Chapter 2
Limb Damage Control Orthopedics

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2.1 Introduction

The damage control (DCO) approach to the injured limb requires the application of damage control orthopedic principles to an extremity. Like the overall DCO approach to the polytrauma patient, limb damage control corrects local metabolic disturbances (e.g., acidosis, contamination, etc.), corrects local hypothermia (e.g., warming the limb, ensuring adequate perfusion, etc.), and reverses coagulopathy (e.g., controlling profound bleeding, etc.). Along with fixing local metabolic disturbances, controlling bleeding, and ensuring adequate perfusion, provisional skeletal stability with external fixation is achieved.

The most important type of extremity injury that benefits from a limb damage control approach is the mangled leg. In addition, a limited limb damage control approach can be applied to complex periarticular/articular injuries. Furthermore, the British Orthopedic Association, in its *Standards for the Management of Open Fractures of the Lower Limb: Short Guide*, has described the use of primary amputation as a "damage control procedure" when there is uncontrollable hemorrhage from an open tibial injury (multiple levels of arterial/venous damage in blast injuries), or for crush injuries exceeding a warm ischemic period of 6 h [1].

The mangled limb is defined as a limb with injury to three of four extremity systems [2] with the systems defined as the soft tissues, nerves, blood supply, and bone

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[3]. The initial treatment decision is between immediate limb salvage or amputation. With limb salvage, these limb injuries require methods of soft tissue injury management techniques such as antibiotic bead pouches and negative pressure dressings (e.g., VAC, etc.) in addition to external fixation. The various applications of damage control external fixation to specific periarticular/articular injuries in the non-mangled limb will be addressed elsewhere in this book.

The clinical decision whether to perform limb salvage or immediate amputation is best made in the context of the contemporary data from the Lower Extremity Assessment Project (LEAP) study. The LEAP data suggests that patient and social factors are the primary determinants of outcome after severe limb trauma rather than the nature of the orthopedic injury itself [4]. The traditional belief that amputation led to superior outcomes following severe lower extremity injury is not supported by the LEAP study [4]. The LEAP data also suggested that plantar sensation and injury scoring systems are not accurate predictors of functional outcome after these injuries. More than 40% of patients had severe functional impairment according to the Sickness Impact Profile, and only 51% were able to return to work. At average follow-up of 7 years for the LEAP study patients, there was a persistence of disability and a lower SIP Score at 24 months across all treatment groups [5]. Only 34% of patients had a normal physical SIP Subscore (≤5). Variables associated with a better outcome included male gender, younger age at the time of injury, higher socioeconomic status, being a nonsmoker, and having better self-efficacy (confidence to perform certain tasks). There was a fairly high incidence of rehospitalization between 2 and 7 years: 39% of limb salvage patients and 33% of amputees.

This chapter will review general principles of limb assessment, various external fixator montages for injuries of the lower extremity as well as the techniques of antibiotic bead pouches, negative pressure wound therapy, and antibiotic nails.

2.2 General Principles

Determining the adequacy of limb perfusion and the neurological status is part of the initial steps in the assessment of patients with a mangled limb. Doppler or conventional angiography assessment can be helpful, as well as the newer option of Computerized Tomographic Angiography (CTA), which requires additional expertise for its performance and interpretation. Specific bony injuries that carry a higher risk of an associated vascular injury include complex fractures of the proximal tibial plateau, often the result of a fracture-dislocation of the knee. The clinical assessment must be repeated at regular intervals and documented especially after reduction or application of splint. Conditions that will require immediate surgery include: vascular impairment (restoration of the circulation with shunts ideally within 3–4 h with a maximum of 6 h of warm ischemia time), compartment syndrome (for the lower leg, 4 compartments should be decompressed with a 2 incision technique), and finally in some multiply injured patients with open fractures or if the wound is heavily contaminated by marine, agricultural, or sewage matter. In any case, both the orthopedic trauma team and the plastic surgeons should agree and document early on a manage-

