The incidences of gunshot wound injuries reported in the literature are higher than those reported for motor vehicle accidents, sports injuries, or industrial accidents. Each year, approximately 30,000 to 50,000 Americans are killed secondary to gunshot wounds. This upper range nearly equals the number of fatalities (59,021) sustained during the 12 years (1961 to 1973) of the Vietnam war. In 2003, the last year for which these statistics are available, 30,136 persons were fatally wounded by firearms, representing 18.4% of all injury-related fatalities. Additionally, for every death, it is estimated that there are at least three nonfatal disabling injuries. This results in as many as 500,000 missile wounds occurring annually. In 1992, an anti-gun study from the Violence Policy Center, a national nonprofit organization based in Washington, DC, reported there were more licensed gun dealers (245,000) in the US than gas stations (210,000).

Gunshot wounds also are a tremendous cost to society. Recent studies have provided varying estimates of gun-related medical costs. One national study, for example, has estimated the total annual cost at 2.3 billion dollars. In a 1994 report, medical spending per hospitalized gunshot victim averaged $25,000. Fifty-six percent of these patients were unemployed, 79% uninsured, and 68% were substance abusers.

Ballistics

The extent of tissue/organ damage depends on a wide variety of factors including the bullet’s diameter or caliber, as well as its shape, velocity, tumbling characteristics, and weight. Bullets are missiles made of lead alloy. The high specific gravity of lead gives maximum mass with minimum air resistance. Bullet tips can be manufactured in many different configurations to enhance their performance, and include pointed, round, flat, and hollow point types. A pointed bullet has less air resistance and travels longer in a straight line than a round-nosed bullet. However, a pointed bullet design confers poor balance, because the center of gravity is shifted to the rear of the bullet. These projectiles, usually at high velocity and in stable flight, will tend to become unstable upon meeting resistance. Thus, upon passing from air to tissue, there is an enhanced tendency for the bullet to turn on its short axis (i.e., yaw). This can be likened to a car hitting a utility pole slightly off center. As a bullet tumbles to 90° of yaw, the size of the wound channel created will be significantly increased, as its kinetic energy is dissipated with great intensity. The much more devastating wounds from a pointed bullet after impact can rival those of expanding bullets and are attributable to this instability. At a given velocity, the smaller the mass of the bullet, the greater the tendency for it to yaw, tumble, and fragment.

Exposing the bullet core at its nose creates expanding type bullets. This core, which is soft and very pliable, rapidly expands on impact. This expansion can be further enhanced by the use of hollow point bullets, where a depression is made in the bullet nose. The purpose is to increase the frontal surface area that the bullet presents to the tissue along its trajectory following impact. For example, as a nonjacketed bullet “mushrooms,” a .30 caliber bullet can develop a .70 caliber...
cross section. By deforming or expanding up to twice their original diameter, hollow point bullets can quadruple the amount of tissue struck. The kinetic energy imparted to the tissue is thus directly related to the cross-sectional area of the missile.

To compensate for barrel friction at high velocities, bullets may be coated or jacketed with materials of higher melting points. Jacketed bullets are primarily utilized in assault rifles. Being jacketed also prevents a bullet from softening or becoming deformed upon impact. The Hague Peace Conference of 1899 required that bullets be “jacketed” in copper to minimize their deformation and resultant tissue damage. Military ammunition has been jacketed ever since. However, these constraints are not imposed on ammunition used by private citizens.

Low velocity is defined as less than 2000 ft/s, while high velocity is equal to or greater than 2000 ft/s. Low velocity weapons include the .45 caliber handgun (869 ft/s), 9 mm semi-automatic (955 ft/s), and 357-magnum handgun (1393 ft/s). Magnum shells and cartridges contain a heavier than standard powder charge, which increases projectile energy by 20% to 60%. High velocity weapons include the AK-47 military rifle (2993 ft/s) and M-16 military rifle (2850 ft/s). Typically, high-velocity missiles are associated with greater soft-tissue damage and wound contamination than low-velocity missiles.

Shotguns are considered to be the ultimate close-range weapon, because they are capable of delivering a load that is considered to be low velocity (i.e., from 1100 to 1350 ft/s) yet highly destructive. Between 47% and 59% of shotgun wounds to the extremities are associated with major soft-
tissue injury, 59% with nerve injury, 24% with vascular damage, and 44% to 47% with bone or joint injury.\textsuperscript{14,15}

The damage caused by shotguns is related to the tremendous kinetic energy that is generated by the increased mass of pellets found within a shotgun shell (Figs. 1 and 2). Range is the most critical determinant of the wounding capacity of a shotgun. Because of the poor aerodynamic shape of a spherical pellet, shotgun pellets decelerate rapidly, losing their kinetic energy in a likewise rapid manner.

At a range of 1 to 2 yards, a single, large, ragged entrance wound will be created, with associated massive tissue destruction. From a slightly longer range of 3 to 4 yards, a large, central wound surrounded by several single pellet wounds is produced. Each of these single pellet wounds, in turn, may be associated with significant tissue destruction. At a range of greater than 7 yards, the pattern of pellet dispersion will be 1 to 3 feet in diameter. At these distances, only a few pellets will hit the target, causing moderate tissue destruction. At a range of 20 to 50 yards, the wounding capacity of a shotgun is negligible.\textsuperscript{16} Shotgun wounds are usually significantly contaminated by the contents of the shotgun shell itself (Fig. 3). This material must be fully debrided intraoperatively.

There are three principles regarding the extent of injury to tissue caused by a gunshot wound: dissipation of kinetic injury, production of secondary missiles, and cavitation. Understanding these principles will guide the orthopedic surgeon’s appraisal of the extent of tissue damage, the need for debridement, potential for infection, and possibilities for osseous and soft-tissue reconstruction.

