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# The Interaction of Projectiles with Tissues and the Management of Ballistic Fractures

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## ABSTRACT

**Wounds to the limbs are the commonest injuries seen during armed conflict and injury results from the transfer of energy from the missile to the tissues. There are a number of factors that determine the transfer of energy, and thus the extent of wounding. These include the velocity of the missile, its shape and stability, and the tissue through which the missile passes. Many of the wounds involve bone, and because of the interaction of missiles with bone, significant fractures can occur.**

**In many previous conflicts amputation was considered the treatment of choice for many limb injuries, but with recent advances in the management of severe open fractures, many of these limbs are now salvageable. Whilst the basic principles of the initial débridement remain unchanged, techniques of fracture stabilisation and definitive soft tissue cover have changed, and it is necessary to consider these in relation to military fractures. Definitive soft tissue closure can be safely delayed until evacuation further down the medical chain, but stabilisation of the fracture must be considered at the time of initial surgery. Many of the advances in fracture management may be unsuitable for use in a military environment due to logistical constraints. In addition it is likely that wound infection will be more common with military injuries, and this will influence the treatment.**

**This paper considers the interaction of missiles with soft tissue and bone, and discusses possible methods of fracture stabilisation in the military environment.**

## General Principles

Projectiles cause tissue damage by either direct or indirect mechanisms. With low-energy injuries such as from knives, the tissue damage is confined to the wound track, and is caused by cutting or crushing. Significant injury will only occur if a vital structure is damaged. Death is unlikely unless a major vascular injury occurs, and in the absence of any direct injury to a clinically important structure, full recovery can be anticipated.

However, with higher energy missiles such as bullets, energy may be dissipated to the surrounding tissues, producing indirect damage outwith the wound tract. Thus a vital structure may be damaged without actually being involved in the wound track. This is more likely to occur with high-energy wounds, especially, although not invariably, from high velocity rifle bullets.

The effect of indirect damage is one of the factors in the increased mortality from high velocity bullet wounds. In a report from Vietnam, bullets were responsible for 30% of penetrating wounds, but caused 45% of the deaths (WDMET 1970). It has been estimated that a casualty struck by a bullet, in a military conflict, has a 1 in 3 chance of dying (Bellamy *et al* 1999). This compares to a 1 in 7 chance of dying if struck by fragments from a shell, and 1 in 20 if struck by a fragment from a grenade (Bellamy *et al* 1999).

It is not, however, the energy transfer that determines the outcome, it is the specific tissue damage that occurs. Low-energy wounds to the heart or brain are more likely to be fatal than high-energy injuries to the limbs.

A number of factors affect the energy transfer from the projectile to the tissue:

*Velocity of the projectile* – The kinetic energy possessed by a projectile is determined by the formula:

$$\text{Kinetic Energy} = \tfrac{1}{2} \times \text{Mass} \times \text{Velocity}^2$$

It can be seen that changes in velocity have a significant effect on available kinetic energy, and the greater available energy accounts for the severe tissue damage seen after high velocity missile injuries. However, high velocity bullets do not invariably cause severe wounds, as the missile may pass through tissue without transferring significant energy. This occurs when the resistance of the tissues is low and the wound track is short, such that the bullet is not slowed, and therefore little energy is transferred. For this reason it is incorrect to divide wounds into high or low *velocity*. In addition, severe injury can occur from low velocity projectiles, not only when a vital structure is directly injured, but also when the mass of the projectile is large. This is particularly true for close-range shotgun injuries (Shepard 1980), which can cause severe tissue injury (Figure 1). The energy *transferred* to tissues defines the work done in mechanical injury, and is the most appropriate index of physical injury.

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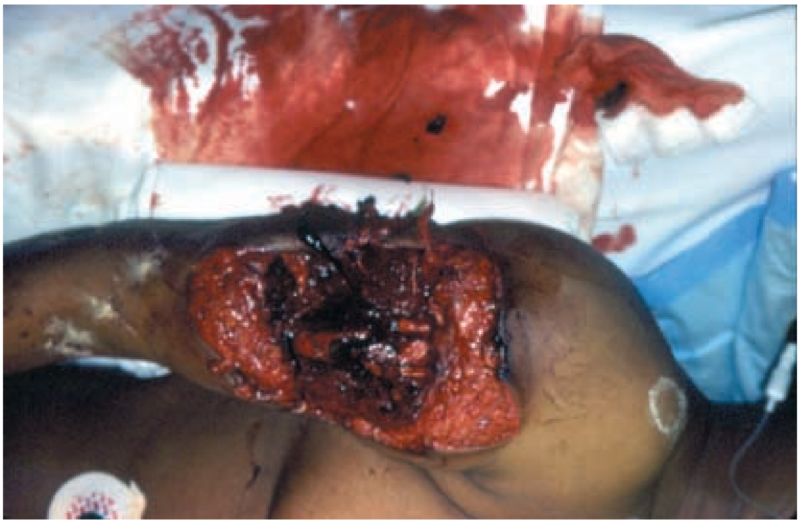

