Treating Civilian Gunshot Wounds to the Extremities in a Level 1 Trauma Center: Our Experience and Recommendations

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ABSTRACT: **Background:** Gunshot wounds impose a continuous burden on community and hospital resources. Gunshot injuries to the extremities might involve complex soft tissue, bone, vascular, musculotendinous, and nerve injuries. A precise knowledge of anatomy is needed to evaluate and treat those injuries.

Objectives: To review our experience with gunshot wounds to the extremities.

Methods: We retrospectively reviewed all civilian cases of gunshot wounds to the limbs treated in our institution during 2003–2005. Altogether, we evaluated 60 patients with 77 injuries.

Results: Of the 60 patients 36 had fractures, 75% of them in the lower extremity and 81% in long bones. The most common fixation modality used was external fixation (33%), followed by intramedullary nailing (25%). This relatively high percentage of fracture treated with external fixation may be attributed to the comminuted pattern of the fractures, the general status of the patient, or the local soft tissue problems encountered in gunshot wounds. About one-fifth of the fractures were treated by debridement only without hardware fixation. We treated 10 vascular injuries in 8 patients; 6 of them were injuries to the popliteal vessels. Fractures around the knee comprised the highest risk factor for vascular injuries, since 5 of the 12 fractures around the knee were associated with vascular injury requiring repair or reconstruction. There were 13 nerve injuries (16.8%), most of them of the deep peroneal nerve (38%). Only three patients had concomitant nerve and vascular injuries. The overall direct complication rate in our series was 20%.

Conclusions: To successfully treat complex gunshot injuries a team approach is necessary. This team should be led by an orthopedic surgeon knowledgeable in the functional anatomy of the limbs.

IMAJ 2009;11:546–551

KEY WORDS: gunshot wounds, civilians, open fractures, vascular injury, penetrating injury, trauma

Gunshot wounds impose a continuous burden on community and hospital resources around the world. The availability of handguns and other low or high velocity rifles is rising and as a result there is a rise in gunshot wound victims seen at community hospitals. Gunshot injuries to the extremities might involve complex soft tissue, bone, vascular, musculotendinous and nerve injuries. A precise knowledge of anatomy is necessary to evaluate and treat those injuries. This article discusses our experience in the treatment of extremity gunshot injuries and compares it to the current literature.

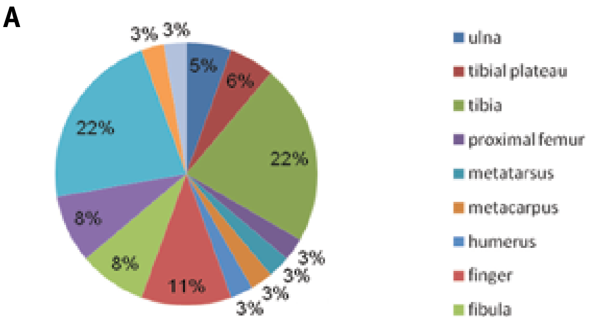
PATIENTS AND METHODS

We retrospectively reviewed all cases of gunshot wounds to the limbs that occurred in a civilian setting and were treated in our institution during 2003–2005. Patients' names were drawn from our local trauma registry. All records were reviewed, including hospital charts, imaging studies, health management organization and outpatient records. The relevant data were collected and analyzed. Sixty patients were identified and reviewed. The mean age was 24.9 years (range 3–68, median 22). There were 58 male and two female patients. Mean hospitalization time was 11.9 days (range 2–48, median 8). Seventy-seven gunshot injuries to the extremities were treated. The median Injury Severity Score was 9 (range 1–25). We used Student's *t*-test and the ANOVA test to find differences among subgroups of patients. Statistical significance was defined as $P < 0.05$.