By definition, kinetic energy is equal to 1/2 the mass multiplied by the velocity squared ($\frac{1}{2} MV^2$). Therefore, increasing the velocity of the missile exponentially increases its kinetic energy. For example, although an M-16 round has approximately the same caliber and weight as a .22 caliber handgun bullet, it is fired at a velocity three times greater, resulting in nearly ten times the kinetic energy.\textsuperscript{17}

Secondary missiles are generated when the primary bullet or missile impacts objects such as cortical bone, teeth, metal buckles, and buttons. Secondary missiles may cause more damage than the primary missile by taking erratic and unpredictable courses and spreading the energy exchange over a wider area. Secondary missiles may also leave several exit wounds. As the velocity of the primary bullet increases, secondary missiles are more frequently produced (Fig. 4).\textsuperscript{17}

Wang and colleagues described three zones of injury secondary to the missile's projectory.\textsuperscript{18} The first zone of injury is the primary wound tract, otherwise known as the permanent cavity (Fig. 5). This cavity results from the actual crushing of tissue directly in the bullet’s path. The second zone of injury is a contusion zone of muscle adjacent to the bullet track. Finally, the concussion zone is the area where the shock waves produced during cavitation have caused damage distant from the immediate bullet contact area.

When a missile enters tissue, a temporary cavity is created along the primary wound tract through the process of cavitation (Fig. 5).\textsuperscript{17} Cavitation occurs when energy distribution from one point spreads into adjacent tissue; the energy of the moving bullet pushes tissue particles away from the impact point, producing a cavity. The resultant stretching, compressing, and shearing of tissue may produce damage extending several centimeters lateral to the bullet tract.

This temporary cavity lasts only milliseconds after bullet impact, expanding and collapsing at a rate that is dependent on the tissue characteristic and the amount of energy transferred by the missile. In low velocity missiles, this temporary cavity is only slightly larger than the remaining permanent cavity. High velocity missiles, on the other hand, produce a
large temporary cavity that is much wider than the permanent cavity. Furthermore, this large temporary cavity is usually filled with water vapor that has a low atmospheric pressure. As a result, contaminating foreign material is more likely to be sucked into the entrance and exit wounds created by the vacuum of these high-velocity missiles.

A narrow 1 mm to 2 mm zone of abraded skin, called the “abrasion ring,” characterizes entrance wounds. This ring is produced when the surface of the skin is damaged by the rubbing or scraping action of one’s clothes as the bullet penetrates the garments and underlying skin. The resulting abrasions are oval or circular “punched-out” lesions. On the palms and soles, they may be stellate in appearance. Oval-shaped wounds imply a more tangential trajectory, whereas a round wound indicates a more direct, perpendicular path toward the extremity.

There are four categories of entrance bullet wounds based on the target range. These include contact, near contact, intermediate, and distant wounds. Contact wounds are created when the muzzle of the gun is held against the body surface at the time of discharge (Fig. 6). These wounds are characterized by blackened, seared margins. Near-contact wounds are created when the muzzle of the gun is a short distance away from the skin at the time of discharge (Fig. 7). These wounds are characterized by a wide zone of powder soot deposited in a zone overlying the area of seared, blackened skin. However, the powder grains emerging from the muzzle blast do not have a chance to disperse and “powder tattoo” the skin. Angled near-contact wounds occur when the gun barrel is held at an acute angle to the skin (Fig. 8). As a result, the complete circumference of the muzzle is not in contact with the skin. The gas and soot emerging from this gap radiate outward, producing an eccentrically arranged pattern. A blackened, seared zone will be located on the same side as the gun’s muzzle. Not only does this identify the site as the point of entrance, but it also identifies the bullet’s direction of travel. A third category of wounds
is described as intermediate. Gunpowder tattooing of skin is the sine qua non of these wounds. Finally, distant wounds may still have carried significant velocity or may just be a “spent” round.

Exit wounds are larger in size than entrance wounds and more irregular in shape (e.g., stellate, slit-like, or crescent) (Fig. 9). There is no abrasion ring present in exit wounds. High velocity missiles may create very large exit wounds. When a bullet enters the body, its path is unpredictable. A bullet deflected by bone can exit in an unexpected location. As a result, it is important to do a secondary survey in these patients ensuring that all of the patient’s skin is visualized and examined. If there is no exit wound, then all of the kinetic energy has been dissipated into the tissue.

It is important to remember that the missile is not sterilized from the combustion of the charge or from friction with the gun barrel. Bullets can therefore be vectors of infection. Wolf and coworkers fired sterile bullets painted with Staphylococcus aureus into a sterile gelatin block. This block subsequently grew out S. aureus. Gonyea reported the case of a man who was shot through his tannery work clothes, with the missile entering his spinal canal. This patient subsequently developed fatal meningitis from Blastomyces dermatitidis. Patzakis and colleagues, in a review of 78 gunshot fractures, compared patients who were and were not treated with antibiotics. In their study, patients who were treated with antibiotics had a significant reduction in infection rate (2.3% infection rate) compared to those who were not (13.9% infection rate). Studies such as these resulted in recommendations for irrigation and debridement of all gunshot wounds, regardless of missile velocity, as well as a mandatory course of intravenous antibiotic therapy.

However, recent studies have questioned the necessity of formal debridement and intravenous antibiotic use in low-velocity fractures treated with closed reduction and casting. Howland and Ritchey, in a study of 111 low-velocity gunshot fractures, concluded that antibiotics were not required in the routine management of these injuries and that debridement should be utilized only if signs and symptoms of infection develop. Geissler and coworkers found no significant difference in the rate of infection in minor gunshot wounds between patients who received 1 gm of intramuscular cefonicid in the emergency room vs. a three-day inpatient regimen of intravenous Ancef. As a result, they concluded that patients with minor gunshot wound injuries could be managed with outpatient oral antibiotics without an increased infection risk. In a retrospective study of 3390 patients by Ordog and colleagues, in 1993, 1.8% developed wound infections related to minor gunshot wounds. The distribution of infection was equally divided between those patients receiving prophylactic antibiotics (56%) and those who did not (44%). Therefore, the investigators found wound debridement and antibiotics to be often unnecessary in minor uncomplicated gunshot wounds. Ferraro and Zinar treated stable, low-velocity tibia gunshot wounds with superficial wound cleansing and skin edge debridement in the emergency room. These patients were then discharged to home on oral antibiotics with no subsequent infections reported. Finally, Woloszyn and coworkers treated low-velocity gunshot fractures in the emergency room with superficial debridement, cast immobilization, and antibiotics. No statistically significant advantage of intravenous over oral antibiotics was found. However, treatment with oral antibiotics did result in dramatically reduced medical costs compared to treatment with inpatient intravenous antibiotics.

