An institutional review board-approved retrospective study was performed at a level 1 trauma center to evaluate the adequacy of current treatment guidelines in the management of humerus fractures following civilian gunshot injuries. Fifty-four patients with a humerus shaft fracture from a low-velocity gunshot wound were included in the study. Twenty-nine patients were treated nonoperatively, while 25 patients had operative treatment, with 14 undergoing plate fixation, 6 having application of an external fixator, 3 receiving an intramedullary rod, and 2 having irrigation and debridement with fracture immobilization provided by a brace. Patient demographics and injury data, radiographic analyses, and treatment complications were recorded. Healing of soft tissue and bony injuries, including fracture alignment in patients treated nonoperatively, was also evaluated. Fifty-two of 54 patients had minor soft tissue damage and were treated successfully with minimal local wound care. Two patients with larger wounds required extended wound care with repeated irrigation and debridement. Overall, 47 of 54 fractures healed with the primary mode of treatment, and 7 patients went on to nonunion requiring further intervention. Of the patients treated nonoperatively, the average deformity was $16.5^\circ \pm 7.4^\circ$ in the coronal plane and $4.4^\circ \pm 4.0^\circ$ in the sagittal plane. This study supports the view that the majority of humerus fractures following civilian gunshot wounds may be treated nonoperatively, with a select group of patients requiring surgical stabilization.
Firearms are estimated to be present in 50% of all households in the United States. Each year, approximately 30,000 to 50,000 Americans are killed secondary to gunshot wounds. For each death, approximately 3.3 gunshot wounds are nonfatal injuries, and it has been estimated that the annual cost of firearm injuries in the United States is $425 billion. As the global prevalence of handguns increases, there are reports of low-velocity gunshot wounds from several countries outside of the United States.

The humerus is involved in approximately 10% of gunshot fractures of the extremities. A review of the literature revealed a few articles dedicated to this topic, which reported on the outcomes of 7, 14, and 38 patients. The largest series reported on the use of external fixation in all 38 cases with 2 nonunions.

Working in an urban level 1 trauma center located in an inner city hospital, the authors treat a large number of gunshot wound injuries. The authors designed a study to evaluate patients with fractures of the humerus following gunshot wounds with the aim of establishing whether current treatment guidelines are adequate in the management of this injury.

Materials and Methods

An institutional review board-approved retrospective study was conducted of the authors’ hospital trauma registry, which was queried for patients who sustained low-velocity gunshot wounds. Low-velocity gunshot wounds were defined as those caused by handguns as opposed to shotguns or rifles, which account for a minority of the injuries seen at the authors’ institution. The registry noted 3724 patients with gunshot wounds and included 1670 with an associated fracture and 621 deaths. Among the survivors with fractures, 149 patients were recorded to have sustained a humerus fracture. Only patients who had sustained a humerus shaft fracture from a low-velocity gunshot wound were included in this study.

Exclusion criteria included shotgun injuries (18 patients) and articular involvement (53 patients), leaving 78 patients. Patient information was retrieved from an electronic medical record system (Cerner Corp, Kansas City, Missouri), which is an electronic database for all patients reporting to the authors’ institution. The variables accessed were age, sex, date of injury, location of injury, associated nerve, artery or other injury, treatment modality, follow-up time, complications, fracture type, and fracture healing. Thirty-eight patients were located from information in the hospital database and returned for a follow-up evaluation. For the remaining 40 patients, the phone records and addresses were either old or incorrect, necessitating other methods to track them. People search engines and white pages were used, including www.spokeo.com. A search of the Michigan, Ohio, and Indiana criminal databases and the National Sex Offender Registry was conducted, as well as a search of social networks such as Facebook and Myspace. This comprehensive search allowed the authors to follow another 16 patients, yielding 54 patients with 55 fractures (1 patient sustained a bilateral injury of the midshaft) with complete medical records and a final follow-up visit. Patients with less than 12-month follow-up were excluded. There were 48 men and 6 women with a mean age of 30 years (range, 18-57 years). The middle third of the humerus was the most common fracture location, seen in 25 patients (46%). This was followed by the distal humerus in 17 patients (32%) and the proximal third in 12 patients (22%). Intra-articular injuries were excluded from this study. Twenty of 54 patients (37%) had multiple injuries, but these may have been caused by a single gunshot wound in some patients. Follow-up ranged from 12 to 136 months, with a mean of 26 months.

Twenty-nine patients underwent nonoperative treatment with a coaptation splint followed by functional bracing (Figure 1). Wounds of the patients treated nonoperatively were addressed in the emergency department with the application of a sterile dressing. These wounds were not formally explored, bullet fragments were not disturbed unless they were superficial and easily removed, and wounds were left open to heal by secondary intention. Nonoperative management included intravenous antibiotics while in the emergency department and if they were admitted for 48 hours, or a prescription for oral antibiotics, commonly cephalaxin for 3 to 5 days, if they were discharged from the emergency department.