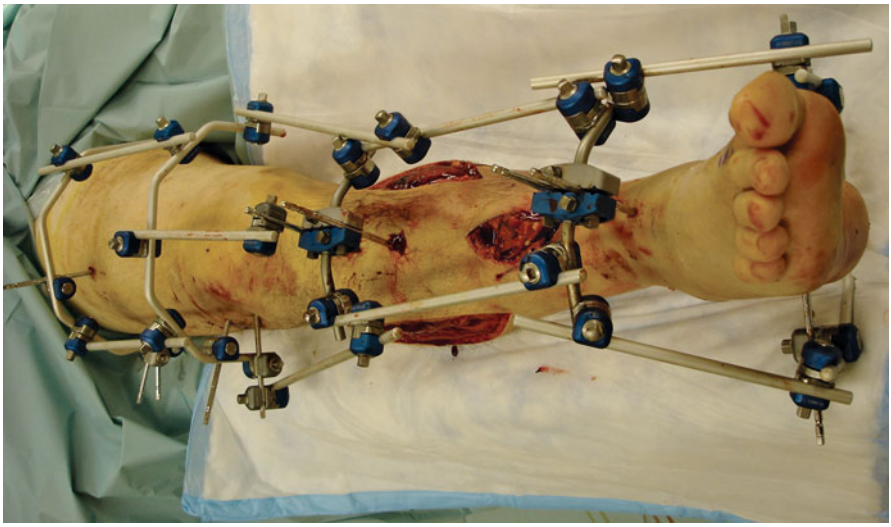

Fig. 2.1 Photograph of a full-length external fixator for a complex, segmental leg injury

ment plan and have in their minds the acute and less acute options. In the emergency room, the wound and soft tissues should only be handled to remove gross contamination, a picture should be taken for documentation purposes (and to prevent multiple handling of the wound), and the size and contamination of the skin defect should be estimated and noted. A saline-soaked dressing should be applied and covered with an impermeable film to prevent dessication before the application of a splint. Intravenous antibiotics should be started as early as possible and should consist of Co-Amoxiclav 1.2 g or Cefuroxime 1.5 g every 8 h continued until the first wound debridement. In case of Penicillin allergy, this can be replaced by Clindamycin 600 mg every 6 h. At the first debridement, patients should receive Co-Amoxiclav 1.2 g and Gentamicin 1.5 mg/kg, and these should be continued for 72 h post debridement or until definitive wound closure and fracture fixation, whichever comes first. Gentamicin 1.5 mg/kg and either Vancomycin 1 g or Teicoplanin 800 mg should be administered on induction of anesthesia at the time of skeletal stabilization and definitive soft tissue closure. These should not be continued postoperatively. The Vancomycin infusion should be started at least 90 min prior to surgery [1].

2.3 Specific Montages

2.3.1 Full-Length Fixator

Indications include segmental leg injury, multilevel fractures of the proximal and distal segments of the leg, or an ischemic leg with vascular compromise. Components

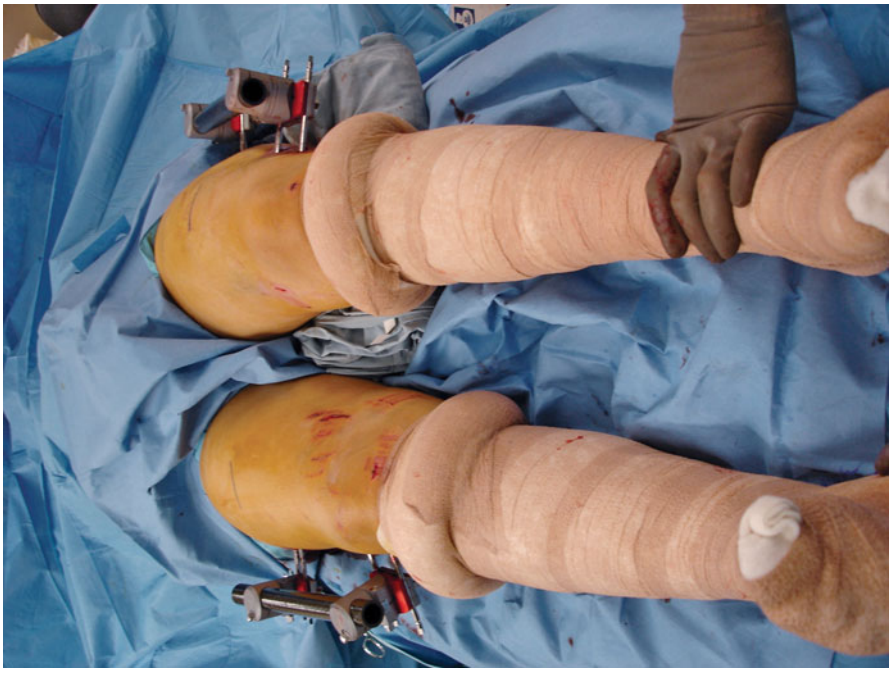

Fig. 2.2 Photograph of bilateral femoral external fixators for bilateral femoral shaft fractures