*Fig 1. Close-range shotgun wound, high-energy transfer wound from a low-velocity weapon.*

## Shape of the projectile

The smaller the area of the projectile presented to the tissue, the lower the resistance, and therefore the lower the energy transfer. Thus there is likely to be a lower energy transfer from a spherical object, such as a ball bearing, than a flattened irregular piece of shrapnel, for the same available energy (Liu *et al* 1988).

With a bullet, the resistance afforded by the tissue is related to the orientation of the bullet. If the long axis of the bullet is aligned with the direction of travel, less energy is transferred than if the bullet yaws (or tumbles) and presents a greater surface area (Kirby *et al* 1981). Bullets are inherently unstable in tissues, and the resistance of the tissue may be sufficient to cause a bullet to tumble. This will result in greater energy transfer to the tissue and thus greater tissue damage. This is one reason why entry wounds are often small, and may be no larger than the diameter of the bullet, whereas exit wounds may be much larger, with torn skin (Janzon *et al* 1997), and a ragged star-like appearance (Figure 2.).

In addition, any deformation, or breaking up of a missile will result in greater energy transfer and more extensive wounding. This is the main reason for the development of soft nose, hollow nose, or dum-dum bullets or the round being deliberately notched to encourage breaking up, to increase the 'stopping power' of a round. Such modifications were made illegal for military use by the Hague Declaration of 1899. Such rounds are still used for hunting and by some law enforcement agencies. Despite the use of 'legal' bullets fragmentation can still occur, particularly if the bullet strikes bone, and this breakup is accompanied by more severe wounding.

## Resistance of the tissue

The energy transfer is also affected by the tissue involved in the wound tract, and is related to the density and rigidity of the tissue. Muscle is more dense than lung tissue, and greater energy transfer occurs when a projectile passes through muscle. More rigid tissue such as bone resists deformation, and offers a greater resistance, resulting in greater energy transfer.

## Mechanism of injury

There are 3 suggested mechanisms by which energy transfer may cause tissue damage:

*Cutting* – Direct laceration by the projectile.

*Overpressure* – As the projectile passes through the tissue energy is lost from the projectile due to the resistance of the tissue. This energy loss results in the development of an overpressure; compressive waves that radiate away from the projectile and can damage tissue. Debate centres on the ability of these waves to produce tissue injuries. Some authors feel that as much as one third of the tissue damage is due to the wave (Janzon *et al* 1985), although other authors feel their role is insignificant (Ryan *et al* 1997).

*Cavitation* – The formation of a temporary cavity, behind the missile, is the most significant factor in tissue injury from high-energy transfer wounds. As the projectile passes through the tissue, energy is transferred to anything in contact with the projectile, and as a result of this energy, the tissue is accelerated away from the projectile. This results in the formation of a temporary cavity as the inertia of the tissue results in continued displacement even after the projectile has passed through the tissue (Figure 3). As well as the obvious injury caused by the compression and shear forces

