Damage Control and Austere Environment External Fixation: Techniques for the Civilian Provider

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Extremity injuries associated with natural disasters and combat are typically high-energy, often open injuries, and routinely represent only part of the scope of injury to a poly-traumatized patient. The early management of these injuries is normally performed in austere environments, and relies heavily on the principles of damage control orthopaedics, with external fixation of associated long bone and peri-articular fractures. While the general principles of ATLS, wound management, and external fixation do not differ from that performed in the setting of civilian trauma, there are special considerations and alterations in standard practice that become necessary when providing this care in an austere environment. The purpose of this article is to review the principles and techniques of damage control orthopaedics and external fixation in the management of extremity trauma in the setting of combat- and natural disaster-related injuries. (Journal of Surgical Orthopaedic Advances 21(1):22–31, 2012)

Key words: war injuries, external fixation, damage control orthopaedics

Introduction

Throughout history, orthopaedic surgeons and their predecessors have played a crucial role in the treatment of war wounded. There is no better example of orthopaedic surgeon involvement in casualty care than our current conflicts in Iraq and Afghanistan. Approximately 70% of injuries sustained during these conflicts involve the musculoskeletal system, and 54% involve the extremities (1,2). The current weapon of choice used by insurgent forces is the improvised explosive device (IED). IED's are constructed from homemade or commercial explosives or conventional munitions and may be employed as buried devices, car bombs, or antipersonnel mines, and detonated by a number of methods (3,4). A recent evaluation of injuries sustained in combat demonstrates that 75% of injuries are inflicted by IED's and 16% from gunshot wounds (5).

Regardless of the injury mechanism, 82% of fractures sustained by our wounded warriors are open (5). Many of these long bone fractures have severe accompanying soft tissue injuries and require emergent irrigation and debridement and provisional stabilization, generally by external fixation, in theater. These procedures are complicated by austere environments, potential lack of conventional orthopaedic resources and equipment, threat of enemy attack, and reliance on aeromedical evacuation for patient transfer to higher echelons of care. The purpose of this manuscript is to review the principles of damage control orthopaedics and discuss techniques for combat and austere environment external fixation that may be useful to our civilian counterparts providing care in mass casualty and disaster relief situations.

Damage Control Orthopaedics

Damage control is, among other origins, a naval term used to describe procedures performed to keep a compromised ship afloat while at sea. In medicine, this term was first utilized by general surgeons to describe immediate

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life-saving procedures to control hemorrhage and minimize lengthy definitive procedures that may be deleterious to patients following trauma. Only after the patient is adequately resuscitated and stabilized are definitive procedures performed (6). The term ‘damage control orthopaedics’ (DCO) was first used by Scalea et al. (7) to describe a similar approach to musculoskeletal injuries. Temporizing treatment measures such as external fixation are used on unstable or borderline patients to stabilize major orthopaedic injuries, halt ongoing musculoskeletal injury, and control hemorrhage. These principles are very applicable to injuries sustained on the battlefield or in the wake of a disaster. Additionally, battlefield orthopaedics must take into account factors such as the number of patients needing treatment, available resources, stability for transport, weather conditions, and availability of medevac (1).

The role of external fixation in DCO has been well described (6). In the civilian trauma setting, DCO refers predominantly to the use of expedient external fixation in the acute management of pelvis and long bone fractures in the multiply injured patient. This provides early fracture stability while avoiding deterioration of the patient’s physiologic condition as a result of either prolonged surgery or embolic phenomena related to the immediate definitive fixation of long bone fractures. External fixation also allows the surgeon to provisionally manage peri-articular fractures, awaiting the recovery of the soft tissue envelope to the point where a formal surgical approach and internal fixation is safe with respect to wound complication risks (8,9).

In the austere environment typically associated with combat extremity injuries, natural disasters, and mass casualties, ‘damage control’ and the role of acute external fixation is expanded beyond this. In addition to limiting damage to the extremity and the overall well being of the patient, it represents the primary, and sometimes only, mode of instrumented fracture fixation available to the surgeon (Fig. 1). External fixation is a rapid means of providing relative fracture stability in preparation for the transport of patients to a higher level of care for continued management, and in temporizing treatment to a large number of patients quickly in the setting of mass casualty events.

