Outcomes and Management for Ballistic Traumatic Arthrotomies in Children

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OBJECTIVES: To evaluate whether operative irrigation and debridement (I&D) is necessary for the treatment of pediatric traumatic arthrotomies (TAs) secondary to gunshot wounds (GSWs) to prevent joint infections.

METHODS:

Design: Retrospective cohort study.

Setting: US Academic Level I Trauma Center.

Patient Selection Criteria: Pediatric patients (age 0–17) with TAs secondary to GSW between 2016 and 2023 with at least 1-month follow-up were included. Arthrotomies included shoulder, elbow, wrist, hand, sacroiliac, hip, knee, ankle, or foot joints.

Outcome Measures and Comparisons: The primary outcome was rate of joint infection between those who received acute operative I&D versus those who received nonoperative management. A subanalysis was completed only comparing "major joints." Within the cohorts, length of antibiotic treatment was compared.

RESULTS: Fifty seven cases of ballistic TA (50 subjects, 82% male, mean age 14.6 years) were included. In total, 31 of 57 joints (54.4%) underwent formal operative I&D with or without fixation, while 26 joints (45.6%) did not. In the operative I&D cohort, 85% were male with a mean age 14.8 years versus 79% male with mean age of 14.3 years in the nonoperative group. Mean follow-up duration was 10.8 months (range 1–56 months) for both cohorts. No joint infections were documented between either group, regardless of treatment (P = 1.0). In total, 38 TAs were major joints: 23 of 38 (60.5%) received I&D, while 15 of 38 (39.5%) did not. All joints received at least 1 dose of intravenous (IV) antibiotics. Among the operative group, 54.8% of joints received ≤72 hours of IV antibiotics (45.2% received >72 hours), compared with 46.2% of joints in the nonoperative group (53.8% received >72 hours).

CONCLUSIONS: Formal operative I&D was not found to be necessary to prevent joint infection after TA secondary to GSW. Prolonged antibiotic use did not affect rates of infection.

KEY WORDS: traumatic arthrotomy, gunshot wound, ballistic fracture, septic arthritis

LEVEL OF EVIDENCE: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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INTRODUCTION

Gunshot wound (GSW) (GSW) injuries among pediatric patients have become increasingly common in recent years, significantly contributing to child morbidity and mortality.[1–3] A substantial proportion of these injuries involve the extremities, frequently resulting in severe ballistic fractures and joint damage.[4–6] Traumatic arthrotomies (TAs) are a common injury associated with GSW, involving disruption of the joint capsule and exposure of the joint space to external contamination.[7]

Traumatic joint exposure is a critical risk factor for the development of septic arthritis.[7,8] Septic arthritis can cause extensive damage to articular cartilage, accelerated post-traumatic arthritis, joint dysfunction, and long-term disability. These outcomes are particularly devastating for younger patients, and, therefore, cases of septic arthritis should be treated emergently in the pediatric population.[9,10] This underscores the importance of treatment strategies aimed at preventing infection and preserving joint integrity.

Historically, TAs have been managed with a combination of intravenous (IV) antibiotics and operative irrigation and debridement (I&D) to prevent infection.[7] However, emerging data in adult populations suggest that formal I&D may not always be necessary for TAs resulting from GSWs.[11–13] These studies have focused on adult populations and cannot necessarily be generalized to pediatric populations, particularly with open physes and higher rates of septic arthritis.[9,10] Although some studies have suggested operative I&D is not necessary for pediatric ballistic fractures, no study has focused on infection rates after ballistic arthrotomies.[14,15] The optimal approach to managing pediatric ballistic TAs remains poorly defined and a topic of ongoing debate.

The objective of this study was to determine the necessity of acute surgical I&D to prevent joint infection after TA secondary to GSW among the pediatric population. The primary outcome assessed was incidence of postinjury joint infection. The null hypothesis was that no difference would

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be seen in postinjury infection rates between joints managed with operative I&D and those managed nonoperatively.

