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# The Epidemiology, Management, and Outcomes of Civilian Gunshot Wounds to the Upper Extremity at an Urban Trauma Center

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**Background:** Gunshot wounds (GSWs) create significant morbidity in the United States. Upper extremity (UE) GSWs are at high risk of combined injuries involving multiple organ systems and may require variable treatment strategies. This study details the epidemiology, management, and outcomes of civilian UE GSWs at an urban level 1 trauma center.

**Methods:** Using the University of Pennsylvania Trauma Registry, all adult patients with UE GSWs from 2015 to 2020 who were at least 6-months postinjury were studied for demographics, injury pattern, operative details, and postoperative outcomes. Fisher exact and Wilcoxon rank sum tests were used to determine differences in treatment modalities and outcomes.

**Results:** In 360 patients, the most common victim was young ($\bar{x}$ = 29.5 y old), African American (89.4%), male (94.2%), and had multiple GSWs (70.3%). Soft tissue-only trauma (47.8%) and fractures (44.7%) predominated. Presence of fracture was independently predictive of neurologic, vascular, and tendinous injuries ($P < 0.001$). Most soft tissue-only injuries were managed nonoperatively (162/173), whereas fractures frequently required operative intervention (115 of 161, $P < 0.001$). Despite a prevalence of comminuted (84.6%) and open (43.6%) fractures, hardware complications (7.5%) and wound infection (1.1%) occurred infrequently.

**Conclusions:** Civilian GSWs to the UE with only soft tissue involvement can often be managed conservatively with antibiotic administration, bedside washout, and local wound care. Even with combined injuries and open fractures, single-stage operative debridement and fracture care with primary or secondary closure often prevail. As civilian ballistic trauma becomes more frequent in the United States, these data help inform patient expectations and guide management. *(Plast Reconstr Surg Glob Open 2024; 12:e5753; doi: 10.1097/GOX.0000000000005753; Published online 17 April 2024.)*

## INTRODUCTION

Amid growing discussions of a gun violence epidemic,[1,2] gunshot wounds (GSWs) present a significant and continuing source of morbidity and mortality in the United States that is particularly worse in certain demographic groups. From 2001 to 2013, more than 1.3 million firearm-related injuries were reported in the United States, and rates of nonfatal firearm injury increased from 22.1 to 26.7 per 100,000.[3] GSWs to the upper extremity (UE) represent a large portion of firearm injuries because they are estimated to account for 14%–17% of all nonfatal firearm injuries treated in the US hospital emergency departments between 2018 and 2020.[4] In contrast to war injuries with high-velocity GSWs (≧2000 ft/s), which have generated the foundation of the literature on GSWs, civilian GSWs are often from low-velocity firearms and disproportionately affect impoverished communities.[5] Moreover, adults younger than 35 years accounted for the majority of nonfatal firearm injuries between 2010 and 2012,[5] signifying that many survivors will live with their injury sequelae for decades. These injuries not only have devastating impacts on patients' lives but also present a significant economic burden. The total lifetime cost

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for nonfatal firearm injuries during the same time interval amounted to more than $4 billion when considering medical and work loss costs.[5]

UE GSWs, due to the complex functional anatomy of the UE, can result in extensive and debilitating injuries that impact activities of daily living.[6] Because these wounds often result in combined injuries involving multiple tissue types, it is more challenging to determine an appropriate treatment plan.[6–8] Current treatments to address GSWs to the UE are variable and may involve antibiotic administration, surgical debridement, external fixation (ex-fix), open reduction and internal fixation (ORIF), microvascular repair, and nerve grafting.[6,9–11] Intervention strategies must respect the distinct needs of tissues involved while minimizing the possibility of complications and reoperation. These goals must also be achieved within the sociocultural factors that put the patient at risk for GSWs, given the high rate of GSW patients lost to follow up after discharge.[12] As such, it is imperative to determine the factors that can predict the treatment course to not only guide medical and surgical decisions but to also better educate patients regarding their prognosis and future management. Therefore, this study details the epidemiology, management, and outcomes of civilian UE GSWs at an urban level 1 trauma center during a 5-year period.

