The incidence of bullet wounds in civilian trauma has increased in many parts of the world, sometimes approaching epidemic level. For surgeons with limited experience there is a bewildering range of apparently contradictory advice on management. An attempt to clarify this for gunshot injuries of the limbs, without major vascular injury, must include current concepts of ballistic wounding, the pathology of soft-tissue wounds and fractures, and of bacterial contamination.

Advice on clinical practice and treatment options cannot be prescriptive because of the wide range of injury patterns and settings, but an understanding of the general principles can guide clinical management.

WOUND BALLISTICS

The interaction of projectiles and biological targets should not be considered merely in terms of the missile velocity or its available energy. The important factor is its tissue interaction: a "high-energy" bullet may sometimes produce a low-energy transfer wound.

Energy transfer. The available kinetic energy of a missile depends on its mass (m) and velocity (v) according to the equation E = 1/2 mv^2, but the tissues involved and other projectile factors will determine the amount of energy which is transferred (ΔE). The rate of energy transfer (dE/dt) is also important; this may vary along the wound track (dE/dx) and in terms of energy flux (ΔE/cross-sectional area). These unfamiliar terms are the major determinants of the pathological effects, and mean that wound management cannot be based on the characteristics of the weapon, be it handgun, rifle, or shotgun. The key is to "treat the wound, not the weapon.

Soft-tissue wounds. A projectile produces a permanent cavity containing fragments of necrotic muscle and clot. Other tissues are stretched as they are thrown aside from the path of the bullet, creating a temporary cavity with zones of contusion and concussion, some devitalised tissue, and haemorrhage within and between muscle fibres. The extent and shape of this temporary cavity are related to the local transfer of energy (dE/dx). There is a transient low pressure as this temporary cavity collapses, which may draw contamination into the wound.

High-speed photographs of temporary cavitation in gelatin targets illustrate certain ballistic interactions. High-energy transfer may produce devastating effects (Fig. 1), but a rifle bullet may travel some distance into a target before it gives up its maximal energy. For this reason there may be less cavitation in the wound track closest to the entry. Temporary cavitation does not always cause a large zone of tissue damage, and skeletal muscle is relatively tolerant, especially with low-energy transfer. For this reason it may be unwise to try to excise all the tissue which may have been affected by cavitation.

Fractures. Projectiles which cause a fracture will transfer energy of the order of a few hundred Joules to the bone. The pattern and comminution of the fracture will depend on the rate of energy deposition (dE/dt) and energy flux. Severe comminution may arise without high local energy transfer, and may be due either to very fast transfer or to concentration in a small area. The way in which the energy is transferred therefore affects the fragmentation: a gunshot fracture of the tibia, caused by a handgun with low- to medium-energy transfer of a few hundred Joules, may be as radiologically comminuted as a tibial 'bumper' fracture, but in the latter the zone of soft-tissue injury will be much more extensive and severe. A highly-commminuted gunshot fracture may have a relatively healthy soft-tissue envelope (Fig. 2), with its important implication for healing potential.

Bacterial contamination. A bullet is not sterilised by firing and may carry viable bacteria into a wound. In addition, clothing may distribute bacteria along the wound track.
from both the entry and exit wounds. Bacteria may be drawn into the low pressure of the temporary cavity and distributed along the wound track. Despite this, gunshot fractures due to indirect interactions with the projectile may have minimal disruption of the surrounding soft tissue and periosteum with little or no contamination. The bacterial flora of a gunshot wound changes with time. The species causing infection in the first few days are

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**Fig. 1a**
A high-energy transfer wound of the thigh. The extent of soft-tissue disruption is suggested on the radiograph (a). At operation, much devitalised muscle was found and excised (b).

