

External Fixation and Temporary Stabilization of Femoral and Tibial Trauma

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External fixation is an important option in the acute management of unstable femoral and tibial fractures and the temporary stabilization of periarticular injuries of the knee or ankle. The value of external fixation as the modality of choice in selective civilian and military applications is well documented. Primary indications include damage control for multitrauma management in patients with concomitant traumatized integument and/or excessive swelling and/or systemic instability and stabilization for transport in hostile or austere environments. The purpose of this article is to discuss the indications for temporary external fixation of lower extremity long bones and complicated distal femoral, proximal tibia, and tibial plafond fractures; to outline technical considerations in the application of temporary external fixation devices; and to summarize the experience in the use of prepackaged external fixators and their indications in combat. (Journal of Surgical Orthopaedic Advances 20(1):74–81, 2011)

Key words: external fixation

External fixation as a temporizing modality in the rapid stabilization of lower extremity long bone and periarticular injuries is well documented in both civilian and military situations. Simple-to-apply fixators may be utilized in hostile and austere environments without radiographic control in order to provide temporary stabilization, to facilitate transport, and to diminish further soft tissue injuries. Recent experiences with prepackaged external fixators in combat situations show them to be effective in preventing further damage during transport prior to definitive management. In more controlled environments, uniplanar fixation affords stable temporization in hemodynamically or systemically compromised multitrauma patients or when definitive treatment is not preferable.

Rigid and semirigid external fixation prevents further soft tissue damage, allows recovery of traumatized skin and subcutaneous tissue, permits wound management, allows elective reconstruction of complex fractures and periarticular injuries and does not negatively impact systemic complications in multiply injured patients. This article discusses the historical aspects of external fixation and delineates indications, contraindications, potential

complications, technical considerations, and case examples to help the surgeon best determine the role of this modality in lower extremity fractures. In addition, it reviews the role of self-contained and prepacked sterile field packs suitable for use on a battlefield or under austere conditions.

External Fixation

Conceptually, external fixation utilizes an external splinting device, most commonly a bar or frame that is attached to the bone. The interosseous anchoring system is most commonly a pin or wire. Pins may be half-pins or full pins, smooth or threaded; they may be self-tapping or require predrilling or tapping. Wires may be thin or thick and tensioned or not tensioned. Most commonly threaded self-tapping half-pins are utilized. The components that facilitate attachment of the pin to the bar include pin-bar/frame articulations and external supports or crosspieces. Threaded pins are inserted into the bone with a minimum of two points of fixation above and below the fracture. The strength of the construct may be increased by “double stacking” the connecting bars or adding an additional set of pins and bar(s) in a different plane, creating a biplanar device. Thin wire fixation employs tensioned wires connected by two or more rings and linked by rods or articulated members and is, in general, a multiplanar construct. Hybrid fixators combine tensioned smooth wire and threaded pin fixation techniques into a single construct. In the temporary fixation of lower extremity complex injuries, uniplanar devices

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Received for publication December 25, 2010; accepted for publication December 26, 2010.

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1548-825X/11/2001-0074\$22.00/0

are preferred; however, there are injuries that cannot be stabilized optimally with uniplanar devices. These simple constructs may be uniplanar or biplanar and are coded as “application of uniplanar device” even if the pins are not parallel.

External fixators may be applied in one, two, three, or more planes. The nomenclature is confusing since CPT coding differentiates only between one or more planes. However, the complexity of the apparatus; the number and combination of pins, wires, and tensional wires; and the time required are the most clinically relevant. CPT 20690 is “application of a uniplane (pins or wires in one plane), unilateral external fixation system.” “Application of a multiplane (pins or wires in more than one plane), unilateral, external fixation system” (e.g., Ilizarov, Monticelli type) is coded as 20692. This is confusing since simple four-pin devices (e.g., Hoffmann II, Stryker) may be applied in a uniplanar or biplanar manner with similar time and ease of application (1). The former is unilateral; the latter is multiplanar. Both are simple constructs and the multiplanar code, while correct, is at best misleading.