METHODS

A retrospective cohort study was conducted at a US level-I academic trauma center. Institutional review board approval was obtained for data collection and analysis (protocol no. 24-476). Data were collected from the electronic medical record by 2 authors. Subjects aged 0 through 17 years who presented at the level-I academic trauma center with GSW were reviewed for an 8-year period from January 1, 2016, to December 31, 2023. Subjects sustained GSWs based on international disease classification 10th edition (ICD-10). The study period was chosen to minimize limitations and errors related to conversion of ICD-9 codes to ICD-10 codes that occurred at the end of 2015. ICD-10 codes included X93 "Assault by handgun discharge," X94 "Assault by rifle, shotgun and larger firearm discharge," X95 "Assault by other and unspecified firearm and gun discharge," X72 "Intentional self-harm by handgun discharge," X73 "Intentional self-harm by rifle, shotgun and larger firearm discharge", X74 "Intentional self-harm by other and unspecified firearm and gun discharge," W32 "Accidental handgun discharge and malfunction," W33 "Accidental rifle, shotgun and larger firearm discharge and malfunction" and W34 "Accidental discharge and malfunction from other and unspecified firearms and guns."

Based on these criteria, a subject list was created that was filtered for orthopaedic consultation for musculoskeletal injury. All orthopaedic consultations and available images were then reviewed for the presence or absence of a GSW-associated TA. Ballistic TAs were identified by (1) intra-articular gas on computed tomography (CT) scan (Fig. 1), (2) intra-articular metallic fragments on CT scan or radiographs (Fig. 2), (3) significant intra-articular joint comminution on CT scan or radiographs (Fig. 3), or (4) a positive saline load test.[16]

All images were reviewed by 2 orthopaedic resident physicians and a pediatric fellowship-trained orthopaedic surgeon. Subjects were excluded if they were injured by a non-firearm projectile (eg, BB gun, airsoft gun) or had <1-month of documented follow-up.

Demographic data were collected for the cohort including age, sex, and ethnicity. Joint(s) that sustained TA were documented. Comparison was made regarding demographics of the subjects who sustained ballistic TAs compared with state demographic data from the 2020 US census reported on census.gov using a χ^2 test.[17]

Subjects were then grouped based on the treatment they received: formal operative I&D versus local wound care of the affected joint(s). Data were collected on additional surgical interventions, antibiotic type and route of administration, antibiotic duration while in the hospital, antibiotic duration on discharge, and GSW injury mechanism recorded in the medical chart (accidental discharge, assault, accidental vs. incidental, and unknown).

The primary outcome assessed was postinjury infection. A second analysis was performed excluding the joints of the hands and feet to determine whether any differences were seen when isolating just "major" joints. This excluded carpometacarpal joints, metacarpophalangeal joints, proximal interphalangeal joints, distal interphalangeal joints, tarsometatarsal

FIGURE 1. Sagittal image on a CT scan of an elbow demonstrating intra-articular gas within the elbow joint.

FIGURE 2. Anterior to posterior radiograph of a foot demonstrating significant intra-articular fracture comminution of the first metatarsophalangeal joint.

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FIGURE 3. Sagittal image on a CT scan of a knee demonstrating an intra-metallic fragment (in this case the bullet) within the knee joint.

joints, metatarsophalangeal joints, and IP joints. Additional comparisons were made for duration of antibiotic regimen, both inpatient and on discharge.

T-tests were used for comparisons of continuous data. Categorical data were compared using either a χ^2 test or a Fisher exact test. Arthrotomy trends were analyzed using a Mann–Kendall trend test with a Kendall Tau to determine the strength and direction of trends. A *P*-value of <0.05 was considered statistically significant for statistical analyses. Statistical analyses were performed using R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Patients

In total, 412 patients presented with a GSW during the study period. One hundred forty-three of these patients underwent orthopaedic evaluation for musculoskeletal injury. Fifty patients sustained 1 or more ballistic TAs and met inclusion criteria, with 57 total joints involved (Fig. 4). Four subjects sustained multiple TAs on presentation. The number of patients presenting with a ballistic TA increased with a compound annual growth rate of 25.8% from 2016 to 2023, with notable fluctuations including a peak of 12 patients in 2022. Overall, the trend reflected a significant upward trajectory in cases during the 7-year period (Fig. 5; $P = 0.03$, $\tau = 0.69$).