include multiple long bars and multiple pin clamps (minimum one per segment). Options are separate pin clamp cluster per fracture segment, or pin clamp in end segments only with floating middle segment. This montage of external fixation spans the whole leg from the hip to the foot (Fig. 2.1). Pitfalls include too much traction on the entire limb, creating excessive soft tissue tension with possible soft tissue swelling, sciatic nerve palsy, and thigh or calf compartment syndrome.

2.3.2 Femoral Shaft External Fixators

Indications for the application of a femoral external fixator include femoral shaft fractures in the unstable polytrauma patient, patient with a significant chest or head injury in addition to a femur fracture, an open femur fracture unsuitable for immediate femoral nailing, or a femur fracture with a thigh compartment syndrome. Components of the frame include one large bar for a one bar frame (Fig. 2.2), or two smaller bars for a delta-type frame, two pin clamps (for a frame with one bar), or four single pin-bar clamps and bar-bar clamps for a delta-type triangular frame. Options include a unilateral straight anterolateral frame with uniplanar pins or a straight lateral frame with multiplanar pins. Pitfalls include iatrogenic damage to the bulk of the quadriceps muscle anteriorly, quadriceps atrophy, pin sepsis, and

neurovascular damage medially or posteriorly to the femoral shaft. The risk of local infection after external fixation of femur fractures (damage control orthopedics) is comparable to those after primary intramedullary nailing of femur fractures [6].

2.3.3 Knee Bridging External Fixators

The across-the-knee application of external fixation is useful for unstable bony segments around the knee. Indications include tibial plateau fractures, knee dislocations, knee fracture-dislocations, or the floating knee segment ("floating knee injuries"). Components include two bars with a bar-to-bar clamp (or alternatively one long bar) and two pin clamps (Fig. 2.3). Options include pin clusters with either one double-pin clamp on either the joint or, for a larger leg, one double clamp plus a single-pin clamp on either side of the joint for multiplanar fixation. In addition to neurovascular damage, other complications of pin insertion include iatrogenic joint capsule penetration, and resultant theoretical risk of joint sepsis from pin tract infections. We have found that this theoretical risk is only a problem in the subgroup of patients who are diabetic or immunocompromised [7]. We suggest avoiding pin insertion at the potential sites of future incisions.