For discussion in this article, we have divided fixators into simple or complex and consider damage-control fixations, in general, to be simple with a minimum number of pins applied in one or two planes and able to be applied easily with no or minimal x-ray control.

Historical Perspective

The original description of the management of long bone fractures with external fixation is attributed to Keetley in 1893 (2). In an effort to decrease malunion and nonunion, rigid pins were inserted percutaneously into the femur and attached to an external splint system. This concept was refined by Lambotte (1912), who added threaded pins and clamps to facilitate the pin–bar interface (3). Raoul Hoffmann, Roger Anderson, and others refined these techniques and developed closed reduction techniques, minimally invasive protocols, and stable constructs. Current external fixation systems still utilize these primary components.

In the early and mid-20th century, good outcomes relative to other forms of treatment were reported with external fixation devices used in long bone fractures (4, 5). However, nonunion, malunion, and pin tract infections complicated external fixation treatment. Open tibial fractures, treated preferentially with external fixation in the 1970s and 1980s, had an inappropriate rate of malunion and pin tract infection (6, 7). More recently, open tibial shaft fractures treated with definitive external fixation have shown lower patient-oriented outcome measures (8).

Pins are the critical element in the external fixation system. They transmit forces from the injured bone to

the external support device or bar and have the potential to loosen and over time may become infected (9). Breakdown of this interface can result in loss of fixation, increased motion, and a predisposition to infection. Often these complications are severe enough to necessitate early termination of external fixation and contribute to poor results seen in this form of management (9).

In the 1960s, acute stabilization of long bone injuries in the multitrauma patient was associated with an unacceptably high mortality rate (10). Acute respiratory compromise and pulmonary failure were attributed to fat emboli from intramedullary instrumentation and suboptimal mechanical ventilation protocols. Mortality rates approached 50% (11). The direct response to these events led to long bone injuries in multiply injured patients being treated with splints, casts, or traction (for 2 weeks or more) prior to definitive internal/external fixation. The paradigm of traction or casting without rigid fixation before definitive stabilization began to change in the 1980s when Bone et al. published a prospective randomized trial comparing early fixation of femoral shaft fractures with traction and delayed fixation (12). The findings of this study showed that the early rigid fixation group had lower rates of acute respiratory distress and provided compelling evidence that early intervention involving rigid fixation was preferable in multiply injured patients. Average time in traction decreased from the previous 9 days to 2 days (13). The enhancement of physiologic factors secondary to long bone stabilization in critically injured patients was demonstrated. However, even the 1 to 2 days of traction and unstabilized extremities was problematic. Given this need for early stabilization, multitrauma patients underwent definitive internal/external fixation of fractures in the acute setting. The prolonged operative time necessary for definitive fixation of long bone fractures, the additional blood loss, and the physiologic stress of anesthesia negated the benefit of early rigid fixation. This led to the concept of damage control orthopaedics (DCO) championed by Pape and others (10). DCO involves the acute rapid temporary immobilization of orthopaedic injuries using uniplanar and bridging fixators to provide temporary stability while the patient is stabilized and definitive care is provided during the ensuing hospitalization.

By providing rigid temporary external fixation, the patient may be stabilized in terms of respiratory and hemodynamic parameters and the soft tissue can recover and wounds may be managed. This allows for elective definitive fracture management. Therefore, total care could be provided without requiring definitive early fixation (13, 14). Although definitive indications and protocols for damage control orthopaedics are evolving, it is evident that damage control is of benefit in specific patient populations. In the general surgery literature, damage control laparotomy improved surgical survival rates in critically

injured patients after abdominal injuries (15). This concept was adopted by orthopaedic surgeons by the use of rapid stabilization of major orthopaedic injuries with emphasis on minimizing blood loss and decreasing the morbidity of the initial operative exposure.