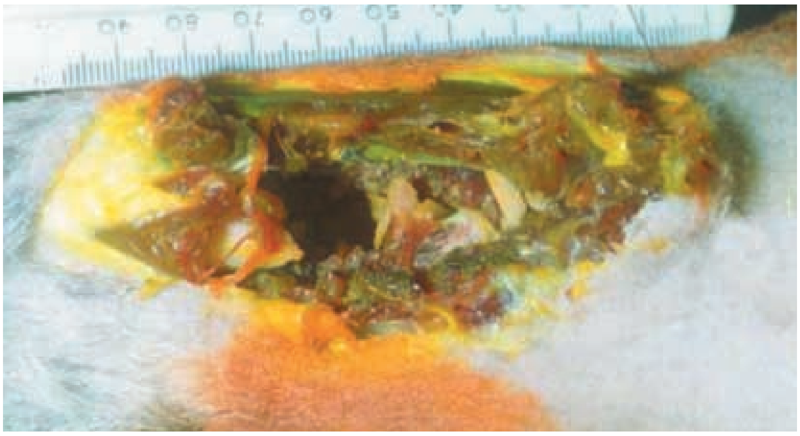

*Fig 2. Large ragged exit wound.*

*Fig 3. Cavitation in gelatin block from high energy transfer.*

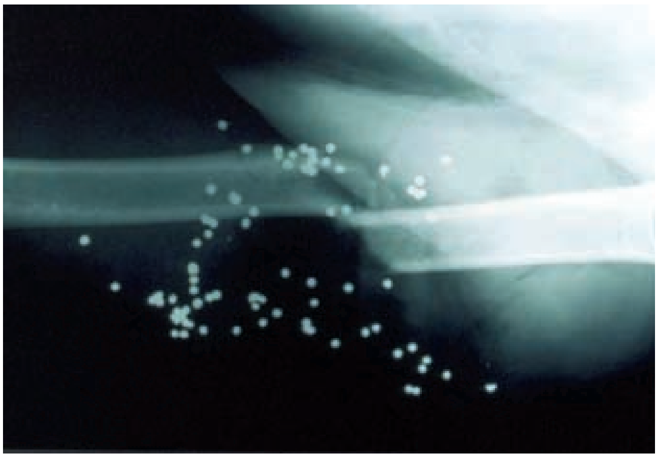

Fig 4. Simple (2-part) ballistic fracture.

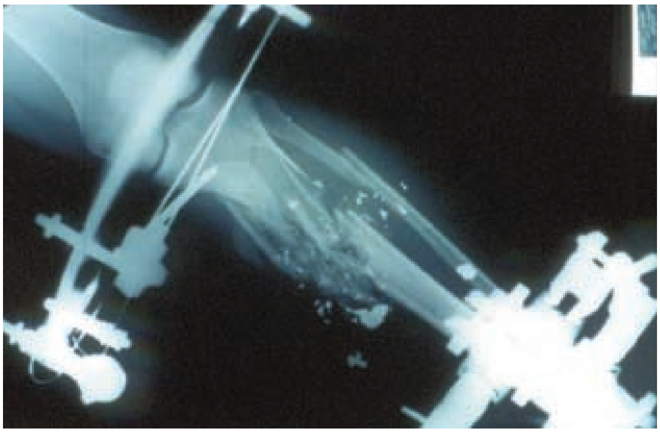

Fig 5. Multifragmentary ballistic fracture (in this case stabilised by external fixation).

applied to the tissues, the negative intracavity pressure (with respect to atmospheric pressure), can result in increased contamination of the wound tract, by drawing material into the wound.

The size of the cavity, although one determinant of the severity of an injury, is not the most significant factor; again it is the properties of the tissue injured which primarily determine the outcome. Muscle is able to withstand the distension produced by the temporary cavity, due to its elasticity, and although the tissue may be contused, recovery is possible. Less elastic tissue, particularly if enclosed by a fibrous capsule for example liver, is unable to withstand the distension and severe disruption is possible (Ryan *et al* 1997). Brain is also very susceptible to distension, and the severe injury resulting from the compression and shearing is usually unrecoverable.

There are a number of factors that are important to emphasize at this stage. Despite the division of wounds into high and low-energy transfer, it is important to realise that these are merely two ends of a spectrum, and that wounds of 'intermediate energy transfer' also occur. It is, therefore, wrong to base treatment protocols on the basis of a division of wounds into two types. The temporary cavity is not an all-or-nothing phenomenon, and the size of the cavity is related not only to the energy transfer, but also to the tissue involved. In addition, although the exit wound of a high-energy transfer wound is usually ragged and large, this is not always the case, and smaller entrance and exit wounds may be present despite high-energy transfer (Ryan *et al* 1997).

## Missile Injury to Bone

As has been discussed above, bone is a more rigid tissue than skin and muscle. This rigidity produces a greater resistance and results in greater energy transfer, and commonly fracture of the bone. In addition to the soft tissue injury, instability of the limb may occur, requiring stabilisation of the fracture site.

Rose *et al* 1988, in a retrospective review, analyzed the extent of bony injury following gunshot injury, and divided the fractures into complete or incomplete, depending on whether some continuity of the bone was maintained. The authors further divided complete fractures into simple, when only 2 main fragments were present (Figure 4), and comminuted, when multiple fragments were present (Figure 5). Incomplete fractures were subdivided into drill hole type when a channel was created through the bone, and a divot or chip type, when part of the cortex was removed, but no channel existed.

