Diaphyseal defects too long to be bridged by cancellous bone graft require complex reconstruction. Distraction osteogenesis requires specialized equipment, has a steep learning curve, and is plagued by attendant pin-site complications and nonunion. Vascularized bone, such as from the fibula, requires microsurgical anastomoses (free), or is limited by pedicle length (pedicled), and has attendant donor-site morbidity (both free and pedicled). The French technique of bone-grafting within induced membranes, otherwise known as the Masquelet technique, offers a viable alternative with minimal complications. In this technique, a cement spacer is placed in a posttraumatic bone defect. Its presence serves a twofold function of preventing fibrous ingrowth into the bone gap, and inducing the formation of specialized tissue or so-called induced membranes around it. Bone graft placed within this tube of induced membranes incorporates into functioning bone.

We present the case of a patient with diaphyseal bone loss and the case of a patient with epimetaphyseal bone loss, both with ongoing bacterial contamination, successfully treated by this procedure. Both patients were informed that data concerning the case would be submitted for publication, and they consented.

**Case Reports**

**CASE 1.** A twenty-year-old woman was struck by an automobile while crossing the road. She sustained an open (Gustilo-IIIB) diaphyseal fracture of the left tibia (AO-OTA 42-C3) with marked loss of the soft-tissue envelope over the medial, anterior, and posterior aspects of the leg. The wound was debrided on admission, and immobilization was achieved with an external fixator (Fig. 1). Two additional surgical débrideaments were necessary to ensure complete removal of extensive road debris contamination and to prepare the wound bed for future soft-tissue coverage. The defect was eventually covered with a vascularized rectus abdominis muscle flap six weeks later. Her recovery was complicated by wound infection with *Klebsiella pneumoniae* and *Escherichia coli*, both sensitive to imipenem.

She was referred to our institution six months after the original injury with an infected tibial nonunion. Radiographs revealed a mid-diaphyseal defect of the left tibia measuring...
60 mm in the smallest axial dimension. The fixator pins were removed in the operating room, and the limb was placed in a plaster cast for two weeks to allow for pin-track healing, after which intramedullary nailing of the left tibia was performed. In the first of two staged procedures, a cement spacer (Figs. 2-A and 2-B) was wrapped around the nail at the location of the defect and allowed to cure, thus bridging the cortical defect. In view of the underlying wound infection, the spacer was impregnated with imipenem. In addition, the patient was given a course of intravenous imipenem for six weeks.

At the second procedure two months later, she underwent repeat débridement, removal of the cement spacer, and autologous iliac crest bone-grafting into the sleeve of induced membranes. The formed membranes had a similar appearance to fascia, and measured 0.5 to 1 mm in thickness. Intraoperative tissue cultures were negative. Radiographs made two months after bone-grafting show regenerated bone around the nail, bridging the fracture gap. At one and a half years of follow-up, radiographic evidence of solid union is present (Fig. 3). She was enrolled in an intensive, supervised physiotherapy regimen and was bearing full weight. She had minimal pain although she did have residual ankle stiffness and a claw-toe deformity.
Case 2. A fifty-year-old man fell from a 4-ft (1.2-m) height onto his right foot. He sustained a Gustilo-IIIB open tibial pilon fracture (AO-OTA 43-C3) and dislocation of the right ankle (Fig. 4). Wound débridement and spanning external fixation was performed emergently. One week later, the fixation was converted to a circular fixator and the defect was

Fig. 4
Case 2. Open Gustilo-IIIB fracture-dislocation of the right ankle.

Fig. 5
Case 2. An antibiotic-impregnated cement spacer has been placed, spanning the 40-mm epimetaphyseal defect between the tibial pilon and the talar dome, and is fixed in situ by a spanning external fixator.
dressed with a vacuum-assisted closure device (VAC; Kinetic Concepts, San Antonio, Texas). Two weeks after the injury, the soft-tissue defect over the lateral malleolus was resurfaced with a distally based sural artery flap. The patient later had *Acinetobacter baumannii* osteomyelitis develop and was treated with a six-week course of parenteral antibiotics. Radiographic comparison with the uninvolved limb revealed gross destruction of the tibial plafond with a resultant epimetaphyseal defect measuring 40 mm from the joint surface. The first stage of reconstruction of the bone defect with use of the Masquelet technique with a cement spacer and application of an articulated ankle fixator (XCaliber; Orthofix, Verona, Italy) was performed ten weeks after the initial injury (Fig. 5).