Most patients were male (82.0%, n = 41) with a mean age of 14.6 ± 3.6 years (range 1–17 years). Between the operative group (84.6% male, mean age 14.8) and nonoperative group (79.2% male, mean age 14.3), neither male predilection nor mean age differed significantly (both $P = 0.62$). Hispanic ethnicity was predominant (74.0%, n = 37), significantly higher than the state's 47.7% Hispanic population based on 2020 US census data ($P < 0.001$).[17] African American patients were also significantly overrepresented (8.0% vs. 1.8% statewide, $P = 0.03$), while non-Hispanic White patients were significantly underrepresented (8.0% vs. 36.5% statewide, $P < 0.001$). Representation among Native American patients (6.0%) and Asian patients (0.0%) did not differ significantly from state population levels ($P = 0.62$ and $P = 1.0$, respectively). The ethnic/racial distribution differed significantly between the operative and nonoperative groups ($P = 0.02$), primarily because all African American patients (n = 4) were in the operative group and all White patients (n = 4) were in the nonoperative group.

Accidental discharge was the leading cause of injury (54.0%, n = 27), followed by assault (34.0%, n = 17). Overall, 12% of cases (n = 6) had an unknown cause. Distribution of the type of GSW injury mechanism did not differ significantly between the operative and nonoperative groups ($P = 0.47$). These data were collected subjectively from the patient or parent in emergency medicine records. Mean follow-up for the cohort was 10.8 months (range 1–56 months) and did not differ significantly between groups with a mean of 10.8 in both the operative and nonoperative groups ($P = 0.99$).

Joints

Of the 57 total cases in the cohort, the most common TA was the knee (21.1%), with 12 total occurrences, followed by joints of the hand (n = 10), joints of the foot (n = 9), and the elbow (n = 7; Table 1). All but 3 patients (94.0%) underwent an informal bedside lavage of the bullet wounds by the orthopaedic resident in the emergency department for their presenting injury.

Operative Management

In total, 31 out of 57 total joints underwent formal operative I&D (54.4%) with or without additional fixation, while 26 joints (45.6%) did not receive operative intervention and were treated with local wound care. Of the 31 joints treated operatively, 18 (58.1%) also underwent open reduction and internal fixation or medullary nailing of an associated fracture. Four cases (12.9%) were indicated for intra-articular foreign body removal, while the final 9 cases (29.0%) underwent operative intervention for irrigation and debridement alone (Table 2). There was no significant difference observed in infection rates between the operative I&D group (0/31) and the nonoperative I&D group (0/26; $P = 1.0$).

After isolating only major joints (excluding joints of the hands and feet), there were 38 total TA cases. In total, 23 out of 38 joints (60.5%) underwent formal operative I&D, while 15 joints (39.5%) did not. Of the 23 cases that underwent operative I&D, 12 cases (52.2%) included fracture fixation, while 3 (13.0%) were indicated for intra-articular foreign