Rose *et al* 1988, reported that for high-energy weapons such as military or hunting rifles, all fractures were complete, and comminuted (multifragmentary). For low-energy weapons, such as handguns, 60% of the fractures were incomplete, and only 22% were multifragmentary.

Further confirmation that high-energy injuries were associated with greater bony damage came from an *in vitro* study from Ragsdale *et al* 1988. They reported that increasing pre-impact velocity was associated with an increased cavitation effect and increased fragmentation. With a handgun and pre-impact velocity of approximately 200 m/s, there were 2 fragments. However, for a military rifle with a pre-impact velocity of nearly 1000 m/s, there were 33 fragments.

Experimental work (Robens *et al* 1982), using metaphyseal bone demonstrated that 3 distinct fracture zones were present with high-energy transfer wounds involving bone. The primary zone consisted of the wound track, where a bone defect was present, a secondary zone, extending approximately 3 cm where multiple fragments were present, but retained their soft tissue attachments, and a tertiary zone with minimally displaced fracture lines extending up to 9 cm from the wound track. The extent of bony involvement can also be significant. In a further *in vitro* model, the comminuted segment was noted to involve 42% of the total length of the bone (Clasper *et al* 2000). This, together with the multiple fragments has a major effect on the stability and management of the fracture.

All these fractures were due to direct injury from the missile, but a fracture may also result even if the missile does not actually strike the bone. These indirect fractures are thought to be due to the cavitation effect, with the acceleration of bone away from the tract of the missile. This type of fracture is usually only seen with high-energy transfer wounds, and the fracture is usually simple rather than the multifragmentary pattern seen when the missile hits the bone (Liu *et al* 1988, Hill 2000).

In his *in vitro* model, Hill (2000) also investigated the contamination of the fracture, and noted greater contamination with direct fractures, when compared to indirect fractures. A further *in vitro* model has demonstrated that the whole fracture site must be considered to be contaminated, but that there was little spread beyond the extent of the fracture (Clasper *et al* 2000). The application of such *in vitro* data to the clinical situation, however, must be viewed with some caution.

Although the extent of bony injury has been graded *in vitro*, little attempt has been made to classify fractures in order to develop treatment protocols. The management of fractures involving the adjacent joint differs greatly from a midshaft fracture of a long bone, both in the initial stabilisation, and also the definitive management.

## Management of Military Fractures

The initial management of open fractures resulting from wartime injuries should be exactly the same as that during peacetime. Life saving measures take priority; maintaining an airway, and ensuring adequate ventilation and circulation. Unless there is life-threatening haemorrhage from an open wound, the fracture should not be dealt with until the secondary survey.

The wound should be thoroughly débrided and washed out, although difficulties with casualty evacuation or mass casualties may impose significant delays. At débridement, often minimal additional skin needs to be excised, although generous excision of muscle may be required. The principle of débridement is to remove all non-viable tissue, with the aim of leaving only pink, healthy-looking, contractile muscle. Fasciotomy, longitudinally dividing the deep fascia around a muscle group is commonly required (Figure 6), particularly with high-energy transfer wounds.

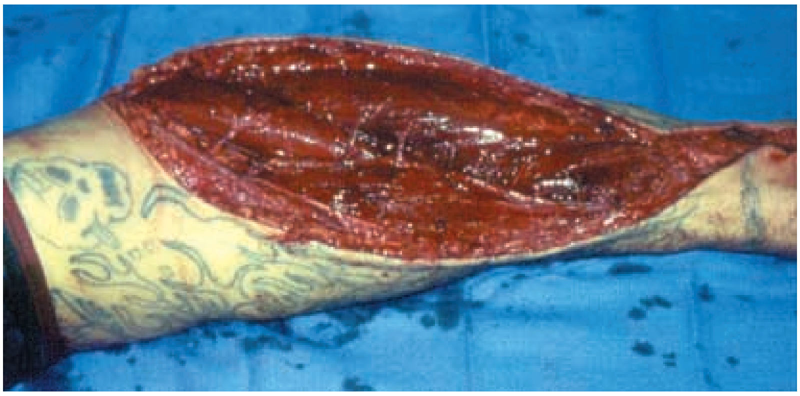

*Fig 6. Fasciotomy of the arm for gunshot wound.*

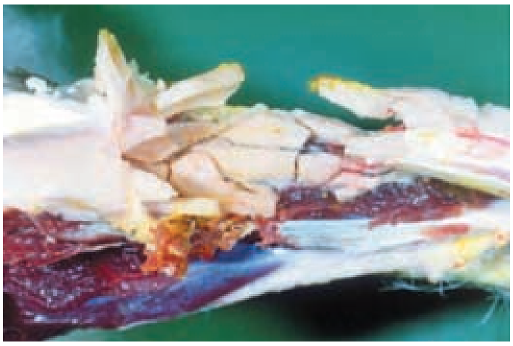

*Fig 7. High-energy transfer wound, despite the extensive bony injury, the fragments maintain soft tissue attachment, and are viable.*