Balanced traction is usually impossible during patient transport, and the potential duration of transport and the possibility of delays render mobile external traction devices imprudent. Splint stabilization is a safe and readily available alternative method of imparting relative temporary stability to long bone fractures in austere environments. External fixation, however, offers several compelling advantages in this unique setting. Injuries sustained in combat, terror attacks, or natural disasters tend to be high-energy, often penetrating, injuries. As such, there is a high incidence of open wounds, necessitating serial wound evaluation and debridement or frequent dressing changes as part of wound management. This is significantly easier for both the patient and the provider to manage with the patient in an external fixator than immobilized in a splint. Additionally, management of negative pressure wound therapy (NPWT) dressings, and monitoring patients for potentially evolving compartment syndrome, is simplified.

FIGURE 1 Hoffman II sterile pre-packaged external fixator for use in the combat environment. The package includes hand drill, as well as 5-mm pins, and sufficient connecting hardware to construct a basic tibial frame.

Techniques for External Fixation in the Austere Environment

The specific techniques employed for damage control external fixation in the austere environment vary greatly as a function of patient volume, associated injuries, open wounds, and available equipment. The general principles, however, remain the same.

First and foremost, standard external fixation principles apply. Optimizing fracture reduction, cortical contact, and increasing pin diameter will increase the stability of the construct. Additionally, increasing the number of connecting rods, decreasing their distance from the bone, increasing the number of pins, and optimizing their spread and location relative to the fracture site also improve stability (10). These factors, however, must be prioritized against competing interests, particularly with respect to the zone of soft tissue injury.

Whenever possible, it is advisable to keep external fixation half pins out of open wounds. This simplifies wound management particularly with respect to closure and soft tissue coverage, and makes application of NPWT dressings substantially less complicated. It is also critical to consider the definitive management of fractures when applying the external fixator, and take care not to obviate the optimal surgical exposure and, when practicable, keep half pins out of the zone of both the surgical approach and the potential definitive implants.

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In austere environments, fluoroscopy, and even power drills and pin driving equipment may not be available. Instead, pins are placed with hand drills. When applying an external fixator in this fashion, the half pins must be placed safely outside of the area of fracture extension to ensure good bicortical purchase, prevent propagation of fracture planes, and prevent conversion to an open fracture by exposure of fracture ends and hematoma via the pin tract. Pin penetration must be determined by feel of the near and far cortices, in conjunction with a sense of how much the pin has advanced relative to the estimated thickness of the bone. Fracture reduction is achieved by regaining length through traction, and by clinical assessment of limb alignment and reducing gross deformity.

Pelvic External Fixation

Pelvic external fixation can be accomplished by placement of pins in the iliac crests (resuscitation frame), or in the supra-acetabular bone (Hanover or Sport frame). The most expedient method is the placement of a resuscitation frame, and this can be done, if necessary, without fluoroscopy.

When fluoroscopy is available, and a percutaneous technique is performed, transverse incisions are preferable to prevent the potential need for additional transverse relaxing incisions after fracture reduction. The most medial pin is placed approximately 2 cm lateral to the anterior superior iliac spine (ASIS), and additional pins placed farther laterally. Two or three pins can be placed in each iliac wing. Pins can be 5 or 6 mm in diameter, and can either be placed in a multiple pin clamp, or independently placed and incorporated into the external fixator construct. Kirschner wires can also be placed along the inner and outer tables to assist with pin orientation between the tables of the ilium during insertion. In general, pins should be placed to converge on the hip joint center, to minimize soft tissue impingement as the patient sits up in bed.

If an open technique is used, the incision is directed along the iliac crest, and should be placed medial to the iliac crest to minimize excessive skin tension on the pins after reduction. Especially if fluoroscopy is not available, it can be helpful to use a drill to open the cortex of the iliac crest, and place blunt pins (if available) by hand, allowing them to pass between the tables, rather than passing in and then back out of the ilium.

The reduction should be performed with an internal rotation force delivered through the iliac wing itself, rather than through the external fixator pins. This is done to minimize the risk of loss of pin purchase during the reduction maneuver. A simple “A-frame” construct is usually sufficient. If you are utilizing a system with 8 mm connecting rods, stacking two sets of rods is advisable. This is not generally necessary when using systems with larger diameter connecting rods (11).