Nevertheless, because wound contamination is not always apparent, most authors still recommend routine antibiotic prophylaxis. In high-energy gunshot wounds and shotgun injuries, treatment with cephalosporin, aminoglycoside, and/or penicillin is recommended. Wounds with significant contamination should certainly be treated with gram positive and anaerobic agents. The use of antibiotics should not be misconstrued, however, as a substitute for the extremely important surgical principle of an extensive surgical debridement of all devitalized tissue in open fractures.

**General Management Principles**

In treating gunshot injuries, one should always remember to follow the fundamental principles (i.e., the “ABCs”) of...
Advanced Trauma Life Support protocols. Attention should be initially directed toward the stabilization and resuscitation of the patient. A thorough history should be obtained from the patient, if possible. The patient may know the type of weapon, approximate range, and angle of the shot. This is important, as entry wounds created by different types of weapon may have similar appearances.

One should ensure that all of the patient’s skin has been visualized on the initial assessment in order to identify the location of all entrance and exit wounds. One also should preserve evidence by cutting around, not through, bullet holes in the patient’s clothing. An adequate wound description should be recorded in the medical chart. A recent study revealed that fewer than 3% of charts had an adequate wound description.5 Bullets should be marked only on the nose or base to preserve rifling characteristics. Wadding or loose shotgun pellets should also be preserved.

Wounds must not be probed with instruments or fingers. If close examination of the wound itself is necessary, it should be explored in the operating room. All major arterial, venous, and neural structures traversing the area can then be thoroughly evaluated at that time. Tetanus prophylaxis is indicated in all gunshot wounds.

**Vascular Related**

A thorough vascular and neurological exam should be performed. Throughout the body, a close association exists between major arterial, venous, osseous, and neural structures. This is especially true of the upper extremity, where a high frequency of combined injuries occurs, including a 50% incidence of associated significant nerve involvement.29 These nerve injuries are a major determinant of long-term functional morbidity in patients sustaining gunshot wounds to the extremities, despite successful management of vascular and orthopedic trauma.

Most vascular injuries that result from penetrating trauma are manifested by well established “hard” physical findings that will usually allow a rapid and accurate diagnosis. These findings include: pulse deficit; a cold, lifeless extremity; cyanosis distal to the wound; a bruit or thrill; a large or expanding hematoma; and pulsatile or uncontrollable bleeding. Pulsatile bleeding is considered to be the most reliable sign of major vessel injury.30,31

If the physical examination reveals such clear evidence of a significant arterial injury, preoperative angiography is usually not needed because it may cause further delay in treatment (i.e., immediate exploration). Outside of the operating room, hemorrhage should be controlled by direct pressure applied to the site.32 Tourniquets should not be used, as they will occlude the rich collateral network that maintains perfusion distal to the injury site. Perfusion of the distal extremity via extensive collateral arteries is probably one reason why the incidence of limb loss in upper extremity vascular trauma is quite low. Clamps should not be placed on bleeding points. The same close anatomic relationships that contribute to the high incidence of combined vascular and nerve injuries are also implicated in the high probability of nerve injury when an attempt is made to place clamps on bleeding vessels. Exploration of the wound, as mentioned prior, should be reserved for the operating room. The absence of these “hard” signs does not reliably exclude arterial injury. Findings suggestive of vascular injury or “soft” signs include a history of hemorrhage; unexplained hypotension; a small, stable hematoma; nerve injury; and proximity of the wound to major vascular structures.

Even after complete arterial disruption, a weak but palpable pulse might still be present. Apparently, normal pulses have been found to be present in 20% of cases with angiographically demonstrable lesions.33 The rich collateral arterial supply is responsible for pulses being palpable distal to the site of significant arterial injury in 25% to 49% of cases.34

With anything less than an easily palpable pulse, the patient should be resuscitated and reevaluated.35,36 Pulse oximetry can be a helpful tool to monitor vascular status. Diminished, noninvasive arterial pressure indices can also be used reliably to identify limbs at risk of arterial trauma with a sensitivity, specificity, and accuracy of 90% or greater.77

Advantages of angiography include its accuracy, sensitivity, specificity, low rate of false negative and/or false positives, its high predictive value, and relatively low rate of complications. Disadvantages of angiography include high cost, a possible significant delay in definitive treatment, interventional risks and complications, and the ability to detect occult findings that may resolve spontaneously.