## METHODS

Approval from the University of Pennsylvania's institutional review board was obtained for this study (protocol #842977). The University of Pennsylvania Trauma Registry was queried for International Classification of Diseases, Ninth Revision codes related to UE GSW. This identified 532 patients who presented to an urban level I as a trauma patient with UE GSWs from January 2015 to January 2020. Injuries were classified as occurring on the UE based on the history and physical examination findings in the provider notes. Patients younger than 18 years old (n = 41), with simultaneous nonballistic trauma (n = 0), or with incomplete medical records (n = 50) were excluded. Simultaneous nonballistic trauma includes any injury that occurred at the same time as the GSW but were not caused by the gunshot itself. Of the 441 remaining patients, 81 died before receiving treatment for their UE injury and were excluded from the outcomes data. Therefore, 360 patients were included in the full analysis. A detailed chart review of electronic medical records was performed to collect patient demographics, injury patterns, and details of any operative and nonoperative interventions. Posttreatment outcomes including wound infection, reoperation details, and follow-up were also recorded for a minimum of 6 months postinjury. Patients were grouped by injury characteristics for statistical analysis. All statistics were completed with STATA V13 (Stata Corp LLC, College Station, Tex.).[13] Univariate analysis was completed using the Fisher exact test for categorical variables and Wilcoxon rank sum test for continuous variables to determine differences in treatment modalities and outcomes between groups; significance was defined as $P$ value of less than 0.05.

### Takeaways

**Question:** What is the current state of civilian, urban upper extremity gunshot wound injuries, specifically epidemiology, management, and clinical outcomes?

**Findings:** Patients were generally young, African American, and male. Soft tissue–only injures were managed conservatively (94%). Fractures were handled operatively (71%), usually with internal fixation. Fractures were predictive of injury to adjacent structures.

**Meaning:** Urban, civilian upper extremity gunshot wounds disproportionately affect certain demographic groups and with even distribution of soft tissue–only and fracture-related injuries, which can often be treated with washout and internal fixation.

## RESULTS

### Demographics

GSW victims had an average age of 29.5 ± 10.9 years. They were predominantly single (78.1%) and male (94.2%). African Americans comprised 89.4%, whereas the remaining racial groups accounted for less than 5% individually. Most were insured (81.1%), 48.1% had smoking histories, and 36.4% had substance use histories (Table 1). There were no associations between injury type and demographic characteristics.

Multiple GSWs (70.3%) occurred more commonly than single GSWs, with an average of 3.2 ± 2.7 GSWs per patient. These concomitant wounds occurred mostly to the abdomen/pelvis (43.1%), legs (39.1%), and chest (34.4%) (Table 2). Over half of all injuries had retained bullets in the UE, which were more likely to be fragmented in the fracture cohort ($P = 0.027$) and whole in the soft tissue–only cohort ($P = 0.004$). Predictors of early fatality for the 81 patients who died before treatment included a greater number of GSWs (four in deceased versus two in surviving patients) and wounds to the chest, abdomen/pelvis, head, and neck ($P < 0.001$ each). No patients with only GSWs to the extremities died before treatment. Other demographic variables such as age, race, sex, body mass index, marital status, employment status, history of psychiatric disorders, or substance abuse were not predictors of early fatality.

### Injury Pattern and Initial Treatment

UE injuries were grouped into five categories according to the tissue affected. These included fractures (44.7%), soft tissue–only (47.8%), neurologic (11.9%), vascular (8.1%), and tendinous (3.9%) injuries. Presence of a fracture was independently predictive of neurologic, vascular, and tendinous injury, and it was rare to sustain any of these injuries without a fracture ($P < 0.001$). Isolated fractures occurred in 65.2% of patients.

All patients were administered antibiotics on initial presentation, most commonly a first-generation cephalosporin (72.2%) or ampicillin-sulbactam (25.0%). Most patients (70.2%) were administered Tdap booster shots. Six patients were diagnosed with compartment syndrome.

**Table 1. Demographics**

| Demographics | n (%) |
|---|---|
| Age* | 29.5 (±10.9) |
| BMI* | 26.5 (±6.1) |
| Sex | |
| Male | 339 (94.2) |
| Female | 21 (5.8) |
| Race | |
| Asian | 2 (0.6) |
| Black | 322 (89.4) |
| White | 17 (4.7) |
| Latino | 4 (1.2) |
| Other | 15 (4.1) |
| Insurance status | |
| Medicaid | 182 (50.7) |
| Medicare | 29 (8.1) |
| Private | 71 (19.8) |
| Uninsured | 68 (18.9) |
| VA | 2 (0.6) |
| Other | 7 (1.9) |
| Marital status | |
| Single | 281 (78.1) |
| Married | 37 (10.3) |
| Other | 42 (11.7) |
| Tobacco | |
| Active | 137 (38.1) |
| Former | 36 (10.0) |
| Never | 135 (37.5) |
| Substance abuse | 131 (36.4) |
| Marijuana | 119 (90.8) |
| Opiates | 18 (13.7) |
| Cocaine | 8 (6.1) |
| PCP/amphetamines | 4 (3.1) |

*Data are represented as mean (±SD).
BMI, body mass index; PCP, phencyclidine; VA, Veterans Affairs.