Twenty-five patients had operative treatment. Indications for operative sta-
bilitation included 13 patients with polytrauma, 5 patients with vascular injury, 2 obese women who had difficulty with functional bracing, 1 nonobese patient who did not comply with splinting, 2 patients with delayed union, and 2 patients with a large soft tissue defect. Both obese women and the noncompliant patient underwent surgery within 4 weeks of the injury. Fourteen patients underwent open reduction and internal fixation of the fracture using a plate and screws (Figure 2), 6 had an application of an external fixation device (Figure 3), 3 were treated with an intramedullary rod, and 2 had irrigation and debridement with fracture immobilization provided by a brace. Thirteen of 14 patients who had open reduction and internal fixation with a plate and screws had bridge plating, and 1 patient with a minimally comminuted fracture had lag screws and a neutralization plate. Antibiotic treatment included 48 hours of intravenous cefazolin postoperatively. Associated fractures of polytrauma in 13 patients who underwent surgical stabilization included trochanteric and subtrochanteric fractures and fracture of the ulna, mandible, olecranon, scapula, proximal humerus, glenoid, radius, metacarpals, scaphoid, fibula, and femur. Four patients in the nonoperative group had associated fractures, none of which warranted surgical fixation.

Twenty-two nerve injuries were observed in 20 patients (37%), which included 15 radial nerve lesions (28%), 3 ulnar nerve injuries (5%), 3 median nerve injuries (5%), and 1 axillary nerve lesion (2%). Brachial artery injuries requiring repair were seen in 5 (9%) patients.

RESULTS

Soft Tissue Injury

Fifty-two of 54 patients had minor soft tissue damage that required minimal local wound care (Figure 4) when they were treated nonoperatively. The remaining 2 patients had larger wounds that required extended wound care with repeated irrigation and debridement. If the decision was made to treat a patient surgically, irrigation and debridement of the area always preceded the selected fixation method. One patient healed by secondary inten-
tion after 2 instances of irrigation and debridement, and a second patient required 4 instances of irrigation and debridement and a rotational latissimus dorsi flap. This patient also had a wound infection and required plate removal.

**Fracture Morphology**

The fractures were classified according to the Association for Osteosynthesis/Orthopaedic Trauma Association classification. Six fractures were simple and 49 were comminuted. They were classified as follows: 11A3 (n=11), 11A1 (n=1), 11A2 (n=1), 12C3 (n=22), 12A1 (n=3), 12B2 (n=1), and 13A3 (n=15).

**Healing**

Overall, 47 of 54 patients healed with the primary mode of treatment and 7 patients went on to nonunion requiring further intervention (1 of 14 open reduction and internal fixation, 2 of 6 external fixation, and 4 of 29 splinting). Two patients with a delayed union in the conservative group were also operated on with subsequent union. The 4 splinted patients who developed a nonunion had all been incarcerated, with 3 having poor follow-up from prison during the healing period. Six months after the initial injury, 1 patient underwent plating and bone graft. The remaining 3 were followed at 43, 62, and 96 months and had a persistent nonunion. All 3 had no health insurance and had not followed up with a physician after being released from prison. Of these, 2 patients underwent plating and bone graft and the authors contacted them for follow-up (Figure 5). The third patient, although offered surgery, did not return.

Of the patients treated with coaptation splints and Sarmiento braces, the average deformity after healing was 16.5°±7.4° in the coronal plane and 4.4°±4.0° in the sagittal plane. The coronal plane deformity was always a varus angulation with convexity laterally. Sixteen fractures healed in extension, 8 in neutral alignment, and 1 in flexion.

**Complications**

Complications included pin site infection from an external fixator in 1 patient, and a wound infection in an operated on patient. The pin site infection resolved following pin removal and oral antibiotics. The patient with wound infection was treated with wound irrigation, plate removal after healing, and antibiotics. All patients treated nonoperatively were administered at least 1 dose of intravenous antibiotics and discharged with an oral regimen of cephalexin (500 mg four times a day). None of these patients was noted to have an infection at the site of injury.

However, it was difficult to ascertain if the patients were compliant with the postdischarge regimen. The overall complication rate was 20.4%, with a 13% nonunion rate and 4% infection rate.

**Nerve Injury**

Twenty patients (37%) had 22 nerve injuries that included 15 radial nerve lesions, 3 ulnar nerve injuries, 3 median nerve injuries, and 1 axillary nerve lesion. They occurred in 1 of 12 patients with proximal injuries, 13 of 26 patients with midshaft injuries, and 6 of 17 patients with distal injuries. Twelve patients belonged to the nonoperative group and 8 were in the operative group. All patients in the operative group underwent nerve exploration. Sixteen (73%) nerve injuries in 15 patients resolved spontaneously over the follow-up period (Table). Among patients who did not show neural recovery, 2 patients had tendon transfers and 3 patients were unable to have surgery due to lack of health insurance.