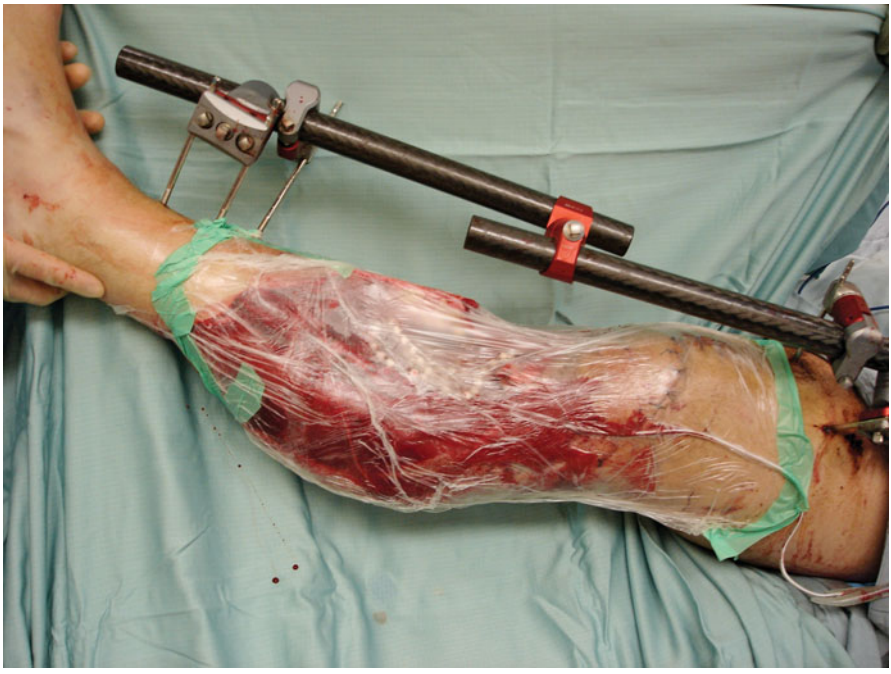

Fig. 2.3 Photograph of an across-the-knee external fixator with an antibiotic bead pouch for a complex tibial fracture with a nearly circumferential soft tissue injury

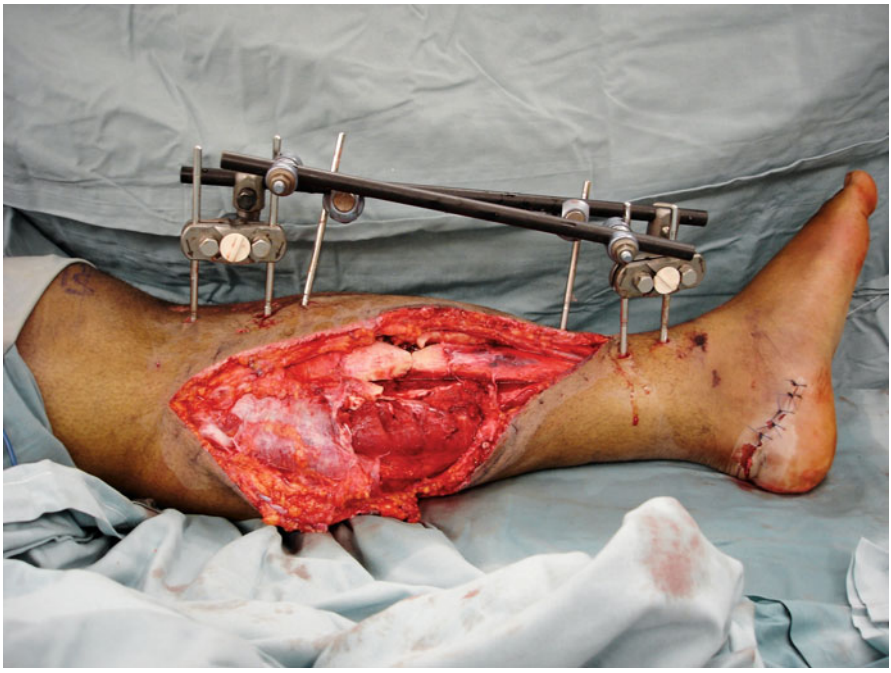

Fig. 2.4 Photograph of an external fixator for an open tibia-fibula fracture

2.3.4 Tibial Shaft External Fixators

Indications for the application of a tibial shaft external fixator are open tibial fractures with gross contamination, especially with a soft tissue injury preventing coverage of bone. Options include simple anterior frame with two double-pin clamps for more stable fractures; more complex frames with multiplanar pin (one double-pin clamp and one single-pin clamp) on either side of the fracture site (Fig. 2.4) can also be useful. Pitfalls include iatrogenic injury to the saphenous neurovascular bundle, the peroneal nerve (common or superficial branch), or the tibial nerve and artery.

2.3.5 External Fixators Across the Ankle Including the Hindfoot

The application of external fixation across the ankle is useful for complex, segmental injuries of the foot and ankle. Indications include damage control frame spanning a pilon fracture, comminuted bi- or tri-malleolar fracture, or midfoot injuries. Components include a partial hexagonal ring for the hindfoot and a partial hexagonal ring for the forefoot, a double-pin clamp with posts for the tibial pins, short rods to