At the second-stage procedure, eleven weeks later, the cement spacer was removed and corticocancellous iliac crest bone graft (40 mm) was inserted into the membrane-lined cavity (Fig. 6) to facilitate ankle fusion. Intraoperative tissue cultures were negative. The medial wound was covered with a rotational skin flap. Seven months later, additional bone graft was placed into the preformed membranous sleeve because of radiographic evidence of nonunion. A cement spacer was not utilized in the second bone-grafting procedure. Nine weeks after the second bone-grafting procedure, radiographs revealed a successful osseous union (Fig. 7).

**Discussion**

The management of segmental long-bone defects is a challenge. The literature has described many techniques, but each is fraught with specific difficulties\(^1\). Autologous...
nonvascularized cancellous bone graft possesses superior osteoconductivity and osteoinductivity, but its use is confined to small defects. Graft incorporation is slow and unreliable, and nonunion may arise when the grafted host bed is of doubtful vascularity.

Larger defects are amenable to vascularized bone transfer or distraction osteogenesis. The latter technique requires specialized training and equipment, and is often associated with complications including pin-track infections and nonunion. The transfer of vascularized bone from the rib, fibula, or iliac crest is another widely utilized technique used to bridge larger defects. Besides being limited by pedicle length (pedicled grafts) and the need for microsurgical anastomoses (free grafts), donor-site morbidity has been reported to occur in up to 19% of patients managed with vascularized fibular grafts. In addition, both approaches require a long treatment time, leading to disuse atrophy of the involved limb, psychological stress, and loss of income.

Describing the Masquelet technique, Pelissier et al. proposed the use of a combination of induced membranes and cancellous autografts to bridge diaphyseal defects of up to 25 cm in length. In this technique, a methylmethacrylate cement spacer induces formation of a membrane, creating a pocket for subsequent grafting. Pelissier et al. determined that these membranes possessed a rich capillary network and have high concentrations of growth factors (vascular endothelial growth factor and transforming growth factor-beta-1) and osteoinductive factors (bone morphogenetic protein-2). Immunohistochemical studies on induced membranes in a sheep model by Viateau et al. established the presence of cells expressing transcription factor CBFA1, and type-I collagen rich extracellular matrix, with few macrophages. With the above characteristics, the membranous pocket prevents resorption of the contained graft, acts as a barrier to outward diffusion of growth and osteoinductive factors, and provides a source of stem cells and vascular cells supporting revascularization and osseous consolidation.

In this report, we describe the cases of the first two patients in our experience with this technique. In both patients, the presence of induced membranes was documented by visual inspection of the fracture gap and its surrounding tissues on removal of the cement spacer; there was no histological confirmation of the presence of these membranes.

The cases of these two patients are illustrative of the Masquelet technique, with a few variations. In both patients, infection was present in the region of segmental bone loss. In the first patient (Case 1), impregnating the cement spacer with an antibiotic targeted at the contaminating pathogens facilitated graft-bed sterilization. This is an extension of the existing concept of antibiotic-impregnated beads in the management of dead space in segmental bone defects, and the use of an antibiotic in this fashion has previously been described for septic nonunion and chronic osteomyelitis. Admixing antibiotic into the cement mixture compromises compressive strength; however, this was not an issue as the cement block serves only as a spacer to obturate dead space, preventing fibrous ingrowth, while directly inducing membrane formation. The case of this patient also demonstrates that the Masquelet concept can be applied successfully with intramedullary nail fixation, which differs from the original technique with use of external fixation.

For the second patient (Case 2), bone loss was of epiphyseal origin. Management of complex tibial pilon fractures is challenging, with early ankle osteoarthritis often being the end result, and primary ankle fusion is an option for the salvage of fractures that are not reconstructible. Bone-grafting within the induced membrane allows for graft preservation in an area of poor vascularity although, in this patient, bone-grafting had to be performed twice. After the initial Masquelet procedure, the large defect had been reduced to a simple nonunion, which was amenable to conventional bone-grafting.

The technique of bone-grafting within induced membranes does not require specialized equipment, it can be performed easily and by surgeons with varying experience and capability, and it is applicable to patients with bone loss of epiphyseal, metaphyseal, or diaphyseal origin.

References