RESULTS

Figure 1 depicts the distribution of bony and soft tissue injuries. We treated a total of 60 patients with 36 fractures, 75% of them in the lower extremity and 81% in long bones [Figure 1A]. Figure 2 shows the distribution of treatment modalities used for the fractures treated in our study. As seen, the most common treatment modality was external

Figure 1. Distribution of gunshot wounds: **[A]** Bone injury, **[B]** Soft tissue injury



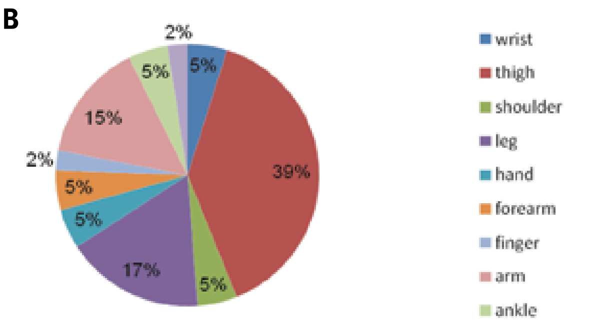


Figure 2. Primary treatment of fractures. ex fix = external fixation, imn = intramedullary nailing, kw = Kirschner wires, orif = open reduction internal fixation

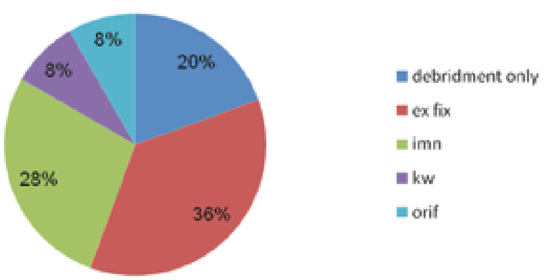
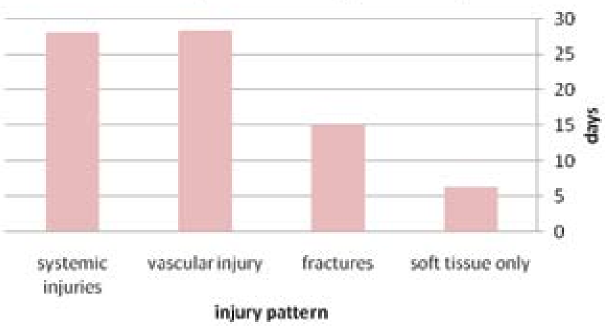


Figure 3. Distribution of hospital stay



fixation (36%), followed by intramedullary nailing (28%), and debridement only without fixation (20%). Primary open reduction and internal fixation were performed in 8% of the fractures. Of the 12 fractures treated with monolateral external fixation, 3 femoral fractures and 1 tibia fracture were later converted to plate, Ilizarov circular fixator, or intramedullary nail, whereas the remaining 9 fractures were treated definitively with the original external fixator. In our series, we operated on 41 soft tissue injuries. Figure 1B shows the distribution of soft tissue injuries. As shown previously, the majority (63%) were lower extremity injuries. We treated 10 vascular injuries in 8 patients; 6 of them were injuries to the popliteal vessels, while the other 4 were to the femoral, brachial, ulnar and radial arteries. One patient had bilateral popliteal injuries due to gunshot wounds in both knees. Of the six injuries to the popliteal artery, four were associated with a fracture to the distal femur, one with fracture of the proximal fibula, and one without a fracture. Of the 12 fractures around the knee 5 were associated with vascular injury requiring repair or reconstruction. Our series had 13 nerve injuries (16.8%), most of which were to the deep peroneal nerve (38%). Only three patients had concomitant nerve and vascular injuries.