Angiography may be more useful for cases in which the limb is viable but where a high degree of suspicion of arterial injury exists. If the patient is stable, preoperative angiography can be performed to exclude the presence of an injury. Angiography may also be helpful if a coverage procedure is planned, especially if local tissue, such as a pectoralis flap, is to be used, to ensure that the blood supply through the primary vascular pedicle is intact.34 All patients with multiple wounds in the same extremity should have angiography, if stable. The extensive dissection required, the need to identify all sites of injury, and distal outflow provide the rationale for this approach. However, even in such cases, early exploration without an angiogram is preferable to a protracted delay. An angiogram can always be performed in the operating room. However, in the absence of physical findings of disturbed circulation, the yield is 10% for occult vascular injury. Dennis and colleagues noted that only 0.8% of patients required surgery for injuries that would have been missed by not performing angiography. These missed injuries were usually minor and tended to heal.39

Duplex ultrasonography, as an alternative, can be as sensitive (95%), specific (99%), and accurate (98%) as angiography.77 Furthermore, it carries no interventional risks, is more cost-effective, and can be performed promptly and portably in the emergency room. Doppler arterial pressure
measurements have been found to be useful in all but the most proximal of injuries to the extremities.40

If it is determined that there is a vascular injury requiring repair, rapid external fixation of the affected limb should be performed. Fracture stability should be obtained first in order to protect the vascular repair; however, when significant ischemia is present, establishing distal perfusion becomes a priority. In this situation, consideration should be given to placing a temporary intraluminal shunt in order to restore distal flow.41 The fracture can then be stabilized, followed by definitive vascular repair. Otherwise, attempts at achieving fracture fixation after arterial repair may disrupt the vascular reconstruction with the repetitive motion of reduction and correction of alignment. Delays of more than six hours in revascularization should be accompanied by fasciotomy to prevent compartment syndrome.32

Vascular injuries caused by gunshot wounds are almost always appropriately managed by segmental resection, even when the vessel is not completely transected.32 The zone of injury attributable to bullet wounds often extends beyond the area that is visibly damaged. A primary end-to-end anastomosis may be performed if the proximal and distal ends can be brought together without tension. Otherwise, repair should be carried out using an interposition graft. After completion of the arterial repair, the distal extremity should be carefully examined to determine the adequacy of revascularization. An intraoperative arteriogram may be valuable in demonstrating the patency of the repair and in identifying anastomotic defects requiring revision.

Due to their close anatomic proximity, combined venous and arterial injuries occur frequently. This is especially true in cases involving the upper extremity. Injury to concomitant veins should be treated with primary repair.32 Ligation has been found to result in a marked reduction in associated arterial inflow, which can jeopardize the patency of any associated arterial repairs.

**Nerve Related**

Nerve injuries also occur commonly in association with upper extremity arterial injuries. The concussion zone of blast injury may cause neurapraxic or contusion injuries that will recover spontaneously. On the other hand, a progressive neurologic deficit may signal the presence of an expanding hematoma or pseudoaneurysm compressing the neurologic structures. Prompt decompression of the hematoma or resection of the aneurysm can often reverse this deficit.38

Electrodiagnostic studies obtained immediately after injury are usually not helpful, as they cannot distinguish between a neurapraxic lesion and more serious injury. Follow-up studies at six weeks and three months can show signs of early recovery, but, again, their utility is limited.38 Early signs of functional recovery on physical examination are reliable, and the order in which recovery occurs is significant. In neurapraxia, recovery does not progress in an anatomic, proximal-to-distal fashion but, rather, is ran-
lead.\textsuperscript{46} This can result in a constant dialysis of synovial lead into the blood. If any question of joint involvement exists, a computed tomography (CT) scan should be performed. Arthroscopy is often necessary for adequate debridement of the joint, but in uncomplicated cases, arthroscopy may provide both valuable diagnostic information and definitive treatment.

\textbf{Summation of Management Principles}

Most low-velocity gunshot injuries may be safely treated nonoperatively on an outpatient basis, as these wounds usually involve only the skin, subcutaneous and/or muscle tissue, and minor cortical bone fragments. Local wound care consists of superficial irrigation and careful cleansing followed by a dressing. As discussed above, controversy persists over the routine use of prophylactic antibiotics in these injuries. While they may not be essential for wounds that are not grossly contaminated, at least 24 hours of intravenous antibiotics should be administered postoperatively to patients with fractures that required stabilization.

High-velocity and shotgun wounds require immediate and aggressive irrigation and debridement. The margins of the entrance and exit wounds should be excised and the missile tract thoroughly irrigated. A wide debridement of devitalized tissue must be performed and foreign bodies removed. The patient should then be returned to the operating room every 48 to 72 hours for serial debridements. All contaminated subcutaneous fat and devitalized muscle must be removed. Bone without soft tissue attachment should be excised. Elimination of dead space is vital. Primary closure of bullet wounds must be avoided because of the possibility of contamination. Secondary wound closure can usually be performed within 5 to 7 days after injury. When wounds cannot be closed without tension, skin grafting or a muscle coverage procedure may be necessary.\textsuperscript{47}

Clinical criteria should be used in determining the need for fasciotomy. Fasciotomy is required less often for upper extremity vascular trauma than for that of the lower extremity.\textsuperscript{44} This difference may be because of the more extensive collateral arterial and venous supply and the smaller muscle mass in the upper extremity. Upper extremity fasciotomy is required most frequently in association with complete transection of both the radial and ulnar arteries.\textsuperscript{34}

Primary amputation of an injured extremity is rarely required, but the decision is a difficult one to make. When faced with a severely injured limb, the decision to amputate must be based on the overall clinical assessment that reasonable functional recovery is extremely unlikely. This situation usually presents itself when combined injury to nerves, bones, soft tissues, and vascular structures is extensive (Fig. 10). Close range shotgun blasts may result in this type of damage.

\textbf{Gunshot Wounds to the Shoulder}

Ordog and coworkers found a 9\% incidence of shoulder injury in gunshot wounds to the upper extremity.\textsuperscript{48} Vascular injuries were detected in 15\% of those wounds and 15\% had fractures that required hospitalization for definitive treatment. Major vascular injury was four times more likely when a patient had a fracture that required definitive treatment.\textsuperscript{48} Recent large series have noted a 25\% association of nerve damage with high-velocity injuries to the axillary and subclavian arteries.\textsuperscript{38}

A trauma series of the shoulder, as well as plain films of the chest, cervical spine, and arm should be obtained in all cases. An anteroposterior (AP) view of the shoulder

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{A. This left leg exit wound exhibits the massive tissue destruction characteristic of M-16 gunshot wounds in which bone is hit by the M-16 round. B. Amputation was the only treatment possible for this injured extremity. (From: Swan KG, Swan RC: \textit{Gunshot Wounds: Pathophysiology and Management}. Chicago: Year Book Medical Publishers, 1989. With permission.)}
\end{figure}
in both internal and external rotation can provide further information. The chest radiograph can be used to diagnose hemothorax and pneumothorax.