The external fixator is an ideal device to achieve these goals. It can be applied rapidly with minimal blood loss. It may be utilized in settings where imaging is not feasible or is unavailable. It allows unimpeded access to soft tissue wounds, permits direct evaluation of possible compartment syndrome(s), and allows care of open fractures. In addition, external fixators may be applied without placing hardware in the zone of injury and can provide immobilization at a site distant from the major wound or fracture. External fixation devices may also be applied without further soft tissue insult and can be disassembled or reconfigured in order to allow debridement or to adapt to changing soft tissue status. In contradistinction, splinting and traction of these injuries may not allow easy access to the soft tissues without untoward motion and do not allow easy access for compartment pressure monitoring. Unlike traction, external fixation does not confine the patient to a bed or interfere with nursing care, transfers, and pulmonary toilet.

Researchers have shown that staged management of femoral shaft fractures in critically ill patients can be beneficial. Damage control orthopaedics has been demonstrated to potentially improve survival rates and minimize complications (16, 17). Pape showed lower rates of pulmonary complications in those patients managed with external fixation followed by intramedullary nailing in femur fractures (18). External fixation is also a valuable adjunct in hostile environments in the management of wounded soldiers. The current conflicts in Iraq and Afghanistan have produced high numbers of severe extremity injuries (19). The development of clinical treatment principles has relied heavily on external fixation (20). The wounded warriors show many of the same indications as civilian populations in terms of minimizing the physiologic insult of the initial operative intervention in the critically injured patient while allowing rapid stabilization in austere battlefield conditions, permitting transport with less pain and less additional morbidity.

Ficke and Pollak demonstrated the logistical challenges which make definitive fixation in the field difficult and emphasized the need for acute damage control in austere environments where proper image intensification, appropriate sterile conditions, proper implants, and access to power equipment are not available (20). In austere and hostile environments, uniplanar external fixation has proved to be a safe and reliable option (20, 21). These principles may be applied in civilian mass casualty events during natural disaster or terrorist acts as well.

Indications

The current indications for use of damage control techniques with uniplanar fixation include the stabilization of open or closed fractures or unstable periarticular injuries. External fixation should be considered 1) in unstable patients with multiple other injuries and concomitant lower extremity osseous trauma; 2) the initial management when definitive treatment should be delayed to optimize the risk–benefit of additional definitive care; 3) in high-energy tibial plateau, distal femoral, or distal tibial fractures in which there are wounds that prevent soft tissue coverage or the skin is unsuitable for definitive of reduction and internal fixation; 4) in the stabilization of the axial skeleton with vascular injury; and; 5) in the austere or hostile environments in order to facilitate care and/or transfer.

External fixation is now commonly used as the initial intervention in the staged approach to distal tibial plafond fractures. Well-established treatment principles call for anatomic reduction, rigid fixation, and early mobilization. However, these injuries are often accompanied by severe soft tissue insults and damage, and early attempts at achieving these goals through traumatized skin caused unacceptably high rates of complications related to skin breakdown and infection (22, 23). However, more recently favorable results have been demonstrated with staged treatment protocols (24, 25). These protocols involve the temporary external fixation of the tibial plafond followed by definitive open reduction and internal fixation when the soft tissues are amenable to surgery. This time frame may be as long as 4 weeks and is usually at least 2 weeks in duration (24, 25). Stage protocols have also been effective for other high-energy periarticular fractures such as tibial plateau fractures (26).

Contraindications

There are few contraindications to acute temporizing external fixation if safe pin placement can be achieved. A thorough understanding of cross-sectional anatomy is necessary for safe use of these devices. Occasionally the location and size of soft tissue wounds or their proximity to a joint may preclude safe pin placement above or below the zone of injury. In such situations when construct stability cannot be achieved, other means of temporary stabilization may be indicated to augment or replace external fixation.