**Table 2. Injury Patterns**

| Injury Patterns | n (%) |
|---|---|
| No. GSWs | |
| Single | 107 (29.7) |
| Multiple | 253 (70.3) |
| Total* | 3.2 (±2.7) |
| Location of GSWs | |
| Same arm | 85 (33.6) |
| Other arm | 36 (14.2) |
| Leg or legs | 99 (39.1) |
| Chest | 87 (34.4) |
| Abdomen/pelvis | 109 (43.1) |
| Head | 35 (13.8) |
| Neck | 20 (7.9) |
| Retained bullet† | 196 (54.4) |
| Whole | 49 (25.0) |
| Fragmented | 147 (75.0) |
| Soft tissue–only | 172 (47.8) |
| Fracture | 161 (44.7) |
| Neurologic injury | 43 (11.9) |
| Vascular injury | 29 (8.1) |
| Tendinous injury | 14 (3.9) |

*Data are represented as mean (±SD).
†Retained bullet in injured UE.

Five were diagnosed clinically, and one was diagnosed using Stryker pressures. Five patients had associated fractures, and four had associated vascular injuries. All received fasciotomies at their index operations. The average time from trauma bay presentation to fasciotomy was 10.6 hours (range: 0.7–46.5 h). No amputations were recorded in this cohort.

## PATIENT OUTCOMES BY SUBGROUPS

### Fractures

A total of 241 fractures occurred in 161 patients. These were distributed mostly to the hand/wrist (34.4%) and forearm (31.1%), followed by the humerus (22.4%) and scapula (12.0%) (Fig. 1). Fractures were overwhelmingly comminuted (84.6%), and 44.4% were intra-articular. Open fractures occurred 43.6% of the time, localizing mainly to the forearm (54.3%), hand/wrist (24.8%), and humerus (18.1%). Fractures were classified as open if the initial examination revealed exposed bone. Gustilo I predominated (67.6%), followed by Gustilo II (25.7%) and Gustilo III (6.7%). Sixteen fractures had a bony gap, with a median gap length of 5 cm. In the trauma bay, initial nonoperative management included splinting/casting (52.2%), washout (41.0%), saline load for possible traumatic arthrotomy (10.6%), and reduction (9.3%).

Patients with fractures were more likely to undergo operative management than nonfracture patients ($P < 0.001$). The majority of fracture patients (71.4%) received operative management. About one third of these patients (27.0%) were taken to the operating room (OR) in under 8 hours, 29.6% within 24 hours, 12.2% within 48 hours, and 31.3% after 48 hours (Fig. 2). Operative fixation was performed for 80.3% of Gustilo I injuries, 50.8% of which went to the OR in under 24 hours. All Gustilo II injuries received operative intervention. Nearly half (44.4%) went to the OR in under 8 hours, and 29.6% went in under 24 hours. Gustilo III injuries were associated with time to OR because all were taken to the OR in under 24 hours. The only other factor associated with time to OR was vascular injury. There were no significant differences in the number of superficial surgical site infections, unplanned reoperations, unplanned readmissions, or thromboembolic complications based on Gustilo class. However, there was a significant difference in the number of compartment syndromes based on Gustilo class, with Gustilo I having the most.

Accounting for all operative fractures, ORIF was the most common fixation (46.4%), followed by intramedullary nailing (11.8%), and ex-fix (7.8%). The humerus was typically repaired with ORIF or intramedullary nailing, whereas the radius and ulna were primarily repaired with ORIF. The carpal bones, metacarpals, and phalanxes utilized mixed modalities, with ORIF and ex-fix being more common (Fig. 3). Complications were rare (n = 18) and did not correlate toward any fixation type. They occurred most commonly in the humerus, radius, and ulna (n = 4 each), followed by the proximal phalanx (n = 3). Complications in the humerus included osteomyelitis and