LENGTH OF STAY

Figure 3 depicts the length of stay of patients divided into subgroups. Twenty patients were hospitalized for 4 days or less. Fifteen of these patients (75%) had soft tissue injuries only, which were treated with operative debridement and intravenous antibiotics. The other five had injuries to bone as well, which required debridement and fixation. The average hospital length of stay for patients with soft tissue injury only, not involving other body systems or vascular injury, was 6.2 days (range 2–25). This is in contrast to patients with fracture whose average hospital stay was 15.1 days (range 2–45). This was found to be statistically significant ($P < 0.001$). The average length of stay for the patients with vascular injuries was 28.4 days, which was also found to be statistically significant ($P < 0.001$). The average length of stay for patients with additional injuries was 28 days, although only two of them had vascular injuries. Ten patients were hospitalized for 20 days or longer (range 25–45, mean 34.9). Six of them (60%) had multiple organ injuries such as abdominal or head injuries and 4 (40%) had vascular injuries. Of the 4 patients who did not sustain multiple injuries, 2 (50%) had severe local injuries involving vascular injury. Correlation between

Table 1. Complications of gunshot injuries in our series

Complication	No. of patients	Treatment	Major/ minor
Compartment syndrome	6	Fasciotomy + split thickness skin graft	Major
Infected non-union femur	1	Sequestrectomy and plating	Major
Non-union tibia	1	Bone grafting	Major
Delayed union of the femur	1	Exchange of nail	Major
Refracture of the tibia		Intramedullary nail	Major
Osteoarthritic wrist joint	1	Arthrodesis wrist	Major
Hardware removal due to pain	5	Removal of hardware	Minor
Joint stiffness	2	Manipulation	Minor
Tendon tears	3	Tendon procedures	Minor

ISS and hospital length stay using the Pearson statistical test was positive at $r = 0.502$.

COMPLICATIONS

The overall direct complication rate in our series was 30% [Table 1]. Six patients required fasciotomy of the lower extremity during the initial procedure due to impending compartment syndrome. They required skin grafting later on. No patient developed delayed compartment syndrome later in the course of hospitalization. Five patients (three with intramedullary nails and two with screws) required hardware removal due to pain. There was one infected non-union of the femur that was successfully treated with sequestrectomy and plating, one non-union of the tibia that was treated with bone grafting, and one delayed union of the femur that was treated with reaming and exchange of nail. One patient had a refracture of his tibia and was treated with an intramedullary nail. Three patients required tendon procedures such as sutures, tenotomies or transfers, and two patients had stiff joints requiring manipulation. One patient with distal radius fracture required an arthrodesis due to pain and osteoarthritic changes. No patient required an amputation, primary or delayed. Our non-union and bony infection rate is surprisingly low compared to the reported literature. For example, Weil et al. [1] reported a 33% deep infection rate and a 13% non-union in their series.

DISCUSSION

Civilian gunshot wounds are mostly caused by low velocity, low energy missiles (300 m/sec and lower). Velocity and missile mass are considered to be the most significant determinants of tissue damage, which in turn is determined by laceration and crushing, shock waves, and cavitation [2]. Laceration and crushing occur when a low velocity missile penetrates tissue causing it to be crushed and forced apart, while shock waves from a high velocity missile can cause damage distant from the missile path. Cavitation, or the formation of a cavity within the tissue, is seen predominantly with high velocity weapons. Another mechanism of injury is damage of soft tissue by secondary projectiles of bullet or bony fragments [3].

Basic and primary treatment is based on Advanced Trauma Life Support principles. The patient should be treated according to his/her condition in a trauma room setting, taking into consideration life-threatening injuries to the head and torso. A careful inspection of the whole body with the patient undressed is essential for evaluating occult gunshot wounds. A thorough assessment of peripheral vascular and neurosensory status should be performed. Documentation of all wounds and deficits is mandatory also for medical-legal reasons. After resuscitation, hemorrhage control and primary survey, the wounds are dressed and the limbs splinted according to the suspected injury. Conventional radiographs of the injured part are obtained and should at least show the joint above and below the injured area in both anteropostrior and lateral projections. When plain films are unavailable fluoroscopy is often helpful. Entry and exit wounds should be sought or the presence of missile confirmed on imaging.