Difficulties can often occur in the débridement of bone, particularly regarding the fate of the many small fragments. Bone fragments without any soft tissue attachments are avascular and should be removed. Often, however, periosteal and other soft tissue attachments are present (Figure 7) and the viability of the fragment can be difficult to determine. Experience is probably the most important factor in deciding the viability of a bone fragment or muscle, although invasive and non-invasive methods of assessing blood flow have been investigated (Hobbs *et al* 2001).

Delayed primary closure of military wounds is the rule, although, in specific circumstances, certain wounds can be closed primarily. High-energy transfer wounds with comminution of the bone should never be closed primarily, and will often require plastic surgical techniques several days after the initial débridement.

## Non-operative management of ballistic fractures

Whilst it is true that in certain circumstances low-energy missile wounds involving bone can be treated non-operatively (Knapp *et al* 1996), much of the data derives from American trauma centres. There are significant differences between these wounds and those seen during military conflicts:

### *Delays in the initiation of treatment*

Few authors report the time delay between injury and the start of treatment for civilian gunshot injuries but, for most casualties, it is likely to be a few hours. This contrasts markedly with the delays reported during wartime. A mean delay of 9.8 hours (range 2 – 30 hours) prior to surgery, was reported for vascular injuries from Croatia (Radonic *et al* 1994). In the Gulf War the mean delay at a British Surgical Hospital was reported to be 10.2 hours for British soldiers, and 24.7 hours for prisoners of war (Spalding *et al*

1991). A delay of several days, before effective treatment is started, has been reported by surgeons working for the International Committee of the Red Cross (Gosselin *et al* 1993).

*Contamination of military wounds*

Although most open fractures are contaminated at the time of injury, it is likely that military wounds are more heavily contaminated with bacteria than civilian wounds. In the Korean War, Lindberg *et al.* reported that all medium and large wounds (wound > 1cm) were contaminated with clostridia, with a mean of 2 different strains of clostridia per wound (Lindberg *et al* 1955). The authors report a seasonal variation in the aerobic bacteria contaminating the wounds. In summer 89% of wounds were contaminated, with faecal organisms the predominant bacteria. There was a mean of 1.7 species of aerobic bacteria isolated from the wounds, despite all wounds being operated on within 5 hours of wounding. Most of the patients had already been given penicillin. In winter, 81% of the wounds were contaminated by aerobic bacteria, most commonly staphylococci and streptococci. There was a longer delay before surgery, with 8-9 hours between wounding and débridement, and there was a mean of 2.8 species of aerobic bacteria isolated from each wound at the time of surgery.

In a further report from Korea, Strawitz *et al* reported the results of serial biopsies from 11 penetrating wounds (Strawitz *et al* 1955). The authors noted that the extent of the wounds was usually worse than the skin wound suggested. They isolated clostridia from 9 of the 11 wounds at débridement, as well as isolating gram positive cocci from all wounds, and gram negative bacilli from 9 of 11 wounds (mean 5.5 species of bacteria isolated per open wound). Unlike civilian open fractures (Robinson *et al* 1989), the wounds reported by Strawitz remained contaminated after débridement. Wound biopsies 5-6 days after injury isolated a total of 11 species of gram negative bacteria and 10 of gram positive cocci (mean 1.9 species of aerobic bacteria isolated per open wound).

These reports confirm that military wounds are heavily contaminated, with 3 – 4 different species of bacteria isolated from most military wounds, and up to 6 different species in some reports (Levaditi *et al* 1939). This compares to only 1 species from most civilian wounds (Lindberg *et al* 1955; Gustilo et al 1976; Lawrence *et al* 1978). The species of aerobic bacteria appear to be very similar, however anaerobic bacteria contaminate most military wounds but are rarely isolated from acute civilian wounds.

It has been reported that the level of initial contamination of a wound is related to the risk of subsequent wound infection (Robinson *et al* 1989), and based on this, military wounds will have an increased risk of infection. Surgical débridement should therefore be carried out on all military fractures.