Complications

Complications include inability to stabilize the extremity, nerve or vessel injury, or pin tract infections. Inability

to provide definitive stabilization occurs either from inappropriate positioning of the pins or an inadequate construct. It most commonly is seen when there is extensive bone loss and/or loss of ligamentous support around the knee or ankle. When this occurs, additional pins, double-stacking, or a multiplanar device may be necessary. The major difficulty that occurs biomechanically is the distance of the bar from the fracture if no inherent stability is afforded by fracture reduction. Nerve and vessel injuries may occur from direct pin injury or by traction. Pin tract infection is time related and, if the pin is left long enough, there is a high probability that it will occur (9). With short-term temporary fixation, pin tract infections are of less concern.

Technical Considerations

When using external fixation as a temporizing intervention, consideration of definitive management of the injury is imperative. Pin placement should be out of the zone of injury and as far away from planned incisions as possible. Pin spread, normally a desirable feature of an external fixation construct, should not be a priority in these situations. Closer clustering of pins allows them to be placed farther from the zone of injury and better keeps them from interfering with definitive surgery. The resultant decreased frame stiffness matters less because of the temporary nature of the intervention.

The same consideration should be given when articulating these pins to the external splinting system. The fixation bars or clamps should not impede access to open wounds or access to compartment monitoring. The pin-to-bar articulating clamps should be oriented such that they are easily accessible to allow for rapid removal or manipulation.

As previously mentioned, the pin–bone interface is critical to effective external fixation. Pin loosening and pin tract infection can negate the utility of external fixators even when used as a temporizing measure. The cause of pin loosening and infection is multifactorial; however, thermal and mechanical damage at the pin–bone interface must be avoided (9). Both have been shown to result in local bone necrosis, sequestra, and fibrous tissue formation at the pin–bone interface (27, 28). Therefore, whenever possible, pins should be predrilled with a low-speed power drill with occasional pauses. The pin should subsequently be inserted by hand. Predrilling and insertion by hand have both been shown to decrease heat necrosis (1, 29, 30–32).

The skin and soft tissues must also be handled with care. The skin should be incised with short longitudinal or “stab” incisions along safe zones. Bone should be reached with gentle blunt dissection. Drill sleeves and trocars should be used during drilling and pin insertion. These

steps add minimal time to the external fixation procedure and should be followed for most patients. Self-drilling pins may nominally shorten procedure time and can be considered for those in extremis in bones with an adequate soft tissue envelope such as the femur.

Choice of External Fixation Devices

A myriad of external fixation devices are approved by the U.S. Food and Drug Administration and marketed in the United States and abroad. In a comparison of military external fixation constructs, Dougherty et al. (1) evaluated the ease of application and biomechanical properties. Using general surgery residents, two military external fixator constructs (Hoffmann II) were determined to be of equal ease and time requirement for application. In the uniplanar construct, four half-pins were utilized in a single plane with two multipin clamps and one spanning bar. In the biplanar construct, four half-pins were connected to three bars by six multipin clamps. The biplanar construct as suspected demonstrated slightly superior biomechanical stability in torsion and manual bending over the uniplanar. Although a third fixator with oblique half-pins was the strongest axial rotation and bending, all are sufficient for transport and initial stabilization. The biplanar pins were slightly easier to apply, but the construct was more complicated and logistically less useful in mass casualty situations, suggesting the facility of a uniplanar device.

Case Example

A 60-year-old female who was involved in a high-speed motor vehicle accident arrived at our institution as a leveled trauma code. Primary survey demonstrated an intact airway, but decreased right-sided breath sounds. Chest radiograph confirmed a right-sided pneumothorax and she underwent chest tube placement. Her systolic blood pressure on admission was 90 mm Hg but improved with a normal saline fluid bolus and chest tube placement. She was noted to be moving all extremities though she had obvious multiple lower extremity deformities.