Femoral and Tibial Shaft Fractures

The techniques for femoral and tibial shaft fracture external fixation in the austere environment do not differ greatly from those performed in the civilian setting. Equipment availablility is often the determining factor of the technique employed.

For femoral shaft fractures, we prefer to place two pins (5 or 6mm in diameter) anterolaterally both proximal and distal to the fracture, at approximately 45 degrees from the sagittal and coronal planes (Fig. 2). This preserves the soft tissue envelope for a lateral incision if needed for definitive management, and helps facilitate patient transport in tight quarters, without painful repetitive contact of the construct with outside objects or personnel. When available, multiple pin clamps are utilized, with outrigger posts angled to minimized the working distance of the connecting rods, yet allow access for management of any open wounds. Two sets of connecting rods are used to improve the stability of the construct in the pane orthogonal to the external fixator pins. For external fixation of tibial shaft fractures, we employ a similar technique, with two 5-mm pins placed perpendicular to the face of the tibia proximally and distally to the fracture, with multiple pin clamps and outrigger posts again angled to minimize the working length of the connecting rods (Figs. 3 and 4). It is important to make every attempt to avoid open wounds, and to keep external fixator pins out of the zone of injury and extent of the fracture. Additionally, the potential necessity of using external fixation as part of

FIGURE 2 Femoral shaft fracture provisionally fixed with external fixation. The pins are placed anterolaterally.

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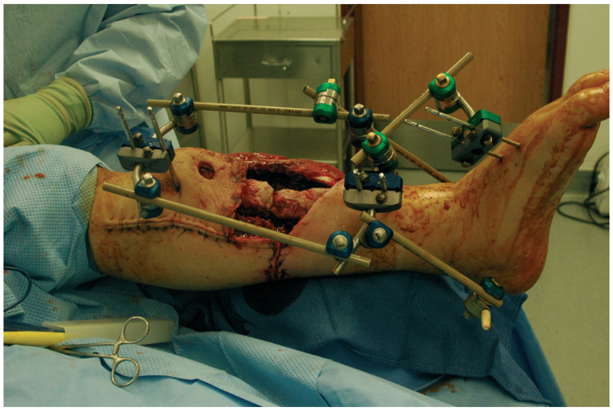

FIGURE 3 Tibial shaft fracture stabilized with external fixation.

FIGURE 4 A) Pins can be placed perpendicular to the face of the tibia, facing anteromedially, or they can be placed anterior to posterior just off the medial crest of the tibia. B) Tibial external fixator pin placed more laterally to avoid fasciotomy incision, protecting the skin bridge, and making placement of NPWT dressings easier.

the definitive treatment should be considered in decision-making regarding pin placement. Reduction can then be afforded with standard reduction techniques, and verified with fluoroscopy, or by traction and restoration of gross limb alignment, when fluoroscopy is not available.

Humeral Shaft Fractures

In the austere environment associated with combat- or natural disaster-related extremity injuries, humeral shaft fractures are more commonly open injuries, and are often associated with large soft tissue wounds, and are likely to represent only a part of injury pattern in a polytraumatized patient (2,4,5). While splint immobilization remains a viable option in this setting, particularly when time and resources are limited, external fixation is often the best method of initial management of open humeral shaft fractures.

External fixator placement for humeral shaft fractures is best done utilizing an open technique, in order to minimize the risks to the axillary nerve proximally, and the radially nerve distally. Longitudinal incisions are made, and dissection is performed sufficient to directly visualize the point of pin insertion on the osseous humerus. The construct is similar to that employed in other long bone fractures, applying standard external fixation principles.

Joint Spanning

For intra- and juxta-articular fractures, fracture-dislocations, and unstable multi-ligamentous injuries, joint-spanning external fixation is often necessary. The general principles for damage control joint-spanning external fixation are similar to those for management of diaphyseal long bone fractures. Provisional external fixation pins should be placed outside the zone of injury using similar techniques with similar goals in mind: adequate stabilization of the injury, avoidance of complicating future definitive treatment strategies (when available) by placing pins out of the fixation zone.