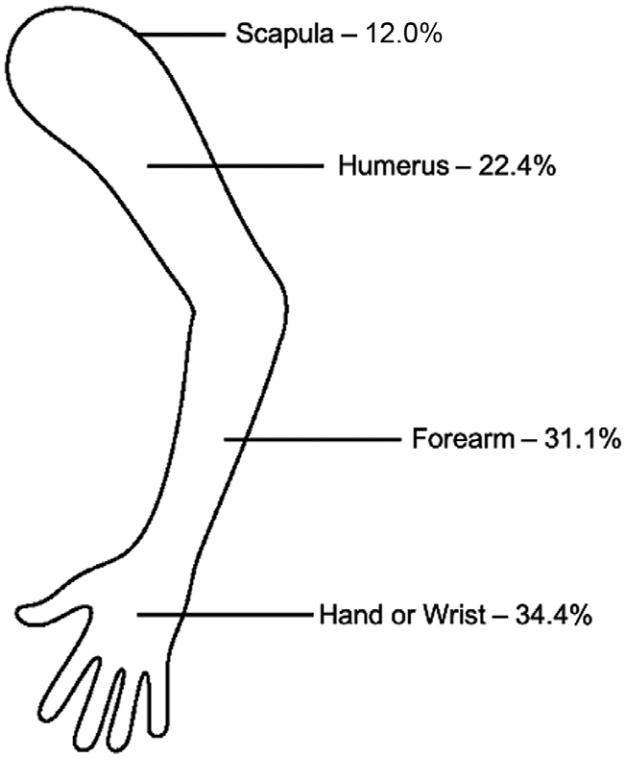


**Fig. 1.** Fractures by anatomic location.

nonunion. The radius included delayed union, malunion, and painful hardware. The ulna included nonunion, osteomyelitis, painful hardware, and deep surgical site infection. The proximal phalanx included malunion and deep palmar abscess.

Patients with fractures were admitted more frequently, required longer hospitalizations, and were more likely to have unplanned readmissions as compared with patients with other injury patterns ($P < 0.001$). These patients also had longer follow-up durations after their index admission (80 versus 17 days, $P < 0.001$).

**Soft Tissue–Only Injuries**

The majority of soft tissue-only injuries (93.6%) were managed non-operatively with antibiotics and/or bedside washout. These patients had lower rates of admission and follow-up as compared with patients with other injuries ($P < 0.0001$). When patients did follow-up, it was for a shorter period than patients with other injuries (16 versus 72 days, $P < 0.001$).

Most soft-tissue injuries that occurred alongside other injury types (such as entry wounds associated with fractures) were left open at the index operation (59.5%). A minority were closed primarily (33.3%) and even fewer required rearrangement of adjacent tissue for closure (0.8%). Twenty-four patients required a second operation for soft-tissue management (6.7%), and most of these wounds were closed during their second operation (n = 16). Six patients undergoing reoperation required skin grafting for closure, and there was one fillet of finger flap. No patients required more advanced techniques such as pedicled forearm or free flaps for closure.

**Neurologic Injuries**

Fifty-five neurologic injuries were recorded in 43 patients. These occurred in the ulnar (29.1%), radial (23.6%), and median (20.0%) distributions, followed by the digital nerves (16.4%) and brachial plexus (3.6%). All brachial plexus injuries were partial transections and did not undergo operative exploration. Nine patients had multiple nerve injuries.

Operative intervention at the time of injury was undertaken for nearly half of patients (21 of 43). External neurolysis was the most common operative management (10 of 21 patients). All radial injuries (four of four, 100%) and nearly half of ulnar injuries (three of seven, 42.8%) were managed with external neurolysis (Fig. 4). A partial nerve injury was found in 53.8% of patients receiving operative exploration. When a complete transection was found, the average nerve gap was around 6 cm. Two were repaired with allograft, one was repaired with autograft, and one was repaired with both autograft and allograft. Nerve gaps repaired with allografts were similar to gaps repaired with autografts (5.2 versus 6.0 cm, respectively). Functionality was difficult to ascertain due to lack of follow-up. Eleven patients with injury to either the median/anterior interosseous nerve, ulnar, radial/posterior interosseous nerve sensory, or common digital nerve returned for follow-up. Their two-point discrimination averaged 9.8 mm (range: 5.0–15.0 mm), with partial nerve transections attaining better average results at 8.7 ± 3.6 mm compared with complete transections at 11.2 ± 5.2 mm. In mixed sensory and motor injuries, 70.3% of patients attained three-fifths or greater muscle activation as measured by the British Medical Research Council Manual Muscle Testing scale. Complications were noted in five (23.8%) patients, with paresthesias (four of five) and dysesthesias (four of five) being most common.