Fractures of the humerus, scapula, or clavicle caused by low-velocity or low-energy projectiles usually do not require surgical intervention. The majority of low-energy humeral-head fractures are not displaced or are minimally displaced, with an intact rotator cuff mechanism. These injuries also do not require surgery.

High-energy injuries that have effectively destroyed the humeral head and articular surface are treated with hemiarthroplasty. Displaced fractures of the greater and lesser tuberosity, as well as displaced glenoid fractures with intra-articular involvement also require surgical stabilization. Fractures of the neck and spine of the scapula demonstrate a high rate of associated disability, especially weakness with abduction, pain, and a decreased range of motion. Scapular neck fractures with more than 40° of angulation and fractures with 1 cm or more of displacement are, therefore, indications for surgical treatment. Scapular spine fractures at the base of the acromion and those with more than 5 mm of displacement are at risk for nonunion and are, therefore, also surgical considerations. Certainly metallic fragments or a bullet in the shoulder joint requires surgical removal (Figs. 11 and 12). Marked comminution, segmental (“floating”) fractures, and early neurovascular repairs are other indications for open reduction and fixation. Anatomic reduction may not be possible because of comminution and bone loss. Open reduction and internal fixation with supplementary iliac bone graft is recommended in fractures that involve the diaphyseal and metaphyseal junction and surgical neck. Cloverleaf or dynamic compression plates can be used if good soft-tissue coverage is present, but care should be taken to avoid subacromial impingement. Intramedullary fixation using locked nails with or without reaming can also be used if the wounds are minimally contaminated. Stabilization of fractures due to shotgun wounds often requires the use of skin grafting or flaps. Shoulder soft-tissue defects may be

![Figure 11](image1.png) Anteroposterior and axillary radiographs of a gunshot wound to the left shoulder joint with associated intra-articular bullet fragments.

![Figure 12](image2.png) Coronal and axial CT scan cuts of a gunshot wound to the left shoulder joint. Note associated intra-articular bullet.
conditions, as is often the case with gunshot wounds, may be
Humerus fractures associated with poor overlying skin
of the nerve combined with rigid fixation of the fracture.
Primary nerve palsy. This approach allows for exploration
of the fracture using a compression plate may also be
fractures with grade I open wounds make the risk of infection
Infection rates of 1.9% to 2.3% after internal fixation of
humeral shaft fractures in patients with multiple injuries.
using compression plate fixation to internally stabilize
ated articular injury, and fractures with associ
comminuted fractures for which adequate reductions are dif
means. The primary indication remains a failure to obtain or
the end result of a flail, anesthetic limb, amputation may
need to be performed.

Gunshot Wounds to the Humeral Shaft
There are no large series of humeral fractures secondary to
gunshots in the literature. The general consensus among
orthopaedic surgeons treating low-velocity, gunshot-induced
humeral shaft fractures is local wound debridement and copi-
ous irrigation in the emergency room, tetanus prophylaxis,
and nonoperative treatment with either a hanging arm cast
or a functional brace.

Indications for the operative stabilization of humeral
shaft fractures caused by gunshot wounds are essentially
identical to those for humeral shaft fractures caused by other
means. The primary indication remains a failure to obtain or
maintain a satisfactory closed reduction. Bullets often cause
comminuted fractures for which adequate reductions are dif-
ficult to achieve and maintain using nonoperative measures.
Other indications for operative intervention of humeral shaft
fractures include patients with multiple trauma, segmental
fractures, bilateral humeral fractures, fractures with associ-
ated articular injury, and fractures with ipsilateral forearm
fractures, i.e., the “floating elbow”.

Union rates averaging 91% to 100% have been achieved
using compression plate fixation to internally stabilize
humeral shaft fractures in patients with multiple injuries.
Infection rates of 1.9% to 2.3% after internal fixation of
fractures with grade I open wounds make the risk of infection
nearly comparable with that of closed fractures. Stabili-
tion of the fracture using a compression plate may also be
considered in a grade II open humeral shaft fracture with a
primary nerve palsy. This approach allows for exploration
of the nerve combined with rigid fixation of the fracture.
Humerus fractures associated with poor overlying skin
conditions, as is often the case with gunshot wounds, may be
more amenable to intramedullary fixation inserted at a site
distant from the fracture. Interlocking humeral nails allow for
intramedullary fixation of segmental or severely comminuted
fractures, as are often seen secondary to gunshot wounds.
Overall results of both flexible and rigid intramedullary nai-
ing of humeral fractures are encouraging. Union rates are
in the 92% to 100% range, with an average time to healing
of between 6 and 13 weeks.

The main indication for external fixation in the treatment
of fractures created by gunshot wounds is for those fractures
associated with large, soft-tissue wounds, including those
requiring neurovascular repair. The fixator causes limited
damage to the blood supply of the fracture, and does not in-
tere with neurovascular anaesthesia or with postoperative
wound care. Because of the lack of large uniform series of
patients treated in this manner, the results of external fixa-
tion of humeral fractures associated with gunshot wounds
are difficult to interpret. Pin tract infections occur in about
10% of patients treated with external fixators. However,
these infections respond readily to systemic antibiotics
and, if necessary, pin removal. Rates of deep infection vary
dramatically and are probably more closely related to the
degree of underlying soft tissue injury. Functional results
of external fixation, though, appear to be as good as those
from intramedullary or plate fixation. In one study, 93.6%
of patients treated with external fixation regained functional
use of their upper extremities. However, incidence of non-
union for externally fixed upper extremity fractures varies
from 5 to 62%. Early autogenous iliac crest bone grafting
may be indicated to reduce the rate of nonunion in patients
with extensive soft-tissue injury, bone loss, or no evidence
of radiographic union at 3 months.