**Fig. 2a**
A gunshot fracture of the distal femur shows extensive comminution (a), but the soft-tissue wound was small with low-energy transfer. Treatment by retrograde femoral nail resulted in bony healing in three months (b), confirming the viability of the soft-tissue envelope.
mainly commensals. The risk of florid infection, rather than contamination, is related to the gross physical characteristics of the wound, the presence of fabric material and the viability of the surrounding tissues.\textsuperscript{15}

**WOUND MANAGEMENT**

Initial management must identify and treat life-threatening injuries by established resuscitation methods.\textsuperscript{16} An involved limb must be assessed and investigated for major vascular injury.\textsuperscript{17} All findings must be recorded and should be photographed when possible. In a civilian setting, forensic evidence should be preserved.\textsuperscript{9}

**Initial dressing and antibiotics.** A sterile dressing cover should be provided as soon as possible and left in place until the wound can be inspected in an operating theatre. Antibiotics play a part in preventing or delaying the onset of infection in military ballistic wounds.\textsuperscript{4,15,16,19} In the past, clostridia and beta-haemolytic streptococci have caused the major fatal infective complications of war wounds to limbs; antibiotic prophylaxis therefore has tended to rely on benzylpenicillin as the mainstay of first-line treatment, particularly for soft-tissue injuries.\textsuperscript{15,16} Penicillin has been associated with a reduction in the morbidity and mortality of war wounds and there is strong experimental evidence to support its continued use.\textsuperscript{15,20-22}

A gunshot fracture carries a risk of staphylococcal osteomyelitis, and most pathogenic staphylococci are now resistant to penicillin. For this reason additional cover is needed with flucloxacillin or a cephalosporin.\textsuperscript{15} A short course of antibiotics is commonly advised,\textsuperscript{15,20-22} but the need for this in low- to medium-energy transfer wounds from handguns in civilian practice has been debated.\textsuperscript{17}

**Wound surgery.** The traditional approach to the surgery of gunshot wounds is based on the treatment of wounds caused by the rifle or machine-gun bullets and large shell fragments of the First World War. The Inter-Allied Surgical Conference\textsuperscript{17} of 1917 emphasised the importance of excision of the skin margin, generous extension of the wound, exploration of all layers and the excision of damaged muscle. This advice has influenced the military management of war wounds for the remainder of this century, but has now been amended.

**Incision and irrigation.** An incision should pass through the skin wound, trimming only its grossly damaged edges, and continue in the axis of the limb, crossing flexor creases obliquely. Damaged subcutaneous fat and shredded fascia are removed. The deep fascia is incised for the length of the incision or beyond it.\textsuperscript{8,13} to allow exploration and relieve pressure within the wound and associated compartments. Irrigation with copious volumes of saline is used to reduce the number of bacteria, and pulsating high-pressure irrigation may be even more effective.\textsuperscript{16,25}

The addition of antiseptic agents or antibiotics remains controversial.\textsuperscript{17} Any evidence of raised or increasing pressure in compartments is treated by complete fasciotomy by an open technique.\textsuperscript{16,22,25}

**Excision.** Muscle is assessed for colour, consistency, contractility and capacity for bleeding.\textsuperscript{5} The criteria for excision or retention have been validated in war surgery\textsuperscript{17} and should be applied in civilian trauma. Piecemeal excision of muscle which fails to meet the criteria for viability ensures that the remaining tissue will be capable of resisting infection from any residual bacteria in the wound.\textsuperscript{15,16,25}

**Dressing and closure.** Dressing the open wound with fluffed-out gauze allows drainage with no need for a surgical drain. Primary closure over a drain is associated with an unacceptable complication rate.\textsuperscript{22}

The principle of staged treatment, using delayed primary suture (DPS) to close wounds with no excessive loss of skin, is widely accepted.\textsuperscript{14,22} Wounds may be reinspected in an operating theatre at 48 hours, but closure should be planned for four to five days after injury. Suturing is appropriate only if all tissues appear healthy and the edges of the skin and deeper tissues can be approximated without undue tension.

**Alternatives to DPS.** A few areas of skin have sufficient vascularity to allow immediate primary closure; the face, neck, scalp and genitalia may be sutured, but only after careful wound excision.

A larger skin deficit may be difficult to close without tension. Split-skin grafting at four to five days may be used over healthy granulation tissue but, as in all trauma surgery, a large defect should be managed with the early help of a plastic surgeon.\textsuperscript{30} The use of an antibiotic bead pouch\textsuperscript{27} is a temporising measure to prevent wound desiccation\textsuperscript{17} and maintain antibiotic levels\textsuperscript{28} until 'second-look' surgery and planned cover.