## Stabilisation of the fracture

All military fractures should be stabilised, even if only with an external splint for comfort and to facilitate soft tissue recovery. As with civilian type-fractures several methods of stabilisation are available, but there are potential problems in the military environment:

*Plaster*

Antonius Mathlisen (1805-78) is credited with the first use of the plaster bandage as a splint; this was actually developed as a means of treating fractures on the battlefield (Van Assen *et al* 1948). Plaster is an inexpensive method that is relatively easy to apply. Little additional equipment is required and plaster immobilisation can be used close to the front line. Good healing rates for both wound and fracture can be predicted. Infections are common with open tibial fractures treated by plaster, but are comparable to other methods of treatment (D'Aubigne *et al* 1974).

The disadvantages of plaster are its inability to control movement at the fracture site, and shortening and malunion which are

*Fig 8. Burnt, fractured legs, unsuitable injuries for plaster or other external splints.*

*Fig 9. Injury demonstrated in figure 8, stabilised by external fixation.*

common with comminuted fractures. This is a particular problem in treating the multifragmentary fractures seen after high-energy transfer wounds.

In addition, military wounds, including fractures, are often associated with other injuries, such as burns, or multisystem injuries. Plaster is not a satisfactory method of stabilising a burnt, fractured extremity, and polytrauma, as in civilian practice, is an indication for surgical stabilisation (Figures 8,9).

Conservative management of open tibial fractures was practiced with good results in the Vietnam War. Witschi and Omer (Witschi *et al* 1970) reported the outcome of 84 tibial fractures caused by missiles, 23 of these were classified as high velocity injuries. The wounds were treated by skin grafting as appropriate, and a well fitting plaster was applied with early weight-bearing encouraged. All fractures healed, the high velocity fractures taking a mean of 22 weeks, and the low velocity injuries taking a mean of 18 weeks. Despite weight-bearing, 83% healed with less than 1cm of shortening. Eleven of the high velocity fractures had associated neurovascular injuries but this did not affect the fracture healing. Witschi reported 7 (8.3%) cases of chronic osteomyelitis in healed fractures.

Plaster does have advantages, and in the management of the open fracture is a safe method of treatment. Its disadvantages are related to stability and access to the wound. In the management of comminuted fractures, or fractures with bone loss, plaster will be unable to prevent shortening. If access to the wound is required, or if stability is needed after vascular repair or soft tissue transfer, plaster should probably not be used as the definitive method of treatment of an open fracture.

### *Other external splints*

The Thomas splint was specifically designed for the evacuation of patients with ballistic fractures of the femur during the First World War. With the increased use of intramedullary nailing in civilian femoral fractures, its use has diminished. It is certainly a useful method of stabilising fractures in the military environment, either alone or in combination with plaster. Other splints are available, including malleable wire and inflatable devices, but their main role is the short-term stabilisation of fractures treated in civilian hospitals.

### *Internal Fixation*

Internal fixation of open fractures due to war injuries was dismissed by the British during both the First (Max Page *et al* 1917), and the Second World Wars (Furlong *et al* 1948). The American military did, however, use delayed internal fixation with some success (Hampton 1946).

Internal fixation of fractures is technically demanding both in surgical skill and equipment. Very good post-operative management is required, and plastic surgical procedures are often necessary. Internal fixation of fractures therefore can not be used close to the front line.

The advantages of internal fixation with plates and/or screws are the accurate reduction and rigid fixation that can be achieved. Internal fixation could have a place as a secondary method of treatment, possibly in combination with initial plaster. Delayed internal fixation has been shown to have a lower complication rate than acute plating (Smith 1974). Despite this, the complication rates of both infection and delayed healing are still high, and with the other advances that have been made, internal fixation probably has little place in the management of the military fracture.

### *Intramedullary Fixation*

Intramedullary (IM) fixation with a nail is currently considered to be the method of choice for the stabilisation of open tibial or femoral fractures in the civilian environment. Its main disadvantage is that the operation is technically very demanding. It requires even more equipment than plating, including image intensification. For IM nailing to be performed in a military environment, it would require a relatively static surgical facility, and would be unsuitable for use near a front line. Intramedullary nailing of femoral fractures caused by war wounds has been reported by Dudley (1973), based on his experiences in Vietnam. There is no follow-up of the patients; however his technique of open nailing, without the ability to statically lock the nail, is likely to result in a high complication rate if used for open military fractures.