**Vascular Injuries**

There were 34 vascular injuries in 29 patients. Brachial (38.2%), ulnar (23.5%), and radial (11.8%) arteries were most frequently affected. A computed tomography angiogram was performed for 72.4% of patients. When operative intervention was performed (15 of 29 patients, 51.7%), the most common repairs included interpositional vein graft (35.0%), ligation (25.0%), primary repair (20.0%), and bypass (10.0%) (Fig. 5). One patient developed an axillary pseudoaneurysm requiring subsequent endovascular stenting. There were no other documented complications.

**Tendinous Injuries**

There were 22 flexor tendon and six extensor tendon injuries in 12 patients. Most flexor tendon injuries occurred in the forearm (63.6%), followed by injuries in zone 2 (22.7%) and injuries in zone 3 (13.6%). Extensor tendon injuries were roughly distributed amongst the digits. Operative intervention was undertaken for most patients (10 of 12, 83.3%) and all injuries were either primarily repaired or debrided. There were three reoperations for tenolysis and no subsequent tendon transfers.

## DISCUSSION

Our study demonstrates that the presence of fracture indicates a greater likelihood of a more severe injury

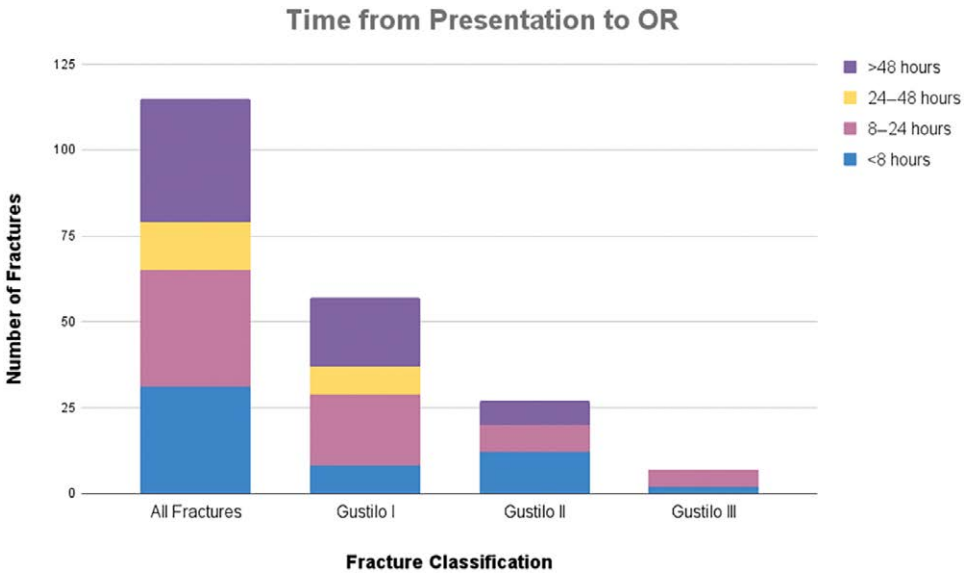


**Fig. 2.** Time to OR for all fractures, Gustilo I, Gustilo II, and Gustilo III injuries.

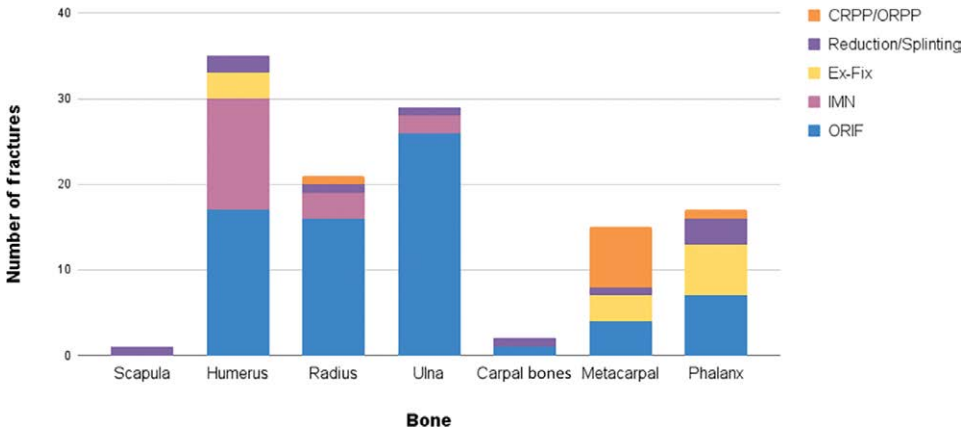


**Fig. 3.** Fixation modality for all fractures. CRPP; IMN, intramedullary nailing; OR; ORPP.

involving adjacent structures. Interestingly, the majority were safely managed with bedside washout and definitive fixation within 48 hours. Similar to Ghareeb et al[8] and Mehta et al[14] showing that concomitant vascular, tendinous, and neurologic injuries occur in 32%–50% of fractures and Straszewski et al[15] reporting an associated higher risk of neurologic injury with fractures, our study revealed that fractures were independently associated with these comorbid injuries. As