In the extremities there are several different tissues to consider: bones and joints, muscle and tendon units, vascular structures, nerves, skin and subcutaneous fat. Although in this article we discuss each structure separately, these structures are closely related and in proximity, and obvious injury to one structure warrants a careful evaluation of adjacent ones. Also, effective treatment of one injury may be impossible without treating other injuries first. Wilson [4] emphasizes the surgeon's knowledge of the anatomic complexity and the challenge to prioritize the injury, select an aggressive surgical approach, and integrate a suitable rehabilitation plan.

BONE

A gunshot fracture is a high energy open fracture by definition. Several studies demonstrated that the heat generated during firing does not make the bullet sterile [5]. Most low velocity gunshot fractures resemble Gustillo and Anderson grade I or II open fracture due to the comparatively mild to moderate soft tissue damage. Stabilizing the fracture is of utmost importance. Stabilization options include splints or cast or, usually, hardware such as external fixation or internal fixation. The choice and timing of the stabilization method depends on the fracture site, pattern and comminution, the soft tissue injury, and the patient's general condition. Primary fixation is especially useful in patients with multiple injuries, complex ipsilateral extremity injuries, severe injuries that require intensive wound care, open displaced intraarticular fractures, or open fractures complicated by neurovascular

ISS = Injury Severity Score

damage [6]. Ganocy and Lindsey [7] suggested a treatment protocol based on the final projectile location, the fracture pattern and the level of contamination. In their opinion, stable, non-contaminated extraarticular gunshot wounds can be treated non-operatively with antibiotics only, whereas intraarticular projectiles should be removed and unstable fractures stabilized. For most high velocity injuries in the extremities, external fixation is the treatment of choice. The standard of care for gunshot fractures in our institution is meticulous operative debridement of all devitalized soft tissue and bone fragments followed by copious irrigation and early fixation of the fracture. The method of fixation is dependent on the above mentioned parameters. In our series, the most common treatment modality is external fixation (36%), followed by intramedullary nailing (28%). Those percentages are different from the findings of Weil et al. [1], who reported a higher rate of intramedullary nailing vs. external fixation in gunshot victims and blast injuries. This relatively high percentage of external fixation can be attributed to the comminuted pattern of the fractures, the generalized status of the patient, or the local soft tissue problems encountered in gunshot wounds. About one-fifth of the fractures were treated by debridement only without hardware fixation. These were fractures that are inherently stable or do not require stabilization (e.g., fibula). Only 8% of the fractures were treated with open reduction and internal fixation. These numbers agree with the report by Weil and co-authors [1]. As reported before, in 8 of the 12 fractures treated with primary external fixators, this was the definitive treatment for union. This high percentage emphasizes the comminuted nature of the gunshot fracture type and the tendency to prefer a biological splint fixation, maintaining a fracture-healing environment.

SKIN AND SUBCUTANEOUS TISSUE

Ordog et al. [8] retrospectively reviewed 28,150 patients with gunshot wounds; 60% of them were treated as outpatients. Four percent had minor fractures not requiring operative stabilization. The patients were treated with local wound debridement, irrigation and an antibiotic ointment. Only 1.8% had wound infections that responded well to oral antibiotics without requiring hospital admission. In their study of 163 patients with civilian gunshot wounds, Brunner and Fallon [9] found no differences between patients who had debridement and wound care and patients who had local wound care alone. Neither group received antibiotics and both were treated as outpatients. The wounds were neither closed primarily nor did they have a delayed primary closure but were left to drain and close secondarily. We debride all simple gunshot wounds superficial to the fascia in the emergency room and leave them open for secondary closure. Our protocol mandates a formal operative debridement for all wounds deep to the fascia, i.e., involving the muscle compartments.