Gunshot Wounds to the Elbow
Gunshots wounds to the elbow are not very common. Vic-
tims of firearm trauma are more likely to sustain trauma to
other parts of an upper extremity. At Martin Luther King,
Jr. Hospital, only 29 patients were treated for this condition
over a ten-year period.

Patients with fractures of the distal humerus, whether
intra- or extra-articular, require an angiogram to assess the
integrity of the brachial artery, even in the presence of a
palpable pulse distal to the injury. Patients with isolated
fractures of the medial or lateral epicondyle, or of the
proximal radius, ulna or both, do not require angiography,
unless the clinical examination suggests a vascular injury.
Injury to the principal nerves about the elbow joint should
be suspected with all gunshot wounds to this area.

Two orthogonal view plain radiographs of the elbow are
usually sufficient to allow determination of the amount of
commination of the bony fragments. Intra-articular fractures
of the distal humerus are best managed with dual plate fixa-
tion. However, in fractures with significant commination,
one may consider external fixation as an alternative option.
Should external fixation become necessary, it should be re-
moved as soon as feasible to allow active motion. Fractures of the radius and ulna are managed using standard AO/ASIF principles. If the radial head is significantly comminuted, it will be less likely to support internal fixation and can be excised. However, prosthetic replacement is ill advised in the acute setting. If significantly comminuted, consider excision of the olecranon with repair of the triceps mechanism. After open reduction and internal fixation, early range of motion exercises are recommended. Patients with neurologic injuries should be maintained in the appropriate splints.

**Gunshot Wounds to the Forearm**

Approximately 4% to 20% of civilian gunshot wounds consist of injuries to the forearm. Most civilian injuries fall into the low-velocity category. Isolated ulnar fractures with less than 10° of angulation or less than 50% displacement can be treated with casting or bracing. In displaced isolated ulnar or radial fractures, compression plate fixation is preferred. Isolated, nondisplaced radial fractures can be treated with cast immobilization. Displaced fractures of both bones are also generally treated with compression plates and early motion. For fracture patterns not amenable to plate fixation, external fixators or intramedullary nails can be used. Bone graft is recommended when significant comminution or bone loss has occurred.

The treatment of high velocity and shotgun injuries resulting in types II and III open fractures is controversial between immediate internal vs. external fixation. Duncan and coworkers noted a significantly higher complication rate in types IIIb and IIIc injuries treated with immediate internal fixation. Their results supported the use of immediate internal fixation in types I, II, and IIIa injuries, but questioned its use in types IIIb and IIIc injuries. In their series, Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds. Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds. Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds. Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds. Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds. Chapman and Mahoney found an infection rate of 41% with the use of internal fixation in type III wounds. However, Moed and colleagues encountered only one infection with the use of internal fixation in type III wounds.

Advantages of external over internal fixation include faster times of application and less collateral blood supply damage. External fixation has provided satisfactory results in the treatment of severe forearm injuries, such as is seen in close range shotgun injuries. Smith and Cooney have proposed a compromise solution. These investigators found good to excellent results with initial external fixation of open forearm fractures, followed by delayed plate fixation and bone grafting as needed.

It is critical to thoroughly assess the vascular status of the limb. In the presence of an injured vessel, Orcutt and coworkers found pulse deficits in 86% of radial injuries and 83% of ulnar injuries. However, the presence of a pulse does not rule out an isolated radial or ulnar artery injury. This is most often due to retrograde flow through the arches of the hand. In addition to palpating the radial and ulnar arteries, and performing an Allen’s test, a vessel with a suspected injury should be palpated while the uninjured vessel is occluded. Loss of the pulse with occlusion of the uninjured vessel documents retrograde flow.

The need for repair of a single vessel injury in the presence of a well perfused hand is debated. However, the repair of a vessel in a two-vessel forearm injury or a one-vessel forearm injury with signs of distal ischemia is well accepted. Data from World War II showed amputation rates of 39% when both radial and ulnar arteries were ligated and 5% when just the radial artery was ligated. Repair of vessels has resulted in patency rates of 47% to 86%.

The surgeon should have a high index of suspicion for the possibility of compartment syndrome in any gunshot wound to the forearm. Lenihan and colleagues recommended 24 hours of close observation for all gunshot wounds to the forearm. Rates of approximately 10% in low velocity injuries have been found. Moed and Fakhouri found a compartment syndrome incidence of 36% in patients with low velocity proximal one-third fractures, and a high incidence was also found with highly comminuted and displaced fractures. Even in the absence of fracture, Moed and Fakhouri found an incidence of 6%. If a compartment syndrome is suspected, intracompartmental pressure measurements should be taken. A single or double incision fasciotomy should then be performed as clinically indicated.

**Gunshot Wounds to the Hand**

The majority of gunshot wounds to the hand are the result of low-velocity handguns. However, the spectrum of these injuries is wide, and includes high velocity assault weapons, shotguns, BB guns, and pellet guns. Appropriate radiographs of the extremity should be obtained in the standard planes. CT scans may be indicated, especially in gunshot wounds to the carpal bones, to assess the extent of bony and articular involvement.

Indications for nonoperative management include absence of joint involvement, fracture displacement, and/or bone loss. Treatment in such cases usually consists of cast immobilization, a short course of oral or intravenous antibiotics, and close follow-up. In cases where joints are involved and obvious disruption of the extensor tendons, flexor tendons, or both is found, the patient should undergo prompt formal irrigation and debridement, stabilization of fractures, and repair of injured tendons or neurovascular structures. The specific means of immobilization and stabilization depend on the fracture pattern and the existence of bone loss. Kirschner wires, mini-plates and screw fixation, cerclage wires, mini external fixator devices (Fig. 13), or primary stabilization with subsequent fusion have all been used with good results. Of key importance is early post-
Gunshot Wounds to the Hip

A gunshot wound to the hip is associated with substantial morbidity and mortality. This injury is often accompanied by concomitant injuries to the abdomen. Both the abdomen and hip require immediate evaluation and surgical treatment to reduce the incidence of sepsis, functional disability, and death.