For joint-spanning external fixation of the knee, pins are most commonly placed from the anterolateral femur and the anterior or anteromedial tibia, depending on the injury pattern (Fig. 5). This anterior femoral pin placement avoids articular penetration, preserves the lateral soft tissues for distal femoral plate placement or intramedullary nail locking, and eases the placement of spanning rods without impingement on the anterior knee soft tissues, permitting periarticular wound care. Ankle-spanning external fixation is typically placed from the anteromedial tibia to the calcaneus in a so-called delta frame configuration. More than one half pin or transfixion pin is required in the foot in order to achieve optimal three-dimensional control of the fracture as well as to prevent ankle equinus. This can be accomplished with multiple calcaneal transfixion pins or the addition of medial and lateral forefoot

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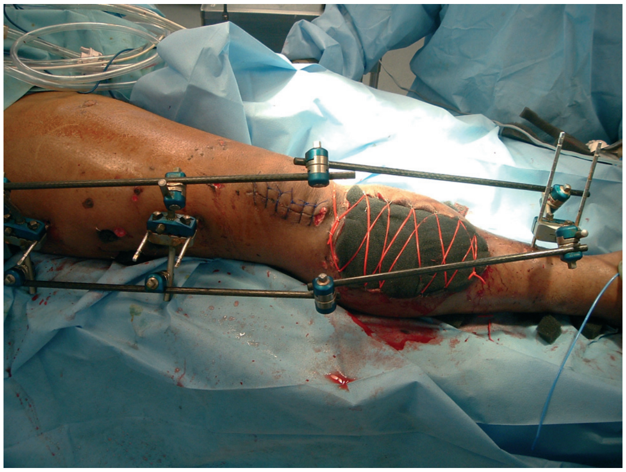

FIGURE 5 Knee spanning external fixator. The pins are placed anterolateral in the femoral shaft, and anterior to anteromedially in the tibia. With the equipment available in sterilely pre-packaged external fixators, long enough bars are not available, and shorter bars must be connected with additional bar-to-bar clamps. Note the placement of the pins distal in the tibia to remain out of the wound and zone of injury, as well as any potential definitive fixation implants.

half pins. A splint in addition to external fixation can be used for this purpose but limits wound access and can be more labor intensive. The placement of posterior dual struts (either medial and lateral co-linear bars or two short bars joined at a right angle) facilitates elevation of the extremity and mitigates concerns regarding the predilection for heel decubitus ulcer formation in these patients.

For elbow-spanning external fixation, connecting rods may be placed between pins in the humerus to either the radius and/or the ulna (Fig. 6). The ulna is subcutaneous and ulnar pin placement is generally safe, but due care

FIGURE 6 Elbow spanning external fixator for severe forearm injury. The pins are placed with open technique in the distal humerus, and placed distal in the forearm to span the zone of injury.

using a larger incision and spreading bluntly to bone is necessary in the distal humerus and distal radius to avoid injury to the radial nerve proper and superficial cutaneous branch of the radial nerve, respectively. Half pin placement in the proximal radius is possible by using a forearm rotation to avoid the posterior interosseous nerve, but is generally avoided due to the proximity of the motor nerve and the thicker soft tissue envelope at that level.

Traction can be useful for proximal femur, hip, and acetabular fractures in circumstances where expedited definitive treatment is possible. Techniques spanning the hip joint are discussed further below. Spanning of the shoulder joint is rarely required as a sling or shoulder immobilizer generally adequate for proximal humerus and glenoid injuries.

Hip and Acetabular Fractures

In the austere surgical environment, the surgeon may not have the time, equipment, or resources to perform definitive fixation of femoral neck or intertrochanteric fractures (Fig. 7). Skeletal traction is the preferred method for temporizing management of acetabular and proximal femoral fractures. Unfortunately, in the fluid environment of combat casualty or mass casualty care, transporting patients with skeletal traction may be difficult or impossible. This being the case, external fixation is preferable to the use of hare traction, Thomas splinting, or other skin traction techniques, as these methods can be associated with devastating skin and nerve complications,

FIGURE 7 Improvised traction device for aeromedical evacuation. A spring-based scale is used against counter-traction in the litter to both provide, and monitor traction for an acetabular fracture.