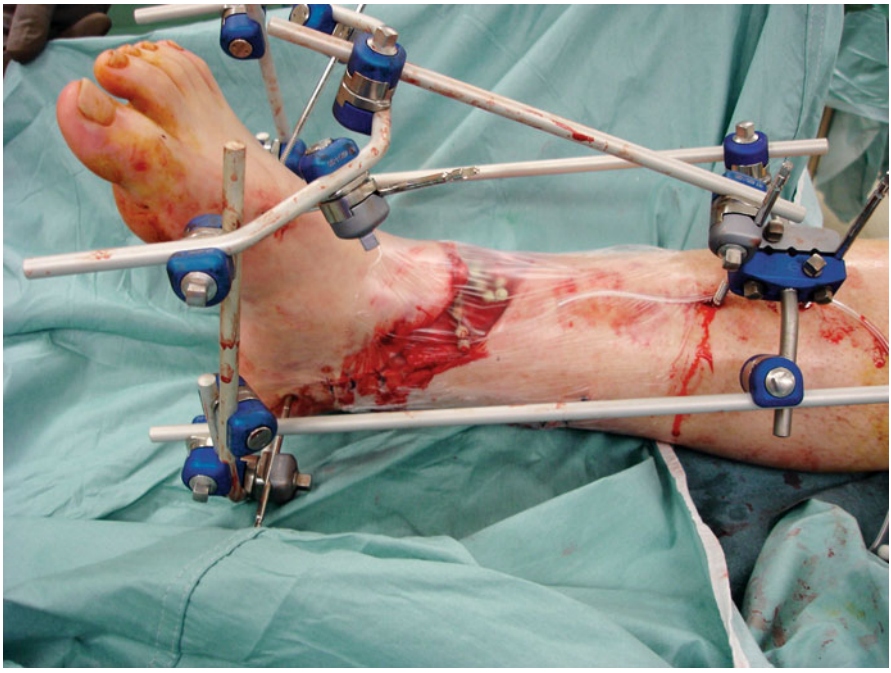

Fig. 2.5 Photograph of an across-the-ankle external fixator which includes the hindfoot as well as an antibiotic bead pouch

connect the hexagonal rings on the foot, three long rods to connect the tibial pin clamp to the foot rings, and bar-to-bar clamps. Options include a complete spanning of foot (hindfoot to forefoot) with proximal tibial pin clamp versus hindfoot pins (without forefoot pins) with tibial pin clamp (Fig. 2.5). Pitfalls include iatrogenic injury to the posterior neurovascular bundle, inadequate purchase in the calcaneus pin, iatrogenic anterior subluxation of the tibio-talar joint, and iatrogenic injury to digital vessels.

2.3.6 External Fixators Across the Ankle Sparing the Hindfoot

This montage is particularly useful for applications where the hindfoot needs to be spanned. Specific indications include mangled heel injuries or open calcaneus fractures or combined ankle and hindfoot articular injuries. Components include double-pin clamp with posts, one partial hexagonal ring, three long connecting rods, and bar-to-pin clamps. Options include first and fourth or fifth metatarsal half-pins plus tibial pin clamp versus first and fourth metatarsal half-pins plus tibial pin clamp (Fig. 2.6). Pitfalls include injury to digital neurovascular bundles and iatrogenic anterior subluxation of the tibio-talar joint.