**DISCUSSION**

Firearms are the second leading cause of injury-related death in the United States. Previous literature reports approximately 3.3 nonfatal injuries for each death due to firearms. In the authors’ hospital database, there were 5.99 (N=3724) patients with nonfatal injuries for each patient who had a gunshot wound and died (N=621). Prior literature has reported that the humerus is involved in approximately 10% of gunshot wounds.
to the extremities. The current authors noted a fairly similar occurrence of humerus fractures in 9% (149 of 1670) of these injuries.

Civilian gunshot injuries are predominantly due to low-velocity weapons (handguns) and usually involve minor soft tissue damage. The current authors observed from their hospital trauma registry that 88% (131 of 149) of the humerus fractures were the result of gunshot injuries from low-velocity weapons and only 2 of the 54 patients included in this study required extensive soft tissue care, with 1 requiring a rotation latissimus flap. Soft tissue injury is the function of energy transfer and is not always related to the velocity of the weapon. Low-velocity gunshot wounds do not commonly present with significant soft tissue injury.

There are only a few studies on the outcomes of humeral fractures following gunshot injuries. Several reports have noted a fairly similar occurrence of humeral shaft fractures—using a coaptation splint acutely followed by a brace. This treatment method is noninvasive; however, it requires that these patients have no serious neurovascular damage and be able to maintain an upright posture or reliably use the brace.

At the authors’ facility, the approach to surgical treatment of gunshot wound fractures begins with debridement of necrotic tissue, followed by irrigation of the fracture site as the authors would treat an open fracture. If the gunshot wound resulted in a comminuted fracture, the authors use a bridge plate. Rarely, a simple or minimally comminuted fracture will have an indication for surgical repair; in these instances, the authors prefer lag and neutralization or compression plating techniques. In the current study, 14 patients were treated with primary plate osteosynthesis, with 1 requiring revision due to nonunion. In another 5 patients (2 external fixation and 3 nonoperative), open reduction and internal fixation was the secondary procedure following failure of primary treatment. All of these patients went on to union. One patient with a nonunion did not return for treatment.

Further, 6 patients were treated using an external fixator. As noted previously, stabilization of the fractured area is essential for successful healing. The external fixator provides a method of quick stabilization, especially following vascular repair, with good visual and surgical access to the wound.

For patients with tenuous skin conditions or multiple trauma, intramedullary nailing may be an option. In the current study, 3 patients were treated with a locked intramedullary nail. Previous reports of humerus fractures have shown high rates of union ranging from 92% to 100% with the use of nails. However, shoulder stiffness and rotator cuff injury following antegrade nailing are often reported.

Apart from bone, a gunshot injury may damage the neighboring neural or vascular structures. Damaged nerves can be identified with a physical examination and may manifest as hypoesthesia, parasthesias, or paralysis. In the current study, 20 patients (37%) had 22 associated nerve injuries, a majority of them (68%) to the radial nerve. The current authors reserve acute inspection of the nerve for patients undergoing open reduction and internal fixation. All other patients are kept under close observation for nerve recovery, with nerve conduction studies performed if no neural recovery has occurred in 3 months. In approximately 70% of injuries, nerve function returns on its own.

Gunshot wound fractures of the humerus may present with associated vascular injury. In the current study, 5 patients (9%) developed brachial artery injury. Of these, 4 also had an associated nerve injury. Prompt diagnosis and treatment of vascular injuries is essential to prevent ischemia and limb loss. The value of angiograms to confirm vascular injury has been previously reported. Treatment involves resection and primary anastomosis of the artery or intervening reverse vein graft. An absent pulse, large hematoma, hemorrhages, and proximity of the wound to a major artery suggest the need for immediate surgical treatment. Fractures following gunshot injuries may be comminuted, and acute shortening of the bone to assist with a vascular injury repair is easily accomplished if necessary.

**Conclusion**

Fracture of the humerus following a civilian gunshot wound is associated with limited soft tissue damage, extensive comminution, and, in the current study, a significant incidence of neurologic (37%) or vascular injury (9%). Many patients can be treated nonoperatively with coaptation splints followed by bracing with good results. Neurologic recovery can be expected approximately 70% of the time. The current authors agree with previous reports and have data from their own ex-
perience that the decision to perform surgical stabilization of the fracture involves polytrauma, obesity, associated vascular injury or extensive soft tissue damage, nonunion, or inability to comply with splinting and bracing. These patients often do not return for follow-up due to socioeconomic reasons, creating a new set of challenges regarding their care.

REFERENCES