In these instances, external fixation is a viable option. When external fixation of proximal femur fractures is performed, we prefer to employ a technique without spanning the hip joint, and instead place pins entirely in the proximal femur. The external fixator can be placed laterally, and pins placed in the greater trochanter, or up the femoral neck if necessary, to stabilize these injuries.

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particularly when the ability to closely monitor patients is limited.

In acetabular fractures with either an unstable hip joint or intra-articular incarcerated fragments, however, the hip joint must be spanned. This technique has been described in the pediatric population in distraction arthroplasty for the treatment of Perthes disease, and proximal femoral osteomyelitis (15,16,18) but its use as "traveling traction" in trauma has not been well described.

The pins are typically placed in the iliac crest in the same fashion as for a pelvic external fixator. Pins are then placed laterally in the proximal femoral shaft, and connected with multiple connecting rods (Fig. 8).

In our experience with this technique in combat casualties, it is effective in immobilizing the hip for comfort during transport, but its ability to provide distraction across the hip joint is less reliable. The soft tissue envelope about the hip is robust, resulting in a necessarily large distance from the bone to the connecting rods, and the working length of the fixator construct is great, secondary to the necessary pin orientation in the iliac crest. These factors, combined with the substantial muscle forces across the hip joint, make it difficult to achieve effective distraction across the hip joint. Additionally, the patient needs to be log-rolled for transport, and multiple transfers can result in the loss of iliac crest fixation.

Combat and Disaster-Specific Limitations and Workaround Techniques

Placing damage control, provisional, and even definitive external fixation devices in an austere environment poses specific technical challenges due to resource limitations. First and foremost among these is the frequent lack of fluoroscopic capabilities. Recent combat surgery experience as demonstrated that this may be due to either the overt lack of a C-arm or frequent unavailability of existing devices due to power outages, generator failures, or component breakage or malfunction; technical support and repair services are often limited and fluoroscopy machines are, in general, not ruggedized.

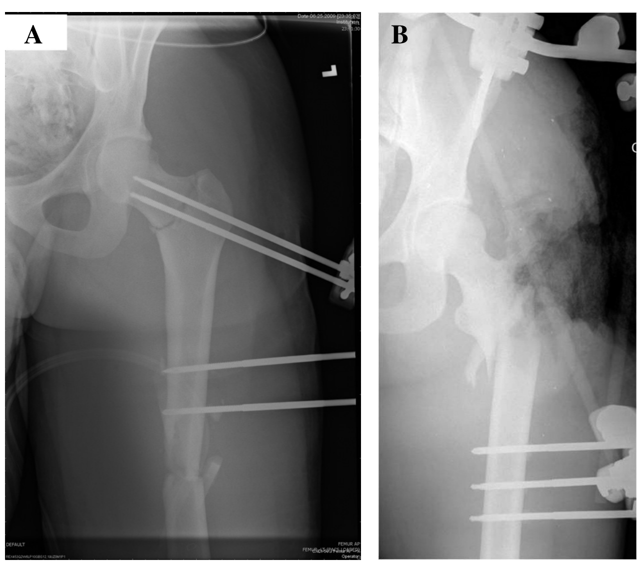

FIGURE 8 A) Proximal femur fracture with temporizing stabilization with non-hip-spanning external fixator; B) Proximal femur fracture stabilized with hip-spanning external fixation.

Placing external fixation in the absence of any radiographic capabilities is possible by elucidating fracture anatomy by careful physical exam. This has a tendency to result in less than optimal pin placement due to difficult to detect comminution or fracture propagation, but is generally preferable to no treatment at all and is safest for diaphyseal fractures without pain or deformity at the adjacent joints. If no radiographs are available and the fracture is peri-articular, placing joint-spanning external fixation may be advisable until some form of radiographic evaluation is available. Fortunately, most deployed medical units with external fixation capabilities in the Global War on Terror also have at least conventional radiography available, as do many natural disaster response teams. A recent review of 55 Type III tibia fractures demonstrated that provisional external fixators placed in the combat theaters were generally safe and effective, with no major complications (18).