In a further report from Vietnam, Rich *et al* reviewed the results of open fractures that required a vascular repair (Rich *et al* 1971), and discussed the method of stabilisation of the fracture. They reported that when IM nailing was used, 50% of the nails required removal for complications directly related to the implant. The most common complication was infection, and the authors concluded that, in the military environment, external splints with the use of transfixion pins was a safer option for the stabilisation of fractures associated with vascular injuries. The high infection rate after primary IM nailing of a heavily contaminated wound has also been confirmed in an animal model (Hill *et al* 1998), and this concurs with a civilian recommendation to avoid nailing certain open fractures when dirty water or agricultural contaminants are present (Templeman *et al* 1998). This is likely to apply to military injuries.

The advantages of IM nailing are the high rates of healing for both wound and fracture.

*Fig 10. Severe soft tissue injury.*

*Fig 11. Multiple injuries with multiple fractures, stabilised by external fixation.*

No additional splints are necessary, and this allows full access to the wound for inspection, dressings or plastic surgical procedures. As with internal fixation, IM nailing should probably be considered as a secondary method of treatment. This could be carried out after evacuation of the casualty, possibly after plaster immobilisation, which would be a good method of initial stabilisation.

*External Fixation*

The use of an external fixator for managing war wounds has been debated, with opinions both for and against its use. Bradford and Wilson reported its use in 1943, when it was first issued to American military hospitals (Bradford *et al* 1943). They felt its use was indicated in patients with multiple injuries, infected fractures, or to prevent complications during evacuation. However Cleveland (Cleveland 1956) in a post war summary reported:

> *'External fixation soon proved itself to be a method totally unsuited to the management of military casualties…its use in both simple and compound fractures was inevitably associated with a high percentage of both infection and delayed union.…The use of this method was therefore forbidden and the apparatus was removed from the hospitals'*

As noted previously plaster is not the ideal method of treatment for fractures with bone loss, vascular injury or extensive soft tissue loss. Given that internal fixation, or IM nailing are not suitable procedures to be carried out in a forward surgical facility, then external fixation has to be considered as an option in the initial management of these complex injuries.

External fixation has been accepted by the British armed forces but they have not as yet fully established the indications. Few external fixators were used during the Falklands War. Spalding *et al* reporting on 63 patients with penetrating missile injuries, described the use of the 'Centrafix Military Pattern' fixator during the Gulf War (Spalding *et al* 1991).

*Complications of external fixation for military injuries*

Dubravko *et al* reported the use of external fixation during the war in Croatia, (Dubravko *et al* 1994). Of the 116 fixations, complications occurred in 79 (68.1%); pin tract infection occurred in 35.3% of all patients, and pin tract osteomyelitis in 7.8% of patients. In addition, 8 (6.9%) of the fractures required reoperation for loss of reduction of the fracture site.

Has *et al* discussed the treatment of limb injuries in a further retrospective review of war injuries from Croatia (Has *et al* 1995). Of 1320 open fractures treated, external fixation was used in 215 (16.3%). Of these 215 fractures, 20 (9.3%) developed osteomyelitis, and 21 (9.8%) developed a non-union. Nine of these 21 subsequently developed osteomyelitis (4.2% of original 215). No information is given about the other 1105 fractures treated by methods other than external fixation.

It can be seen, therefore, that external fixation has been accepted as the treatment of choice by many surgeons in the management of open fractures from missiles. This is despite the fact that few reports have any follow-up data, and those that do report a pin tract infection rate of up to 35.3%, and osteomyelitis in 7.8% of patients (Dubravko *et al* 1994). Fracture healing is often delayed, with a non-union rate of 9.8% (Has *et al* 1995). Given that military open tibial fractures have a higher infection rate than civilian injuries, pin tract infection may also be more common with military injuries. Malunion rates have not been reported, but 6.9% of fractures in one series required re-operation for loss of reduction (Dubravko *et al* 1994).

*Summary of methods of stabilisation*

It is apparent that plaster and external fixation are the methods of choice for the initial stabilisation of military fractures. For many fractures, plaster is the ideal method, but for complex injuries external fixation is required. These indications include:

- unstable fractures, due to severe comminution or bone loss where plaster will not maintain adequate stability
- severe soft tissue injury, where microvascular anastomosis may be required such as for free tissue transfer (Figure 10)
- fractures with associated vascular injury, where vascular repair is required
- multiple injuries (Figure 11)
- patients requiring evacuation, especially with femoral fractures.