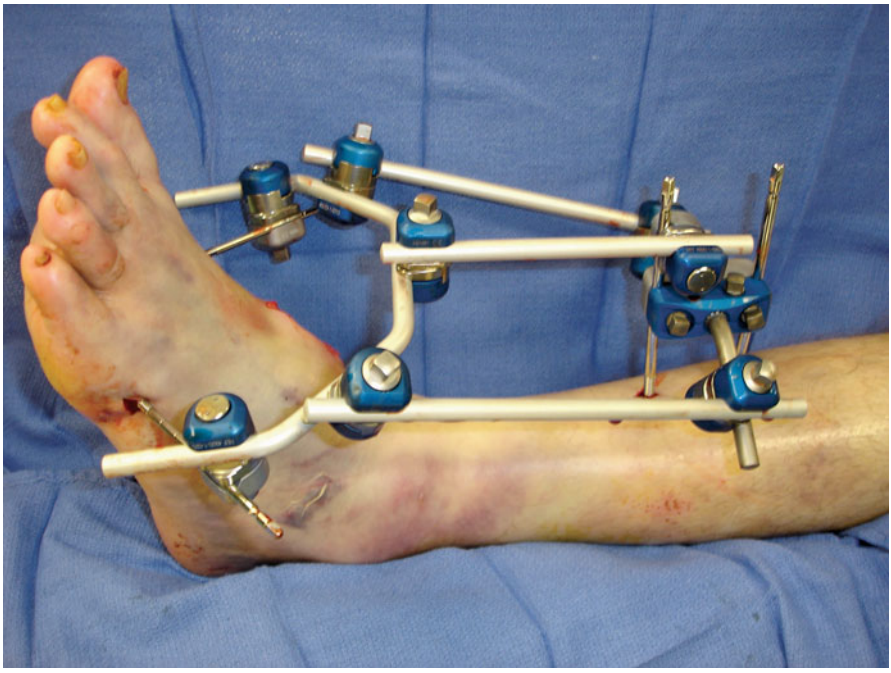

Fig. 2.6 Photograph of an across-the-ankle heel-sparing external fixator

2.4 Adjunctive Measures

2.4.1 Antibiotic Bead Pouches

Antibiotic bead pouches are useful for grossly contaminated open fracture wounds that will need additional staged debridements, as well as wounds that after debridement cannot be closed primarily. An antibiotic bead pouch consists of a porous plastic film placed over the soft tissue defect to establish a "closed" bead-wound-fracture environment containing high levels of antibiotics at the fracture site. Seligson et al. reported that antibiotic bead pouches lower infection rates after open fractures [8]. In a series of 227 open fractures in 204 patients with the antibiotic bead pouch technique, there was a 0% infection rate in grade I open fractures, 1.2% infection rate in grade II open fractures, and 8.6% infection rate in grade III open fractures [8].

One or more chains of antibiotic bead chains are placed in the wound. If more than one chain is used, the bead chains are connected to each other by twisting them together. A suction drain is brought out through normal intact skin and is used to collect overflow only and the suction is intentionally released. The soft tissue defect is covered with an occlusive wound dressing after ensuring that the surrounding skin is dry. Tincture of Benzoin or Mastisol is used to enhance the adhesiveness of the film to skin. The bead pouch dressing is changed in the operating room every

48–72 h. The advantages of the bead pouch are that the open wound is isolated from the hospital environment, high local concentrations of antibiotics are delivered locally in the wound, and systemic toxicity from antibiotics is avoided. One theoretical disadvantage is the development of resistant strains of bacteria; however, this has not been a clinical problem.

2.4.2 Negative Pressure Wound Therapy

Vacuum-assisted wound closure (VAC) is an application of negative pressure wound therapy which has increasingly been used for treating open fracture wounds. VACs were previously termed topical negative pressure (TNP), subatmospheric pressure (SPD), vacuum sealing technique (VST), negative pressure wound therapy (NPWT), and sealed surface wound suction (SSS) [9]. The VAC appears to increase the rate of granulation tissue formation compared with saline dressing-treated wounds [10]. The VAC may also reduce bacterial counts in wounds. In bacterial clearance studies, conducted by infecting wounds with *Staphylococcus aureus* and *Staphylococcal epidermidis*, bacterial levels remained below 10^5 organisms/g of tissue for all treated wounds while bacterial levels in control wounds remained above 10^5 organisms/g of tissue until day 11 [10, 11]. The VAC may also decrease the need for future free flaps or rotational flaps. The components of the VAC system include an electrically powered programmable pump capable of generating a negative suction with a controlled pressure usually ranging from 25 to 200 mmHg with the option of continuous or intermittent suction. This unit is connected to a system of disposable sterile sponge kits complete with tubing and plastic adhesive drape commercially available in three sizes: small, medium, and large. One end of the tubing originates from the dressing with a noncollapsible, side-ported evacuation tube. The other end is connected to a canister to collect the wound exudates. The essential part of the setup is the special pressure distributing dressing made up of open cell polyurethane foam which is positioned in the wound cavity or over the flap. The pore size is carefully designed to maximize tissue growth and is generally 400–600 μm [10]. A semipermeable occlusive adhesive dressing seals the wound from external environment. Portable vacuum-assisted wound closure systems, which are battery operated, are available for ambulatory and highly mobile patients.

The VAC has to be applied after the wound has been debrided. The foam dressing should be cut geometrically to fit the wound with care taken to place the foam material into the deepest portion of the wound. The sponge should be loose and expanded, not tightly packed. A plastic adhesive drape is then placed over the sponge, overlapping the wound margins by 5 cm or more to obtain an airtight seal. The plastic drape can be easily placed under or wrapped around external fixation devices to maintain the pressure seal. The tubing should be elevated off the skin surface and "flagged" by the adhesive drape to avoid undue tubing pressure to skin or bony prominences. After vacuum pressure is applied and an airtight seal is achieved, the sponge will collapse and apply equal subatmospheric suction pressure to the sides and base of the wound. An open wound is converted to a controlled, closed wound [12].