When placing external fixation devices without fluoroscopic guidance, it is helpful to measure the radiographic distance from nearest extent of the fracture to externally palpable anatomic landmarks (e.g., from the most distal and proximal aspects of the fracture to the knee joint line and the tip of the greater trochanter, respectively, for a diaphyseal femur fracture). Half pins should ideally be placed at least 1 to 2 inches away from the fracture to avoid complicating future treatment and ensure a stable construct is not compromised by unappreciated fracture extension. Further spread of pins may be necessary for open injuries to permit adequate surgical extension of the traumatic wound, delivery of the bone ends and fracture debridement; placement of pins within traumatic wounds should be avoided whenever remotely practicable. A standard percutaneous stab incision is then made at the desired pin location, and blunt spreading to bone with a hemostat is performed in the usual fashion. By then walking the half pin anteriorly and posteriorly along the bone for generally cylindrical bones (e.g., femur, humerus), the most proud portion of the cortex is identified to ensure by cortical purchase and avoid tangentially uni-cortical pin placement or sliding off the bone with attempted pin advancement. Once the pin is started into bone, steady force and rate of either a manual or power drill is advised because this provides optimal tactile feedback informing the surgeon of

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when the far cortex is encountered –changes in advancement rate, applied force, or starting and stopping the drill repeatedly tend to dramatically lessen the reliability of this tactile cue. Once the far cortex is encountered, and additional 8 to 10 turns will generally result in optimal bicortical purchase with the pin protruding 6 to 9 mm beyond the far cortex (15). When construct stability is a major concern and doubt regarding pin placement exists, a few additional millimeters of pin protrusion is usually preferable to a unicortical pin, but intentional far protrusion of pins is ill-advised due to risks of soft tissue irritation or overt neurovascular injury. When placing more than two pins to be married to a single multi-pin clamp, the most proximal and distal pins in each clamp are placed prior to any central pins to avoid inadvertently "walking" oneself off of the bone. Blind reduction is then achieved via a combination of longitudinal traction, gross restoration of anatomic alignment, translation, and rotation, and, for non-comminuted fractures, palpable opposition of opposing cortical fragments.

When sterile instruments are not available, peel-packed composite pin-to-bar external fixator kits are extremely useful (Fig. 1). If only unsterile, civilian power tools are available, sterile technique for placement of half and traction pins is still feasible by using a one sterile, one clean hand technique, with particular attention to not touching the business end of the pin with the contaminated hand. Several varieties of hand drill are available for pin placement when power tools are not available. This makes half pin placement modestly more difficult and markedly slower, but reliable construct stability can be achieved in virtually all cases with appropriate diligence. Bracing the fractured segment or having an assistant apply counterpressure is always advisable when drilling in bone, but this is even more essential for manual pin placement in order to avoid pin slippage or angulation. Self-drilling, self-tapping pins are likewise always useful for hastily placing an external fixator on a sick patient or in an austere environment, but become even more essential when the pins must be placed manually as these reduce both the number of steps and the margin for error involved.

As for any external fixator placed for open trauma, enough space below clamps and connecting rods should be left to facilitate wound care. Depending on the resources available, wound management may range from negative pressure wound therapy with reticulating open cell foam (NPWT/ROCF), antibiotic bead pouches, or simple moist or Dakin's solution-soaked gauze. Although we do not advocate placing pins directly into a traumatic wound, sometimes this is either unavoidable or a pin must be placed close enough to an incision or wound that the pins must be "incorporated into the NPWT dressing in order to achieve and maintain a suction seal. In these instances, pre-wrapping the near portion of the external pin with a strip of the occlusive dressing or Ioban (3M, St. Paul, MN), prior to trying to bridge the wound to the pin, placing other circumferential adherent dressings over the top of the occlusive dressing, and overwrapping the pins with snug gauze to maintain pressure and prevent loss of suction are all useful adjunctive techniques.

In addition to patients in extremis, mass casualty situations or even literally operating in an unsafe environment may make time of the essence when placing provisional or damage control external fixation. Towards this end, transfixion pins in the calcaneus, proximal tibia, and/or distal femur can be placed quickly and safely without fluoroscopic guidance. This so-called 'traveling traction' can provide adequate distraction and provisional stabilization of many lower extremity injuries at or below knee level in an expeditious fashion.