As discussed above, high-energy transfer wounds involving direct contact with bone are severe injuries, are likely to have a significant soft-tissue injury component, and are unstable. It is likely that the majority of these fractures will need stabilisation by external fixation. For indirect fractures, where comminution is less likely and for low-energy transfer wounds plaster is an ideal method of stabilisation if easy access to the wound is not required.

*Fig 12. Multifragmentary fracture of the humerus.*

*Fig 13. Injury demonstrated in figure 12, initially stabilised by external fixation.*

*Fig 14. Injury demonstrated in figure 12, treated by definitive stabilisation by internal fixation.*

## Secondary Management of the Fracture

For fractures treated by plaster, if a satisfactory position is confirmed on subsequent radiographs, plaster can be used as the definitive treatment. If any delay in healing occurs, early bone grafting with or without appropriate internal fixation should be carried out.

However, the long term outcome of external fixation in the treatment of military fractures is not known, and complications occur in civilian use of external fixators. Many of the problems associated with external fixation are due to its prolonged use, and it is possible that initial external fixation should be used initially with conversion to a different method of stabilisation at a later date when better facilities are available (Figures 12-14).

One method of treatment, which has been considered for peace-time fractures, but has not been investigated for war injuries, is external fixation at the time of initial débridement followed by early conversion to an IM nail. This conversion might be possible at the time of wound closure, if the casualty has been evacuated to a hospital with the necessary facilities. This has all of the initial advantages of external fixation, providing immediate stability, and facilitating evacuation. Early conversion to an IM nail

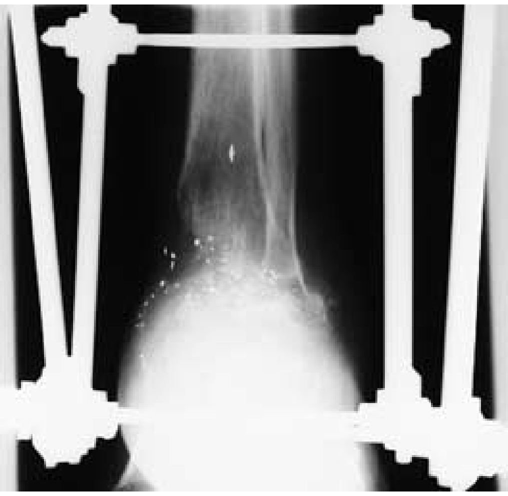

*Fig 15. Arthrodesis of the ankle joint for severe gunshot injury.*

would avoid the disadvantages of delayed union or pin tract infections, which are associated with the prolonged use of external fixators. This technique would also allow the definitive management of the injury to be safely delayed until all treatment options are available.

If the fracture involves a joint surface, and the fragments are displaced, plaster, external fixation and IM nailing are not suitable methods of definitive treatment. If reconstruction is possible and suitable facilities are available, early fixation with screws and/or plates should be carried out (Figures 12-14). If reconstruction of the joint is not possible, the position should be accepted and early mobilisation carried out. Fusion of the joint is an alternative for some joints, particularly the ankle and wrist (Figure 15) but should be avoided at the hip and especially the elbow if possible.

### Specific Bones

In general, fractures of the upper limb are best treated by plaster and other external splints. External fixation should be avoided unless there are specific indications. Secondary internal fixation may be required, but will not be carried out until the patient reaches a base hospital.

Fractures of the femur should initially be stabilised by a Thomas splint or external fixation. Secondary conversion to an IM nail can be considered at a base hospital.

Open fractures of the tibia will be one of the more common injuries seen during armed conflict, and initial stabilisation by plaster or external fixation is recommended. Secondary conversion to an IM nail offers the advantages discussed above and experimental work is being carried out at Porton Down to help to define its role.

## Summary

The interaction of projectiles and tissue results in the transfer of energy, and tissue damage, either directly from the projectile, or by the effects of energy transfer. With higher-energy projectiles, greater energy transfer can occur and more tissue damage will result. With wounds involving bone, fracture can occur, and this may result in instability at the fracture site leading to greater soft tissue damage. In addition to débridement of the wound, the fracture site may have to be stabilised, and a number of methods are available.

Initial treatment by plaster or external fixator is appropriate, but later conversion to other methods may be required. Initial external fixation followed by later conversion to an intramedullary nail is a potential solution in the stabilisation of military fractures, particularly the more common lower limb fractures. Provisional research at Porton Down has confirmed that this is a viable option, but further work is required.

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