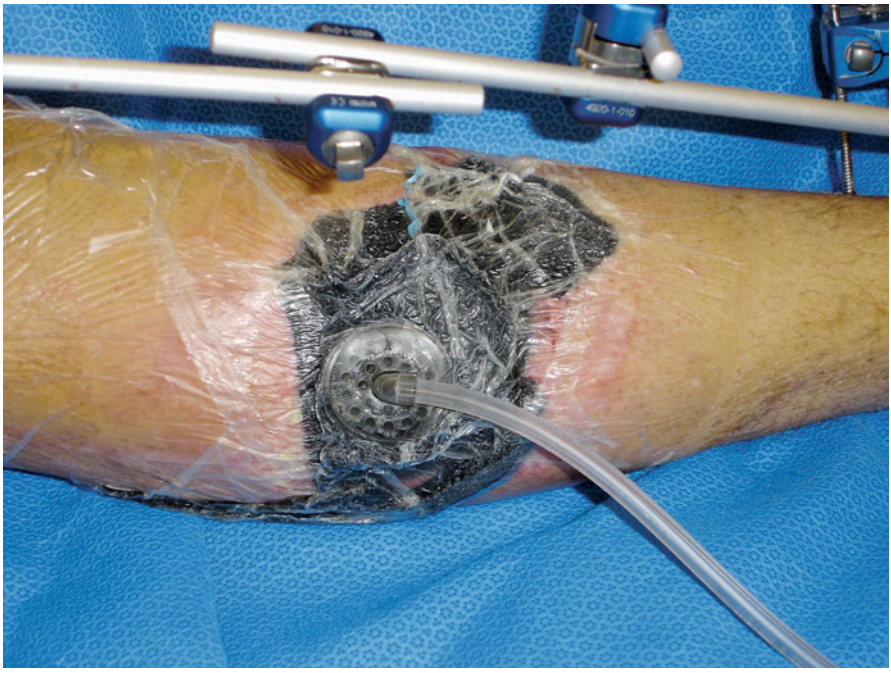

Fig. 2.7 Close-up photograph of a vacuum-assisted wound closure dressing

A sterile plastic occlusive dressing is used to cover the sponge (Fig. 2.7). The wound is not considered sterile, and a clean controlled approach to sponge change is entirely satisfactory. Vacuum-assisted closure sponges optimally should be changed every 48 h. Patients usually require pain medicine for sponge changes. Children and some adults may require sedation or anesthesia during changes. However, most dressing changes can be managed without difficulty at the bedside by specialized nursing staff. Patients with the VAC device can be managed outside of the hospital on an outpatient basis. Many patients who have been treated with antibiotic bead pouches or VACS have external fixation of long duration. External fixation of more than 3 weeks' duration can increase the chances of bacterial contamination of the intramedullary canal. Such cases often need removal of the external fixator combined with antibiotic nail insertion as a temporary bridge to sterilize the medullary canal in preparation for a staged nailing with a conventional, metal nail.

2.4.3 Antibiotic Nails

The antibiotic nail can be thought of as an intermediate step in a staged treatment of combined bony and soft tissue injuries of the lower extremity where definitive internal fixation is not safe because the soft tissue envelope is not intact. Antibiotic nail-