VASCULAR INJURIES

As mentioned before, vascular structures are frequently injured because of their proximity to bone [10]. A delay in the diagnosis or treatment can result in a chronic debilitating handicap due to ischemia and limb loss. Prompt restoration of blood flow is mandatory in traumatic peripheral arterial injuries [11]. Damage to vessels can result also in death due to exsanguination. Dorlac and team [12] reviewed patients with isolated civilian gunshot wounds to the extremities arriving dead at the hospital or requiring cardiopulmonary resuscitation in the emergency room. He found that in 71% the wound was in the lower extremity and 81% were proximal to the knee or elbow. The damage may result directly from the bullet, from secondary missiles such as bone fragment, or from cavitation or shockwave effects. The injury to the vessel can be occlusive (due to transection or thrombosis of the vessel) or non-occlusive (an intimal flap tear or a pseudoaneurysm). In their survey of 43 gunshot wounds to the extremities, Makitie and colleagues [13] found 11 femoral arteries and 6 popliteal injuries. In our series, we treated 10 vascular injuries in 8 patients. Six of them were injuries to the popliteal vessels, the other four to the femoral, brachial, ulnar and radial arteries. One patient had bilateral popliteal injuries due to gunshot wounds to both knees. Of the six injuries to the popliteal artery, four were associated with a fracture to the distal femur, one with fracture of the proximal fibula and one without a fracture. Due to advances in diagnosis and treatment of vascular injuries, rates of amputation decreased dramatically, with limb salvage rates exceeding 86% [14]. In our series none of the patients required amputation – primary or delayed. Injuries can present acutely or up to several months in cases of an arteriovenous fistula. The presence of "hard signs" of arterial injury such as absent pulses, unequivocal signs of ischemia, profuse hemorrhage, pulsating or expanding hematoma warrants urgent surgical intervention [15]. We have found that arterial pressure index is a sensitive tool for identifying a vascular injury. According to our protocol an arterial pressure index ratio of 0.9 or less warrants further investigation. Limitations for this test are bilateral injury, severe soft tissue injury, intimal flap producing near-normal flow, collateral flow, and arteries that do not produce palpable pulses (profunda femoris, profunda brachii) [16]. For patients with equivocal findings of vascular injury such as diminished pulses, angiography yields the greatest benefit, particularly in avoiding unnecessary surgery [15]. In cases of proximity wounds without hard signs of vascular injury, further investigation is needed. In our series we found that fractures around the knee comprised the highest risk factor for vascular injuries, as 5 of the 12 fractures around the knee and 4 of 7 distal femur fractures were associated with vascular injury requiring repair. These findings correlate with the findings of Nikolic et al. [17] that 34% vascular injuries required repair in their series of 50 missile injuries to the distal femur.

Angiography reduces unnecessary explorations for proximity wounds and can provide therapeutic intervention such as stenting or embolization. In a study using routine arteriography, the negative surgical exploration rate in patients with "soft signs" of arterial injury or with proximity wounds fell from 84% to 2% [18]. Significant angiographic findings are obstruction, extravasation of contrast agent, early venous filling, irregularity of the vessel wall, a filling defect, and a false aneurysm. There is, however, a low yet measurable complication rate, with complications such as allergic reaction, renal failure, and formation of a local hematoma or a false aneurysm at the site of catheterization. Historically, angiography was the imaging modality of choice, but recent studies show that non-invasive studies such as duplex Doppler ultrasonography are as sensitive as arteriography in most cases. In a study by Knudson et al. [19], 86 extremity injuries were assessed using color-flow duplex imaging. No missed arterial injuries were found. Many centers now successfully manage proximity wounds by repeated physical examination over a 24 hour period and reserve angiography only for those patients with abnormal physical findings or an arterial pressure index less than 0.9 [20]. Norman and co-workers [21] studied gunshot fractures to long bones and concluded that routine use of arteriography is not indicated unless there are abnormal findings on vascular examination. Many investigators still recommend that a gunshot wound in the immediate vicinity of major vessels should be studied angiographically or explored surgically. Wound exploration involves low morbidity (3%) and is often a routine part of wound management. Angiography can be used intraoperatively with a fluoroscope. In our institution we do not use angiography routinely even in proximity wounds but rely on serial physical examination of the limb at risk. We use angiography when the physical examination is equivocal and no wound exploration is planned.