An AP radiograph of the pelvis and a cross-table lateral should be obtained in all patients who have sustained a gunshot wound near the hip. Judet 45° oblique views of the pelvis are useful when an acetabular injury is suspected.

Joint contamination can occur when a bullet enters the hip capsule. Bacteria can gain access to the hip by contiguous spread from the bullet through the fracture caused by the bullet. Any patient with a bullet wound between the umbilicus and the proximal one third of the thigh is at risk of hip joint penetration. Fractures of the acetabulum, femoral head, or intracapsular portion of the femoral neck are the best radiographic evidence of joint violation.

When plain radiographs are inconclusive, a fluoroscopically assisted arthrogram can be used to detect hip joint violation or an intracapsular bullet (Fig. 14). A hemarthrosis indicates joint violation. The aspirate should be sent for cell count, culture, and gram stain. The arthrogram may show a missile in contact with or surrounded by contrast. A hole in the capsule results in extravasation of contrast. A trail of contrast may demonstrate communication between the joint and bowel or bladder.

CT of the hip should be obtained prior to an arthrotomy to remove a bullet in the acetabulum. By identifying associated intra-articular fractures as well as localizing the bullet, the CT scan can assist in planning the surgical approach.

A hip aspiration and arthrogram should be performed on every high-energy gunshot wound to the hip. Every gunshot wound to the hip that has an associated transabdominal injury requires an immediate arthrotomy. All patients who sustain large bowel injuries should have a colostomy, and small bowel injuries should be repaired. Bullets in communication with synovial fluid and intra-articular bone fragments should also be removed by an arthrotomy. Indications for internal fixation include unstable intra-articular fractures and unstable femoral neck fractures. Emergent reduction and stabilization of displaced femoral neck fractures is recommended when bone stock is adequate to achieve stable fixation. If the blood supply to the femoral head remains intact and the fracture unites, a good result can be antici...
pated. Otherwise, hip arthroplasty or fusion can be planned on an elective basis. Femoral neck fractures with small cortical defects at the point of bullet impact can be treated nonoperatively.

**Gunshot Wounds to the Femur**

At the time of presentation, conventional anteroposterior and lateral radiographs of the femur, including the hip and knee, should be obtained. Patients should be placed in balanced skeletal traction if a surgical delay is indicated. Ninety-three percent of femur fractures resulting from low-velocity gunshot wounds are classified as having Winquist and Hansen grades III or IV comminution. Early femoral stabilization using an interlocked nail should be used for all patients. Cephalomedullary nails are used for complex femur fractures that have fracture extension proximal to the lesser trochanter.

An indication for external fixation of a femoral shaft fracture is a large soft tissue wound associated with high-velocity missile and shrapnel injuries. However, the complication rate, including implant failure, pin tract infection, and residual loss of knee motion are significant. As a result, the treatment for high-velocity gunshot wounds to the femur is local wound care and intravenous antibiotics followed by delayed closed intramedullary nailing with aggressive wound debridement and flap closure. However, Nicholas and McCoy and Bergman and coworkers have both recommended immediate reamed intramedullary nailing regardless of bullet velocity. Even though there was extensive bony comminution and soft tissue disruption in these high-velocity injuries, the immediate insertion of an intramedullary nail did not appear to disturb fracture or soft tissue healing. When coupled with wound irrigation and debridement, and a delayed primary closure, no significant increase in deep wound infections were noted. Furthermore, Bone and colleagues showed a significant decrease in the number of pulmonary complications in their group undergoing early instead of delayed femoral stabilization.

**Gunshot Wounds to the Knee**

Radiographic examination of a gunshot wound around the knee includes an anteroposterior, lateral and oblique view. CT can provide valuable information regarding the extent and complexity of the fracture pattern. The evaluation of a patient with a gunshot injury to the knee must pay particular attention to the likelihood of a vascular injury. After the patient’s neurovascular status has been evaluated, one may then proceed to defining the skeletal implications of the bullet and/or its fragments. One must determine whether the bullet has penetrated the knee joint, because this directly affects the treatment plan. The trajectory of the bullet may raise the clinician’s index of suspicion. When an intra-articular fracture is not evident on plain radiographs or other studies, infiltrating the knee joint with saline may be useful. Subsequent extravasation would help to confirm knee joint penetration. Knee joint aspiration may also be useful. A bloody aspiration, which is consistent with joint penetration, requires joint irrigation and debridement. When isolated missile penetration has occurred, joint irrigation and debridement may be accomplished successfully.
using arthroscopy. Retained intracapsular bullet fragments should be removed at this time. Excellent results have been reported in the arthroscopic treatment of patients with low-velocity gunshot wounds involving the knee joint.

If no fracture or only unicortical knee defects are present, and the wound was due to a low-velocity force, then nonoperative treatment is indicated. Unstable fracture patterns should be treated with open reduction and internal fixation. In cases with massive soft-tissue injury, external fixation spanning the knee with later conversion to internal fixation should be performed. The use of postoperative bracing and early motion for fractures with stable fixation is recommended.

**Gunshot Wounds to the Tibia**

Radiographic examination consists of anteroposterior and lateral views, which should include both the knee and ankle joints. In proximal and distal gunshot wounds, CT may help to assess the possibility of intra-articular bone and metal fragments as well as articular displacement.

