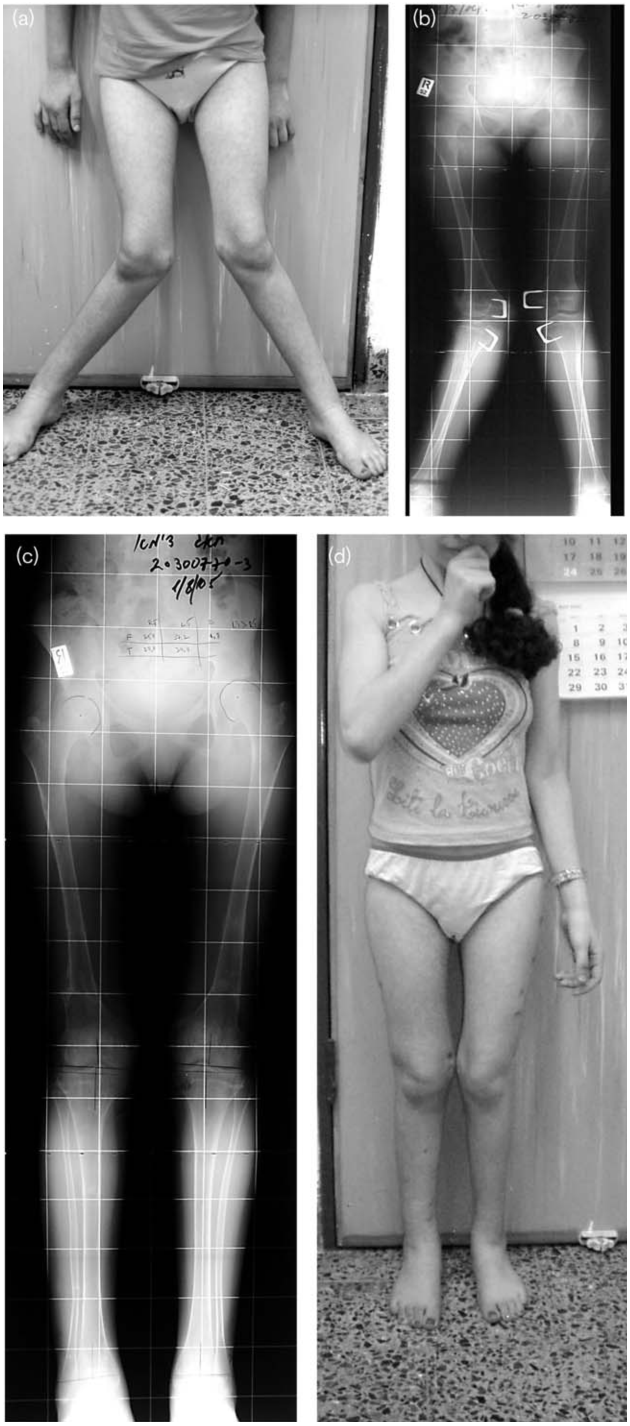
The Ilizarov external fixator dramatically improved our ability to correct various muscular skeletal deformities. This method spread throughout the world and became a useful tool in many centers for various conditions [1–3]. The main problem with the Ilizarov external fixator, however, is difficulty in correcting multiplanar and complex deformities. Another obstacle is the steep learning curve, so that in most situations successful management of complex deformities can be achieved only after years of experience. Basically, correction of a single plane deformity (e.g. angulation only) is not a problem for the Ilizarov external fixator but, when rotation and translation need to be corrected, replacement of hinges and frame adjustment need to be performed in most

Fig. 3

(a) A 7-year-old boy with post-traumatic growth arrest of distal tibia and foot joints with severe distal tibia valgus and 40 mm shortening. (b) Clinical picture after frame removal.

circumstances. TSF simplified many of the problems and allowed simultaneous correction of six-axes deformities without frame modification through strut adjustments only. The ability to simultaneously correct six-axes deformities with mathematical accuracy and superior stability over other external fixator systems makes, in our opinion, the TSF the external fixator of choice for the correction of complex deformities.

Fig. 4



(a) A 14-year-old girl with severe genu valgum. (b) X-ray before Taylor spatial frame correction. (c) X-ray after correction of deformities. (d) Clinical picture after correction of deformities.

We reviewed everything published in this area until the time of writing this manuscript. The most comprehensive source of information is Charles Taylor's personal web site [4]. Another useful information source is a chapter written by Taylor in Paley's book [5]. Despite the wide use of TSF, the number of published articles is limited. All report experiences with relatively out-of-date chronic modes and a limited number of patients, ranging from five [6] to 54 [7].

Binski [7] reported excellent results with treatment of acute tibial fractures by TSF. He achieved anatomic reduction in 96% with a union rate of 93%. Three patients who did not achieve union after the first procedure achieved union after the second procedure. In conclusion, the author stated that TSF has universal application for virtually any type or location of tibial fracture. Feldman *et al.* reported two important articles. In the first [8], they analyzed the outcome of TSF treatment of 19 patients (22 tibias) with adolescent and infantile tibia vara; 21 of 22 tibias were corrected to normal parameters (within 3°). The authors stated that TSF allowed safe and accurate correction of the tibia vara. In the second paper, Feldman *et al.* [9] analyzed their experience with the treatment of tibial malunion and nonunion in 18 patients; of the 18 patients treated by TSF with adjunctive bone graft as necessary, 17 achieved union and significant correction of their deformities in six axes. Fadel and Hosny [10] reported the results of treatment of 22 patients. They concluded that their results were encouraging but less favorable than with the Ilizarov external fixator.

We report the results of a relatively large number of patients with varied and mostly complex conditions. The most serious complications in our study were femoral fractures in three patients. We feel that this complication can be prevented. We did not dynamize the frames before removal and judged bone consolidation based on X-rays only. This was our mistake. TSF gives excellent stability but, after correction and especially in case of lengthening, the system must be dynamized before removal. Now, we replace TSF struts with Ilizarov rods and loosen them to achieve system dynamization. Another possible option is removal of several struts before fixator removal, in order to ensure that patients do not experience any pain.

Our most common complication (45%) was superficial pin tract infection. Usually this complication resolves after a short course of parenteral antibiotic treatment and modification of pin care. In general, despite many challenging cases, our results are comparable to the good results achieved by other published series of TSF treatments [7–9].

Obvious disadvantages of TSF are a deficit of small rings and struts for the correction of deformities in small children, which is otherwise difficult or impossible. Another problem is the high cost of TSF equipment.

Fig. 5

(a) A 3.5-year-old child with bilateral severe knee flexion contractures and clubfeet. (b) Clinical picture after application of Taylor spatial frame. (c) Clinical picture after frame removal during walking.

Nevertheless, in our opinion, TSF is the most accurate and stable fixator available today, with a relatively short learning curve.

Conclusion

We believe that the TSF is an excellent tool for the correction of multiple plane deformities in children and adolescents and significantly expands our ability to correct precisely the most difficult deformities.

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