A secondary clinical reappraisal “survey” demonstrated a large soft tissue injury and traumatic right knee arthroscopy with patellar tendon disruption. The patient also had a type 2 open right femoral shaft fracture and type 1 open left supracondylar femur fracture (Fig. 1). She also had an open right distal tibial plafond fracture with an ipsilateral talar neck fracture with extrusion of her talar body (Fig. 2).

A damage control pathway was followed. All open fractures were meticulously debrided. She underwent



FIGURE 1 Scout of trauma CT demonstrating segmental right femoral shaft fracture and intra-articular left supracondylar femur fracture.



FIGURE 2 Scout CT of lower extremities showing right distal tibial pilon fracture and talus fracture.

spanning external fixation of her open left supracondylar femur fracture. The author's preferred construct for peri-articular fractures surrounding the knee is depicted in Figure 3. Care was taken to place pins out of the way of the incisions for definitive management of the injury. Pin spread was maximized in the tibia and was clustered in the femur. She also underwent external fixation of her open right femur fracture (Fig. 4). Given our eventual plan

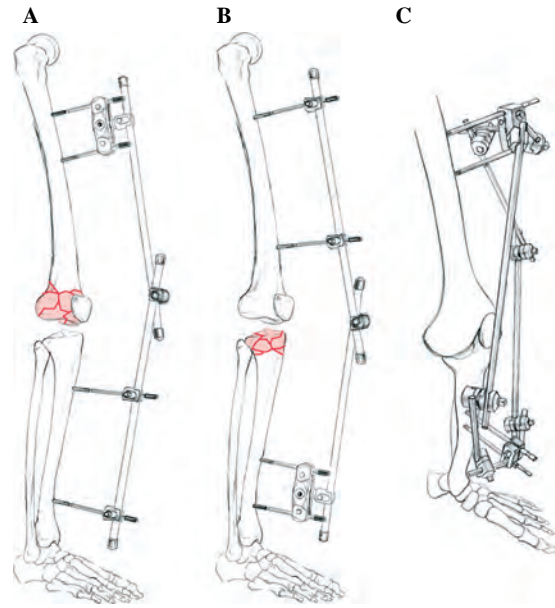


FIGURE 3 Suggested simple uniplanar bridging external fixator constructs for periarticular fractures about the knee. **(A)** Pin spread is maximized in the tibia and pins are clustered in the femur to avoid compromising definitive surgery. **(B)** In a similar fashion in proximal tibia fractures pin spread is maximized in the femur and clustered in the tibia for similar reasons. **(C)** Four-pin construct using additional bars and connecting clamps for additional distance from fractures without compromising stability.



FIGURE 4 Scout CT after temporary spanning external fixation of multiple lower extremity injuries.

to intramedullary nail this side, less emphasis was placed on pin placement, although we were careful to place pins well away from her soft tissue injury.

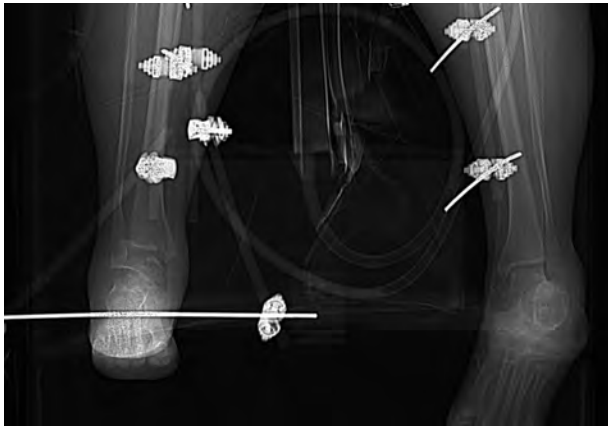


FIGURE 5 External fixation of ipsilateral distal tibial pilon and talus injuries.