Provisional External Fixation as Definitive Treatment

When operating in an austere combat environment or disaster relief scenario, advanced definitive treatment options may be limited, lacking, or completely absent. Under these circumstances, monolateral external fixation may ultimately need to serve as the definitive treatment of the patient's injuries. One drawback to pin to bar external fixation is the lack of rigidity of the construct and the so-called play in the system. For non-comminuted fractures, greater stability can be achieved via cortical opposition and compression; after optimizing fracture reduction, fracture compression can be facilitated without compromising the achieved reduction by loosening one side of the frame, compressing the fracture, re-tightening the frame, and repeating with the contralateral clamps and bars.

Monolateral pin-to-bar external fixators can be modified to tolerate full patient weightbearing by placing additional orthogonal half-pins above and below the fracture with additional longitudinal and transverse or oblique rods, or the addition of more than one calcaneal transfixion pin.

Controversies in Damage Control Orthopaedics

Vascular Injuries and External Fixation

The timing of fracture stabilization in the setting of a vascular injury requiring repair continues to be a point of contention between orthopaedic surgeons and their vascular colleagues. Advocates of vascular repair prior to skeletal fixation cite a study by Starr et al. that demonstrated no incidences of disruption of a prior vascular repair during subsequent fracture fixation (19). This study, which only evaluated fractures of the femur concomitant with vascular injuries requiring repair, demonstrated no outcome differences in 26 patients with internal fixation

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of femoral shaft fractures before or after vascular repair. They advocate for temporary shunting if ischemia time is expected to be prolonged, and likewise (20) advocated for vascular repair prior to skeletal stabilization. They studied 27 patients with long bone fractures and associated vascular injuries requiring repair. Their outcome measure was an increased, but not statistically significant, difference in rate of fasciotomy (in the case of lower extremity injuries), in the patients undergoing fracture fixation first. This difference was attributed to increased ischemia time as the vascular repair was delayed by fracture stabilization. Twenty-three of the patients in the series were treated with immediate definitive internal fixation, whereas only four were treated with temporizing external fixation. They also noted no iatrogenic vascular repair disruptions with subsequent fracture fixation.

In skilled hands, external fixation of long bone fractures can be performed very quickly, much faster than the 3- to 4-hour delays documented in the McHenry series where patients were treated predominantly with immediate definitive fixation. Karavias et al., in 1992, advocated for initial external fixation followed by vascular repair (21). In the austere combat environment, we recommend expeditious temporizing external fixation, followed by vascular repair. This decision, however, remains one that should be managed on a case-by-case basis, and one that should be made as the result of a multidisciplinary discussion.

Conversion from Provisional External Fixation to Intramedullary Nailing

The use of external fixation as provisional fixation of a femoral shaft fracture in damage control orthopaedics, in open fractures requiring serial debridement, or to protect a vascular repair is commonplace. For combat casualties, external fixation provides a means of traveling traction needed for multiple medevac flights. In addition, external fixation allows mobilization and positioning of the patient for pulmonary toilet and nursing care. Nowotarski et al. reviewed 59 femur fractures in 54 patients treated initially with external fixation and subsequently converted to intramedullary nail stabilization. The average time to conversion was seven days and 55 fractures underwent transition to intramedullary nailing in a single procedure. The remaining four had draining pin sites and were transitioned to skeletal traction 8 to 15 days prior to intramedullary nailing. The results demonstrated a 1.7% infection rate and union rates at 6 months was 97% (22). The authors concluded that conversion from external fixation to intramedullary nail was safe and had a low associated infection rate. Recent literature has shown that conversion from external fixation to intramedullary nail is safe when performed within 2 weeks in the absence of pin sites infection (23,24). If prolonged external fixation is required or a pin site infection develops, a pin holiday can be performed and the patient placed in skeletal traction until time of definitive intramedullary nailing.