**Splintage.** Even when there is no fracture, the injured limb needs support and stabilisation by a plaster cast or backslab, to protect the soft tissues.\textsuperscript{9}

**Non-operative management.** In recent decades a much less aggressive surgical approach with non-operative management for simple gunshot wounds has been reported from a number of North American hospitals.\textsuperscript{20,21}

**Soft tissues.** Civilian experience has led to a concept of the 'minor' gunshot wound which is a low-energy transfer injury of the soft tissues (Fig. 3). At some centres these soft-tissue wounds have been treated on an outpatient basis after wound irrigation. In one series of over 3000 patients the overall infection rate was under 2%.\textsuperscript{20} About 40% of these had antibiotic cover, but infection (mostly *Staphylococcus aureus*) was not significantly reduced by this. Risk factors for infection in such wounds include undue delay between wounding and treatment, the lack of basic wound cleansing before attendance, a wound size of between 1 and 2 cm, and failure to comply with instructions on wound care.

**Fractures.** Carefully selected gunshot fractures may also be treated by early wound irrigation, dressing, antibiotics and splintage.\textsuperscript{22} Many low- to medium-energy transfer wounds involving fractures which do not need operative fixation are
In certain centres with great experience this non-surgical approach may be a safe and efficient use of resources, but it must be emphasised that proper assessment of soft-tissue injuries may actually require surgical exploration. The indirect evidence inferred from the position, size and extent of the entry and exit wounds, and the radiological appearance may not be enough at centres without considerable experience. If there is any doubt about the amount of non-viable tissue in the missile track, the safe management is by operative exploration.

Military setting. In this situation the main problems arise from high-energy transfer wounds, rather than the smaller wounds seen in civilian practice. Small-fragment ('shrapnel') wounds, however, are now common in modern warfare and are similar to civilian low-energy transfer wounds. This has led to the recognition that carefully selected soft-tissue wounds may be treated without operation.

A major concern in military surgery is how to distinguish those wounds which can be managed by non-operative treatment, with prompt antibiotic cover, from those which require operation.

Treatment of fractures. There is still much debate over the treatment of fractures caused by gunshot. A wide range of methods ranging from the non-operative such as ‘low-tech’ splintage through external fixation to internal fixation or intramedullary nailing, has been advised. The basic principles should be borne in mind. Does the wound need exploration? Does the fracture need reduction? Will the reduction be stable without fixation? What are the facilities and expertise available for immediate after-care and for follow-up?

Traditionally, the internal fixation of gunshot fractures has been condemned, but several major trauma centres have shown that intramedullary nailing of such fractures of the femur gives a favourable outcome as does internal fixation of other gunshot fractures. Many military medical services now recommend early external fixation for the stabilisation of fractures. It is recognised that this is not definitive treatment, but allows good management during evacuation through later echelons of care. The use of external fixation as definitive treatment has been associated with high rates of complication, and it has been shown that femoral and humeral fractures can be well managed even more simply by splintage or bracing in ‘third-world’ conditions.

In the choice of management it is important to remember that, like any other compound fracture, a gunshot fracture requires careful assessment, especially of the soft-tissue injury, and the use of fixation methods which are appropriate to the fracture pattern, the associated envelope and the expertise which is available.

CHOICE OF TREATMENT

Surgeons faced with a gunshot wound need to make carefully reasoned clinical decisions based on an understanding of the mechanisms involved. Figure 4 shows a proposed decision-making sequence which takes account of some of the variables.

Neither bullet velocity nor available energy can provide a guide to tissue damage in gunshot fractures; the surgeon should not ‘treat the weapon’. The state of the soft-tissue envelope and the fracture pattern are the key factors, and are determined by energy transfer. The aim is the preservation of healthy soft tissue with minimal non-viable tissue.
and contamination. This will allow fracture healing with any of a variety of different methods of stabilisation appropriate to the fracture pattern. Especially for massive wounds, a viable soft-tissue environment must be established before addressing the bony problem. Treatment must be based on careful assessment of the wound and available expertise and facilities. There is no dogmatic 'treatment of choice' for gunshot fractures.