A spanning external fixator was placed to her right distal tibial plafond fracture and ipsilateral talus injury (Fig. 5). After failed attempts at closed reduction, no acute attempts at open reduction of her talar body displacement were made, given the patient's tenuous systemic condition. She was taken back to the operating room as soon as she stabilized for urgent reduction of her talus fracture. The author's preferred construct for pilon fractures is shown in Figure 6. Again care was taken to place pins out of both the zone of injury and the zone of definitive

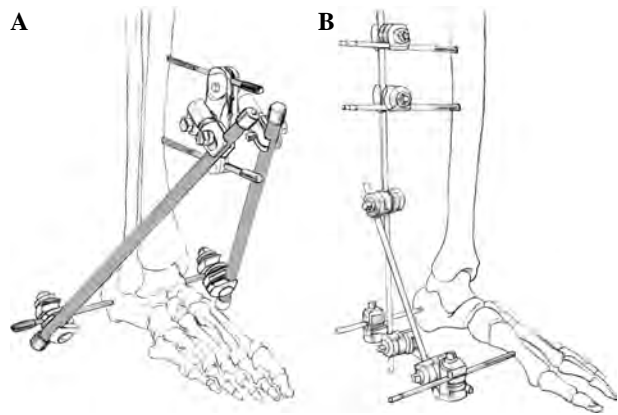
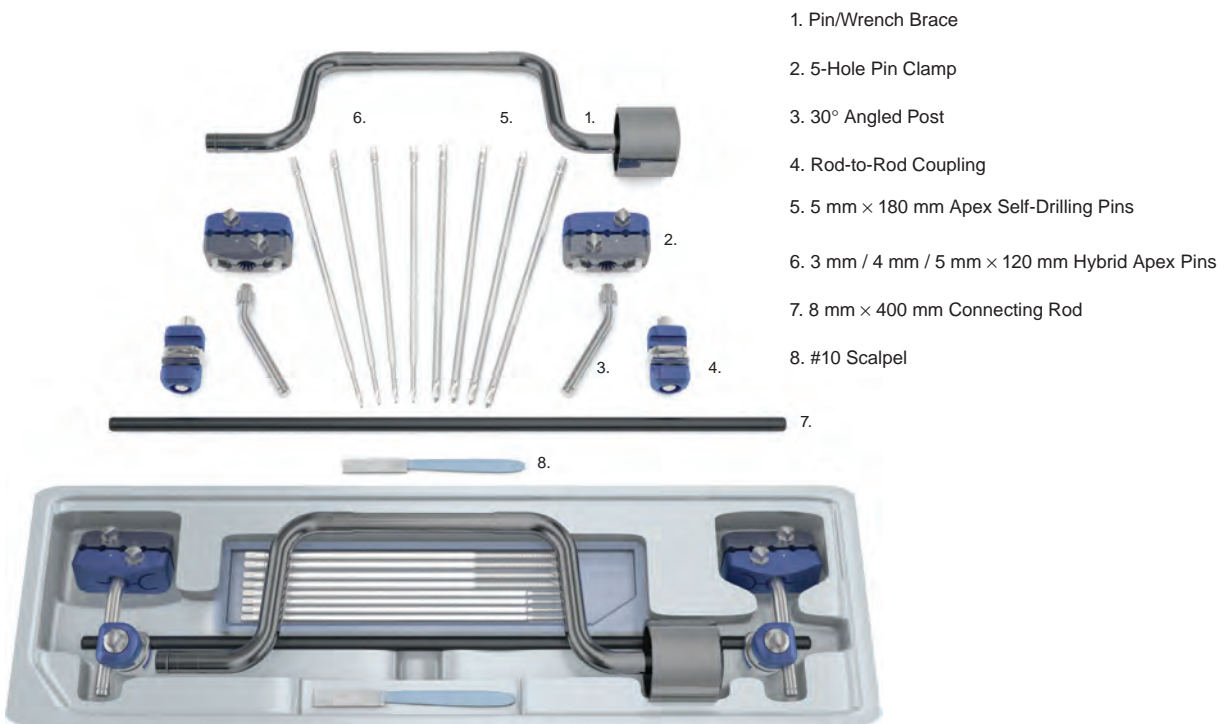


FIGURE 6 Options for bridging external fixator suitable for periarticular ankle fractures, distal tibia fractures, ankle fracture-dislocations, and unstable complex fractures of the talus. **(A)** Biplanar construct. **(B)** Uniplanar construct.

repair. The knee joint was spanned given her significant soft tissue injury and extensor mechanism disruption.