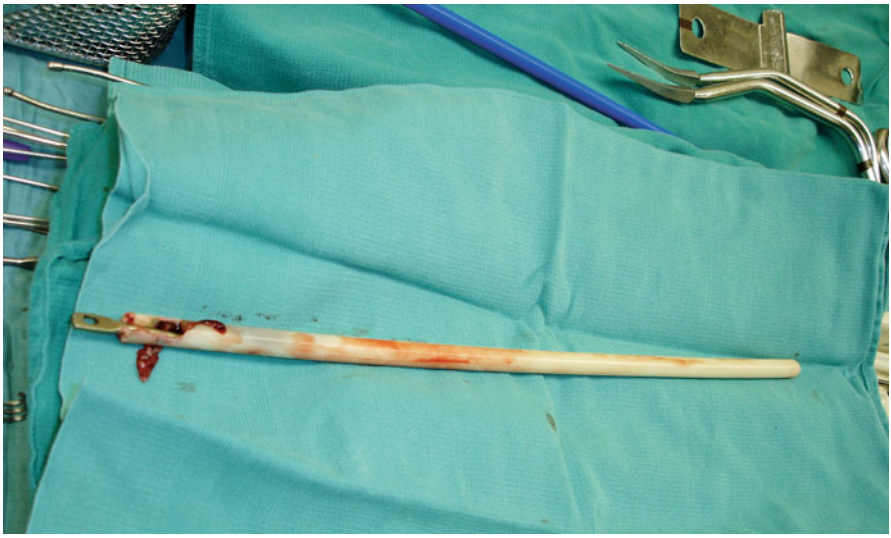

Fig. 2.8 Photograph of an explanted antibiotic nail

ing ought to be considered if external fixator has been prolonged (more than 3 weeks) even in the absence of a documented pin tract infection, or in the case of external fixation with a pin tract infection when intramedullary nail is desirable. Antibiotic-impregnated cement is capable of eluting high concentrations of antibiotics even 36 weeks after implantation [13]. The advantages of using an antibiotic nail include the opportunity to wait for definitive bone battery culture results from the intramedullary canal, time for the noninfected pin tracts to heal, temporary bony stability, and eluted high local antibiotic concentrations.

The technique of antibiotic nailing has been well described [14, 15]. After the external fixator is removed, the pin tracks are curetted and irrigated. The limb is then prepped and draped, and a standard nailing entry site is made with the knee flexed on a triangle. The medullary cavity is entered with a Küntscher awl and a ball-tipped guide wire is passed across the fracture site and confirmed by fluoroscopy. The medullary cavity is progressively reamed and the reamings are sent for culture. The antibiotic nail is usually prepared on the back table using an appropriate length 3.5 or 4 mm diameter Ender nail (Howmedica, Mahwah, NJ), antibiotic of choice (Gentamicin, Tobramycin, Vancomycin), two packs of 40 gm bone cement, vacuum cement mixer, cement gun, and a 40 French chest tube. Antibiotic nails made using a 40 French chest tube are of 10 mm diameter. Care is taken to ensure that the Ender nail extends over the full length of the cement or else fragmentation of cement tip can occur upon antibiotic nail removal. It is also important that the cement does not cover the proximal end of the Ender nail where the eyelet is located (Fig. 2.8). The nail is inserted by hand pressure or using a bone tamp on the end of the Ender nail using gentle taps. The antibiotic nail is usually not inserted as deeply as standard intramedullary nails in order to facilitate later extraction.

Table 2.1 Various montage types

Injury pattern	Montage
Fracture shaft femur	Femoral external fixator
Supracondylar femur	Anterolateral knee spanning fixator
Fracture patella	Knee-spanning fixator
Fracture tibial plateau	Knee-spanning fixator
Knee dislocation	Knee-spanning fixator
Floating knee	Knee-spanning fixator
Fracture tibial shaft	Tibial external fixator
Fracture tibial pilon	Ankle-spanning fixator
Ankle dislocation	Ankle-spanning fixator
Open calcaneus fracture	Ankle-spanning fixator (without hindfoot pins)

2.5 Conclusion

Limb damage control is an approach for limb salvage that combines and addresses complex soft tissue and bony lower extremity injuries. Although the mangled lower extremities are perhaps the best indication for a full limb damage control approach, a limited focus of limb damage control in the form of temporary external fixation is useful for complex periarticular injuries around the distal femur and both ends of the tibia. This approach emphasizes temporary external fixation coupled with wound coverage with antibiotic bead pouches or vacuum-assisted closure. Various options for limb damage control external fixation montages exist for these injuries (Table 2.1). Adjunctive measures such as antibiotic beads, VAC, and antibiotic nails are useful. Limb damage control as a limb salvage technique is supported by the LEAP study data. Prospective studies of limb damage control may be the key to answering unanswered questions about the timing of surgery and functional outcome. A limb damage control approach requires a multidisciplinary team, a global limb assessment, and orthopedic surgeons taking the lead in decision making [2].

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