The use of external fixation as a means of provisional stabilization in tibia fractures is well established. However, the optimal timing and/or acceptable limitations timing of conversion to definitive fixation (intramedullary nailing or plate osteosynthesis) remains unknown. Similar to femoral shaft fractures, conversion to definitive fixation from external fixation depends on the patient's physiologic and soft tissue status. In combat casualties, tibia fractures are the most common major extremity injury, comprising 48% of lower extremity fractures, with 79% being open fractures (5). In a meta-analysis, Bhandari et al. (23) evaluated tibial fractures managed with planned conversion to intramedullary nailing. Nine studies were included with a total of 268 patients and including 52% open fractures. They concluded if external fixation use was limited to 28 days or less there was a 83% decrease in infection risk (23). Clearly, earlier conversion, when practicable based on patient and injury factors, is preferred; however, given the paucity of literature on conversion of external fixation of tibia fractures, more in-depth studies are needed and the decision and timing of conversion should be determined on a patient by patient basis.

Fasciotomy

Leg Fasciotomy

In the austere environment of combat casualty care or mass casualty setting resulting from a natural disaster or terror attack, the surgeon should have a low threshold for release of a suspected or impending compartment syndrome of the leg. While the presence of a tibia fracture or a crush injury to the leg, is not itself an indication to perform compartment releases in the austere environment, early release in the setting of combat extremity injuries has been shown to result in a decreased rate of complications associated with the condition (25) Compartment pressure testing is unlikely to be available, and the surgeon must rely on clinical suspicion and exam; however, the feasibility of close clinical monitoring with serial exams in a mass casualty or disaster scenario is itself suspect. Furthermore, patients evacuated to other treatment locations may be without surgical care for unpredictable periods of time, and the initial provider generally does not accompany the patient. Patients may also be traveling by air, and there is conflicting data on whether or not altitude causes an increase in compartment pressures (26,27) Therefore, given the unreliability of clinical exam in the diagnosis of compartment syndrome and the potential infeasibility

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of serial exams, combined with the morbidity associated with missing the diagnosis, it is advisable to be aggressive in the treatment of potential compartment syndrome by opting for early surgical release if there is clinical concern.

Lower leg fasciotomies should be performed using a two-incision technique, and with 15 to 20 cm incisions spaced at least 8 to 10 cm to minimize the risk of necrosis of the intervening skin bridge. The lateral incision should be centered over the intermuscular septum, roughly 2 cm anterior to the head of the fibula. The medial incision should be located 1-2 cm posterior to the posterior margin of the tibia, to ensure that the bone remains covered after the release is complete (Fig. 9).

Foot Fasciotomy

Treatment of compartment syndrome of the foot is controversial. There is disagreement as to whether the sequelae of an untreated compartment syndrome are worse than the complications associated with the surgical management of the condition. If foot releases are to be performed, it should be performed as early as possible in the disease process. Continued nonoperative management should be considered in the setting of a foot compartment syndrome that is detected greater than 12 hours after injury. Infection risk and surgical complication rate increases if releases are not performed within this 12-hour window. There are four required incisions if all compartments are involved. Two dorsal incisions, a medial forefoot incision along the plantar surface of the first metatarsal, and a calcaneal incision based medially from the posterior extent of the calcaneal tuberosity towards the base of the first metatarsal.

FIGURE 9 Leg fasciotomies performed for tibia fracture. The incisions are of appropriate length to adequately release all compartments, and are well spaced to prevent compromise to the anterior skin bridge.

The current AAOS risk management guidelines recommend early release to avoid the disabling sequelae of a missed compartment syndrome. Concern remains, however, about a potentially increased risk of infection and wound complications with foot compartment releases in the austere and potentially contaminated environment of combat extremity injuries. Furthermore, whether or not other outcomes (e.g., neurologic function, neuropathic pain) are improved in patients undergoing fasciotomy remains controversial (28).

CONCLUSION

The general principles of external fixation apply in austere surgical environments, as they do in the civilian hospital setting, and it remains the mainstay of the initial care for extremity fractures in this setting. Perhaps ‘damage control’ is not the most appropriate term, as this early management is not so much an attempt to delay treatment and not induce further damage to the patient and the limb. Rather, it should instead be thought of as a calculated and systematic initiation of the process of limb reconstruction. Approaching ‘provisional’ external fixator placement through this shifted paradigm, one can ensure both that initial patient management is optimized and subsequent treatment options are not compromised; furthermore, when external fixation becomes, by occasional necessity, the definitive or only treatment the patient will receive for their fracture, this possibility was considered prior to initial placement of the device and the external fixator can be readily adapted to that role.

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