Estimated blood loss for all aspects of the surgery was 200 mL. Operative time was 60 minutes. She was taken to the intensive care unit and underwent appropriate resuscitation. Over the ensuing 3 weeks, she underwent definitive management of all of her orthopaedic injuries. She was discharged to a rehabilitation facility 1 month after her initial trauma.



Components

FIGURE 7 Hoffmann II Military Field Pack (Stryker) (used with permission by Stryker).

1. Pin/Wrench Brace
2. 5-Hole Pin Clamp
3. 30° Angled Post
4. Rod-to-Rod Coupling
5. 5 mm × 180 mm Apex Self-Drilling Pins
6. 3 mm / 4 mm / 5 mm × 120 mm Hybrid Apex Pins
7. 8 mm × 400 mm Connecting Rod
8. #10 Scalpel

Use of External Fixation in Combat

During World War II, the United States Army utilized Roger Anderson's fixator, but poor design, surgical inexperience, and poor pin fixation, which led to pin tract infections and osteomyelitis, created a negative backlash in the United States and ultimately a ban on the use of the device in the U.S. military. Alternatively, Hoffmann modified his fixator for military use which, combined with appropriate surgical techniques, demonstrated effective external fixator use in Europe. The importance of external fixation in modern warfare is well documented in the Gulf Wars and Afghanistan. The United States Armed Forces have effectively used prepacked, self-contained, sterile Hoffmann II external fixators (Stryker, Mahwah, NJ) (31). The Hoffmann II Sterile Military Field Pack is designed for field use in combat conditions. Carried by medical personnel, it can be applied rapidly in battlefield



Tibia Shaft Frame - Single Rod

FIGURE 8 Unilateral long bone construct assembled from Hoffmann II Military Field Pack (Stryker) (used with permission by Stryker).



Tibia Shaft Frame - Double Rod

FIGURE 9 Unilateral long bone construct with double bar for additional stability for complex unstable injuries assembled from two Hoffmann II Military Field Packs (Stryker) (used with permission by Stryker).

conditions to effect safe transport, to prevent further extremity damage, and to minimize pain (Fig. 7) (32). The pack, which is composed of an insertion device, eight self-drilling pins, two angled posts, two pin clamps, two rod-to-rod couplers, and one connecting rod, is sterile and lightweight and can be inserted by a single provider. The Hoffmann II can be assembled as a unilateral single-bar construct for simple tibia or femur fractures or for the unstable knee or ankle (Fig. 8); alternatively, a second bar (using components from a second pack) may be added for additional stability (Fig. 9).

The Israeli Defense Force utilized external fixation for battle casualties during the 1973 and 1982 wars for definitive care in 78 limbs and with conversion to alternative fixation in 32 patients (33). Subsequent reports in battlefield conditions support effective conversion from temporary to definitive fixation (34).

Experience with a combat-applicable prefabricated pack (Stryker, Hoffmann II) has demonstrated that it can be applied effectively under austere conditions, can be converted electively to other constructs and devices, and is sufficiently portable (35). The need for additional stability and biomechanical enhancement in certain fractures may be achieved by using two packs or more (Fig. 9) (36). Military Field Packs must be portable, sterile, self-contained, adaptable, and modular.

In summary, external fixation devices are a valuable adjunct to the management of lower extremity osseous injury. Current devices when used by knowledgeable personnel provide temporary fixation in damage-control situations and military kits may be used in battlefield and disaster environments.

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