such, these patients had a more complex clinical course and were significantly more likely to undergo surgery, be admitted more frequently, and require longer hospitalizations. Moreover, these multitissue injuries may complicate future reconstructions and may require staging of procedures, as our cohort showed that patients with fractures had a range of 0–10 procedures. Although antibiotic administration for nonoperative GSW fractures is controversial, many centers (including ours) gave antibiotics on presentation nearly universally.[8,10,11] Additionally, almost half of all injuries were washed out in the trauma bay, and more than half were taken to the OR. Possible factors that influenced the decision to washout in the trauma bay, OR, or both included location of the wound, severity of the injury, and degree of contamination. Further studies will be necessary to determine if washout timing influence outcomes.

In contrast to the overall fracture cohort, open fractures were almost always taken to the OR. Similar to Ghareeb et al[8] and Kiehn et al,[11] early operative intervention was our institution's more common practice, with around 75% taken to the OR within 48 hours. However, in contrast to these prior studies and Tarkunde et al,[16] where Kirschner wires were the predominant fixation method, our study showed that internal fixation was preferred.[8,11] This trend toward permanent fixation is likely due to both the high degree of comminution, fracture location, evolution in fracture management patterns over the years, and the anticipated low follow-up rate among this cohort. The outcomes overall were encouraging because complications including nonunion, malunion, and osteomyelitis occurred only 7% of the time, and were within comparable

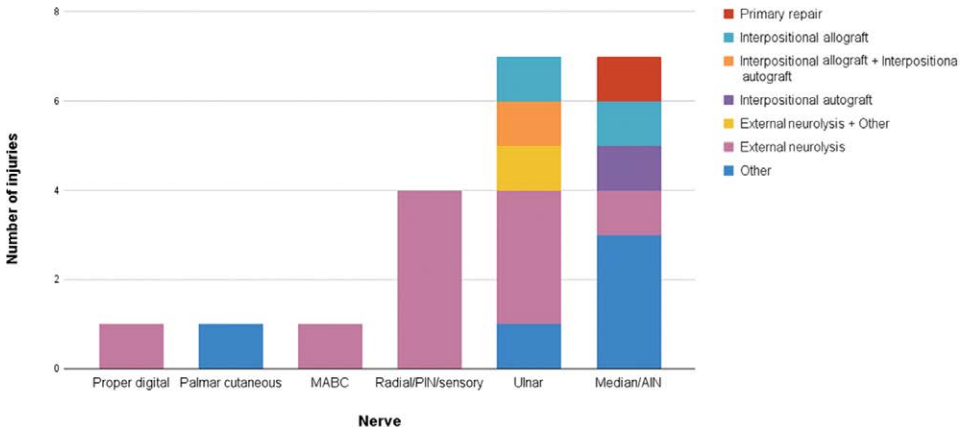


**Fig. 4.** Operative management of nerve injuries. AIN, anterior interosseous nerve; MABC, medial antebrachial cutaneous; PIN, posterior interosseous nerve.