Limbs can tolerate warm ischemia time of up to 6 hours. More than 6 hours of ischemia will almost always result in muscle necrosis and possibly permanent damage. In patients with combined vascular and nerve injuries, prophylactic fasciotomy should be performed at the time of arterial repair unless a method for continuous pressure measurement is available.

Surgical options include temporary polytetrafluoroethylene (PTFE) shunting [22], end-to-end reanastomosis, or interposition reverse saphenous vein graft. In a review of low velocity arterial injuries, Smith et al. [15] found that end-to-end anastomosis was feasible in 65% of 285 arteries after debridement of damaged ends. Similar numbers were reported by Gorman [23], who managed 37% of high velocity injuries with vein grafting. Since most vascular gunshot injuries involve damage to a segment of the artery, we usually place a temporary shunt, followed by prompt skeletal stabilization and then a definite arterial repair, usually with a reverse saphenous vein graft.

NERVE INJURIES

Nerves pass in close proximity to bones and vascular structures and are commonly injured when vascular injury is present. In fact, a physical examination demonstrating acute nerve injury raises suspicion of vascular injury and usually warrants further investigation to rule out arterial injury. In our series, we found 13 nerve injuries (16.8%); the majority of them were to a deep peroneal nerve (38%). Only three patients had concomitant nerve and vascular injuries. Concomitant arterial and nerve injury will most likely result in a non-functional limb. in a study by Visser et al. [24], only 7% of patients with concomitant nerve and arterial injury had a normal functioning limb, despite successful vascular repair, as opposed to 39% of patients with arterial injury alone. Nerve injury presents clinically with hypoesthesia, parasthesias, or paralysis. Since spontaneous recovery is usually expected in neuropraxia and axonotmesis, the question arises: should we explore all nerve injuries; and if so, when? Several studies addressed this issue. Omer [25] reported spontaneous recovery in 69% of patients with nerve injuries due to gunshot wounds, between 3 and 9 months after the injury. We usually explore wounds presenting with obvious nerve injury. If possible we tend to suture the nerves using the epineural technique, and if the nerve ends are damaged or the wound is contaminated we mark the nerve ends and return to the operating room, at a later date for a definite nerve-grafting procedure. It is important that the nerve be repaired without tension.

CONCLUSION

Gunshot wounds impose an increasing burden on both urban and rural society. As shown in this article, many gunshot victims have complex injuries to the extremities involving bones, soft tissue, veins, arteries, and nerves. Treating these complex injuries requires a team approach. Our institution's policy dictates that this team be led by an orthopedic surgeon knowledgeable in the functional anatomy of the limbs. Many decisions are made throughout the course of the treatment, from the timing and extent of the primary surgery, the secondary reconstructive surgery and final rehabilitation. We emphasize the need for repeat evaluations for undiagnosed proximity injuries, especially vascular injuries and compartment syndromes. Fasciotomy should be performed in any case of suspected impending compartment syndrome. In our series, no compartment syndromes were missed. Careful attention to wounds in proximity to important structures is mandatory. In our institution all gunshot wounds that penetrate deep to the subcutaneous fat and the fascia are treated in the operating room. In this series we demonstrated that multiple system injuries, vascular injuries, and to a lesser extent fractures are indicators for longer hospital stay. This is important when counseling the patient and his or her family. Due to the rising incidence of gunshot wounds to the limbs, it is crucial that the practicing physician and trauma surgeon have this knowledge. This increase poses a greater medical, social and economical burden. Principles such as those emphasized here will improve patients' treatment and reduce costs.

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