The majority of gunshot fractures encountered in a civilian population are low velocity with minimal soft-tissue damage. These low velocity fractures are frequently associated with a Type I open wound and a nondisplaced or locally comminuted fracture. These injuries can be treated essentially as closed fractures on an outpatient basis. This usually consists of long leg casting after superficial wound cleansing and skin edge debridement in the emergency department. A functional brace can be exchanged for the cast within the first six weeks after injury.

Patients with low-velocity gunshot injuries involving the diaphysis or metaphysis associated with an unstable tibia fracture (Winquist-Hansen types III or IV) should be treated with debridement and osseous stabilization. After soft tissue debridement, immediate interlocked, intramedullary nailing is recommended for diaphyseal fractures. Velazco and coworkers, Wiss, Henley and Mayo, Whittle and colleagues, and others have shown excellent results in unreamed nailing of open tibial fractures. However, unreamed nails offer less stability and stiffness than reamed nails. Since the nonunion rate for unreamed, interlocked nails approaches that of external fixation, one may want to use a reamed nail or consider the use of early bone grafting.

Open tibial pilon and plateau fractures are often complicated by massive soft tissue swelling and late wound problems. Therefore, for proximal and distal gunshot wounds to the tibia, some authors recommend a thin-wire, external fixator. This protocol has been reported to reduce the incidence of skin slough and infections without compromising the principles of stable fixation and early motion. In a similar fashion, a spanning external fixator may be used to stabilize this injury primarily. When sufficient healing of the soft tissue envelope has occurred, conversion to definitive internal fixation can then be performed.

High-velocity gunshot wounds to the tibia require repeat debridement, early wound coverage, and subsequent bone grafting. These high-energy injuries may be complicated by neurovascular deficit, compartment syndrome, infection, and nonunion. Indications for the use of external fixation for high energy gunshot wounds to the tibia include: (1) injuries with significant soft tissue deficit (grade IIIB); (2) significant bone loss; (3) vascular injury; (4) severe contamination; (5) injuries that are at risk for amputation and that require multiple debridements (grade IIIA and IIIB); and (6) comminuted fractures too proximal or distal for intramedullary nailing. However, external fixation pin infections can result in joint sepsis when pins penetrate the joint capsule or there is fracture extension within the joint. Complications such as these can therefore exceed the benefits that unreamed, interlocked nails provide for lower-grade (I to IIIA) open fractures. Secondary intramedullary nailing, after initial or failed external fixation for open tibial fractures, has been reported to have satisfactory results; but caution must be taken with this method because of the risk of spreading infection from pin tracks.

Despite the principles of fracture stabilization, intravenous antibiotics, extensive soft-tissue irrigation and debridement, and delayed wound closure, some patients with high-energy, grade IIIB and IIIC injuries will do best with early below-the-knee amputations. When considering primary amputation vs. limb salvage, the following questions must be asked:

- **Is the vascular injury reparable?** Failure of arterial repair was the main cause of limb loss in one series of patients.

- **Can the skeletal injury be reconstructed?**

- **Is the soft tissue viable or can durable soft tissue coverage be achieved?** Increasing severity of soft tissue injury is associated with a greater probability of limb loss.

- **Is innervation present, or possible?** Although an extremity with motor power might function as an autoprosthesis, in the absence of protective sensation such an extremity can become a severe liability, prone to unrecognized injury and chronic infection.

If all four of these questions cannot be answered affirmatively, then primary amputation should be strongly considered. The duration between injury and repair is less important than the severity of ischemia. While several formulas have been developed to determine if primary amputation is appropriate, they are not infallible. When the course of action is unclear, it is reasonable to attempt salvage. If it then becomes evident that the extremity is nonviable or it remains insensate, an amputation should then be performed.

**Gunshot Wounds to the Foot**

Nonoperative treatment consisting of local wound cleansing with antiseptics and copious lavage irrigation, with superficial debridement of necrotic tissues at the entrance and exit
sites, can be performed in low velocity gunshot wounds.\textsuperscript{84} In general, high-velocity and shotgun induced fractures of the foot should be stabilized at the earliest possible opportunity, either by closed or open reduction, using a minimum of internal fixation.\textsuperscript{22} Internal fixation is indicated in cases of intra-articular fractures, in those near vascular repairs, and in low-velocity gunshot wounds.\textsuperscript{85}

More commonly, temporary external fixation is advocated, especially in cases involving significant soft tissue or osseous loss.\textsuperscript{46} Determination of the full extent of tissue necrosis may not be possible at the time of initial debridement. As a result, it is prudent to do limited debridement of all obvious necrotic tissue acutely. When the tissue has been adequately and serially debrided, definitive internal fracture fixation with or without soft-tissue free flaps can be performed.

It is a positive trend that the number of gun dealers, or federal firearms licenses (FFLs), in the United States was reduced from 245,628 to 54,902 between 1994 and 2005, a reduction of almost 80%. Only five states (Alaska, Idaho, Montana, Oregon, and Wyoming) are now credited with having more intrastate licensed gun dealers than gas stations. These dramatic reductions in FFLs are due to, in part, to various types of licensing and legislative reforms, such as the Brady Law (1994) and better implementation of laws requiring FFL holders to be held only by legitimate business owners.\textsuperscript{86}

**Battlefield Conditions**

While this discussion centers on the care of gun wounds from the perspective of civilian events; contemporary combat theatre is germane in terms of management principles under field conditions. On the modern battle field, extremity vascular injuries dominate and conditions are, by comparison to civilian settings, uncontrolled and unclean. During Operation Iraqi Freedom, extremity vascular wounds comprised 50% to 75% of treated injuries, keeping in mind that these are all virtually high-kinetic energy injuries from high explosives and munitions with shrapnel as well as high-velocity firearms. Adding to the volume of extremity wound presentations in contemporary combat is that there is now a better survival rate for truncal injury casualties who also typically have extremity injuries.\textsuperscript{87} In both civilian and military settings, application of principles of good wound management and continuity of care by the transporting personnel and the trauma surgeon is vital to limb salvage and recovery.

**References**

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