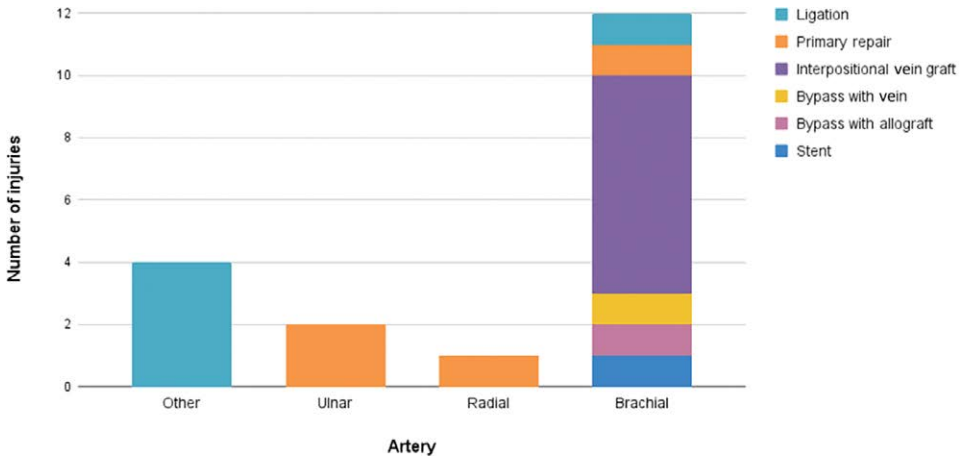


**Fig. 5.** Operative management of vascular injuries.

ranges seen in the literature.[8,11,17] We found no significant differences in outcomes based on the timing of operative intervention and found no relationship between fixation type and complications. This suggests that permanent hardware in a clean wound and good-quality soft-tissue coverage with an appropriate washout and debridement at the time of initial operation is a safe choice.

Although UE anatomical structures are closely positioned and can pose tremendous operative challenges, our study found that the vast majority of soft tissue–only UE injuries could be managed nonoperatively. In line with prior literature, management was relatively uncomplicated with the majority left to close via secondary intention even if taken to OR, and infections were rare.[6] Our study demonstrates that bullet removal from soft tissue–only and fracture injuries was generally not warranted. Operative reconstruction of soft tissue–only injuries was rare and usually involved skin grafts or local tissue rearrangement. This is most likely due to the low-velocity mechanism of civilian GSW injuries, as soft tissue–only injuries requiring extensive soft-tissue reconstruction tend to be more associated with high-velocity GSWs.[18–20]

GSWs to the UE produce an ongoing source of morbidity, especially among certain demographic groups, particularly young African American male patients. Similar to national data showing non-Hispanic Black or African American male patients under 44 years had the largest increase in firearm homicide rate from 2019 to 2020,[21] our study supports this trend by demonstrating this same demographic also accounts for an overwhelming portion of nonfatal firearm injury to the UE. Our findings are also consistent with comparable studies showing an average age under 35 years and male predominance,[8,17,22–24] which reflects the disproportionately greater burden borne by this vulnerable population. Moreover, these injuries also generate significant economic challenges. Song et al[25] showed that in the first year postinjury, survivors of nonfatal firearm injury saw an increase in medical spending by $2495 and cost sharing by $102 per person per month as compared with controls. As national gun violence rates remain high and hospitals across the United States continue to see large volumes of these cases, these social determinants warrant special consideration when targeting gun violence prevention efforts and understanding the challenges that these patients face with recovering from these injuries.

Limitations of our study include its retrospective study design and lack of follow-up, both in the quantity

of patients reporting to postoperative appointments and average duration of follow-up. Standardized measures for assessing patient satisfaction and functional outcomes at follow-up appointments were also inconsistently reported. Our study also had a selection bias, identifying patients through the trauma database, which undercounts isolated UE GSW injuries that were treated in the emergency room and not the trauma bay. Additionally, as our patient cohort was taken from a large metropolitan area, these results may not be generalizable for all civilian injuries in the United States. Future directions include obtaining patient reported outcomes that may better capture occupational challenges and lifestyle modifications as a result of their injuries.

## CONCLUSIONS

GSWs of the UE remain a significant source of morbidity and mortality, particularly for certain demographic populations served by our urban level 1 trauma center. Fractures and soft-tissue injuries were the predominant injuries sustained by patients. The presence of a fracture was predictive of more complicated injuries, including vascular, tendinous, and nerve injuries. Most fractures were successfully treated with internal fixation at the time of initial operation with a low complication profile. By contrast, soft tissue–only injuries rarely required operative management and could be safely managed via local wound care with debridement as indicated. Given limited follow-up, future studies should investigate the impact of UE GSWs on long-term functional outcomes, especially given the greater incidence in certain demographic groups that have been shown to have disparities in healthcare access.

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## DISCLOSURE

*The authors have no financial interest to declare in relation to the content of this article.*

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