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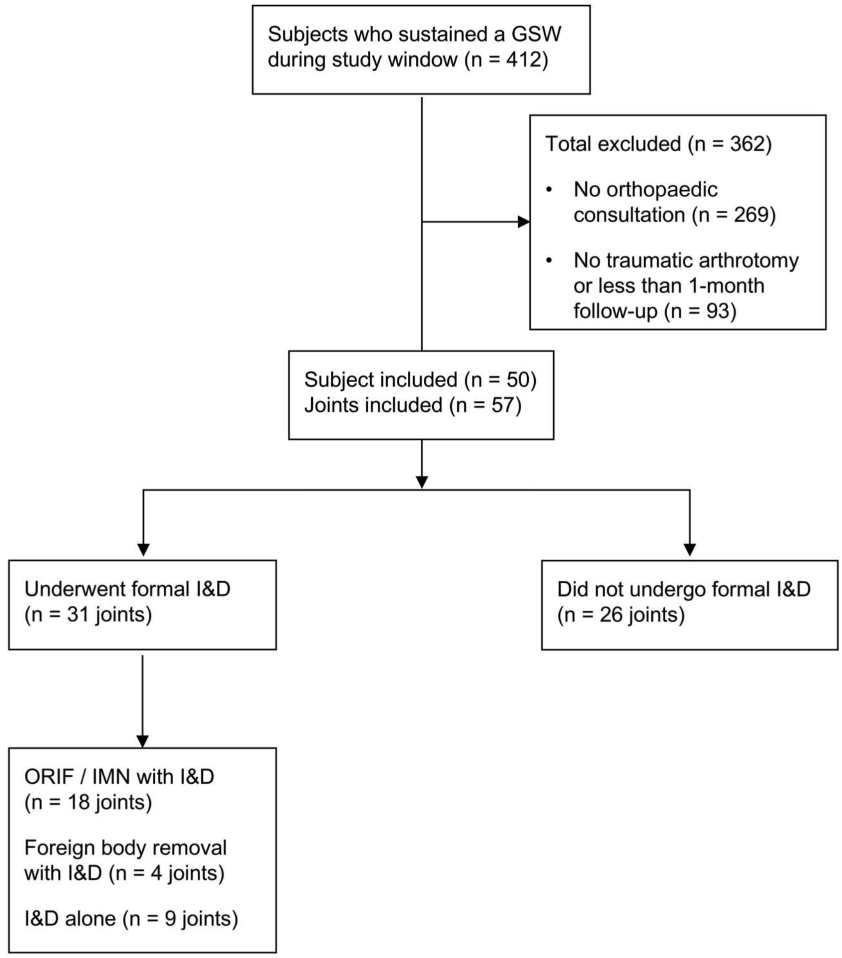

FIGURE 4. Cohort flow diagram demonstrating cohort selection. I&D, irrigation and debridement; IMN, intramedullary nail fixation; ORIF, open reduction internal fixation.

body removal, and the final 8 cases (34.8%) underwent operative intervention for I&D alone.

Antibiotic Management

Antibiotics were administered to all 50 patients (all 57 joints), either while in the emergency department or perioperatively in the operating room. Each patient received at least 1 dose of IV cefazolin (100%). The average total length of antibiotic treatment among both cohorts was 4.5 days and did not differ significantly between the operative group (4.1 days) and the nonoperative group (5.0 days), $P = 0.37$. These numbers were skewed by the multiple patients who were on prolonged antibiotic regimens (5 days or greater) for injuries to the head, chest, abdomen, or pelvic organs. After exclusion of these patients with polytrauma, the average total length of antibiotic treatment among both cohorts was 4.0 days and still did not differ significantly between the operative group (4.1 days) and the nonoperative group (3.8 days), $P = 0.75$ (Table 3).

Overall, 9.7% of joints in the operative group received only a single dose of IV cefazolin versus 11.5% of joints in the nonoperative group received only a single dose of IV cefazolin. When antibiotic duration was stratified by ≤72 hours or >72 hours of treatment, 54.8% of joints in the operative group received ≤72 hours of antibiotic treatment versus 46.2% of joints in the nonoperative group, while the remainder of joints received >72 hours of antibiotic treatment (operative: 45.2% vs. nonoperative: 53.8%; Table 4). Overall, 12.9% of operative joints (n = 4) were discharged on an oral antibiotic regimen for an average of 8.5 ± 1.7 additional days, whereas 26.9% of nonoperative joints (n = 7) were discharged on an average of 6.4 ± 1.9 additional days of oral antibiotics. No significant differences were observed between the operative and nonoperative groups across the antibiotic duration subgroups (IV only, ≤72 hours, >72 hours, and discharge on an oral regimen). None of the patients in the cohort developed postinjury joint infection or septic arthritis regardless of treatment strategy.

DISCUSSION

In this retrospective study of 57 pediatric ballistic TAs, no infections occurred. The results of this study suggest that there was no difference in infection rates between pediatric ballistic TA's managed with formal operative I&D and those managed with local wound care. All patients remained free of infection regardless of length of antibiotic treatment.

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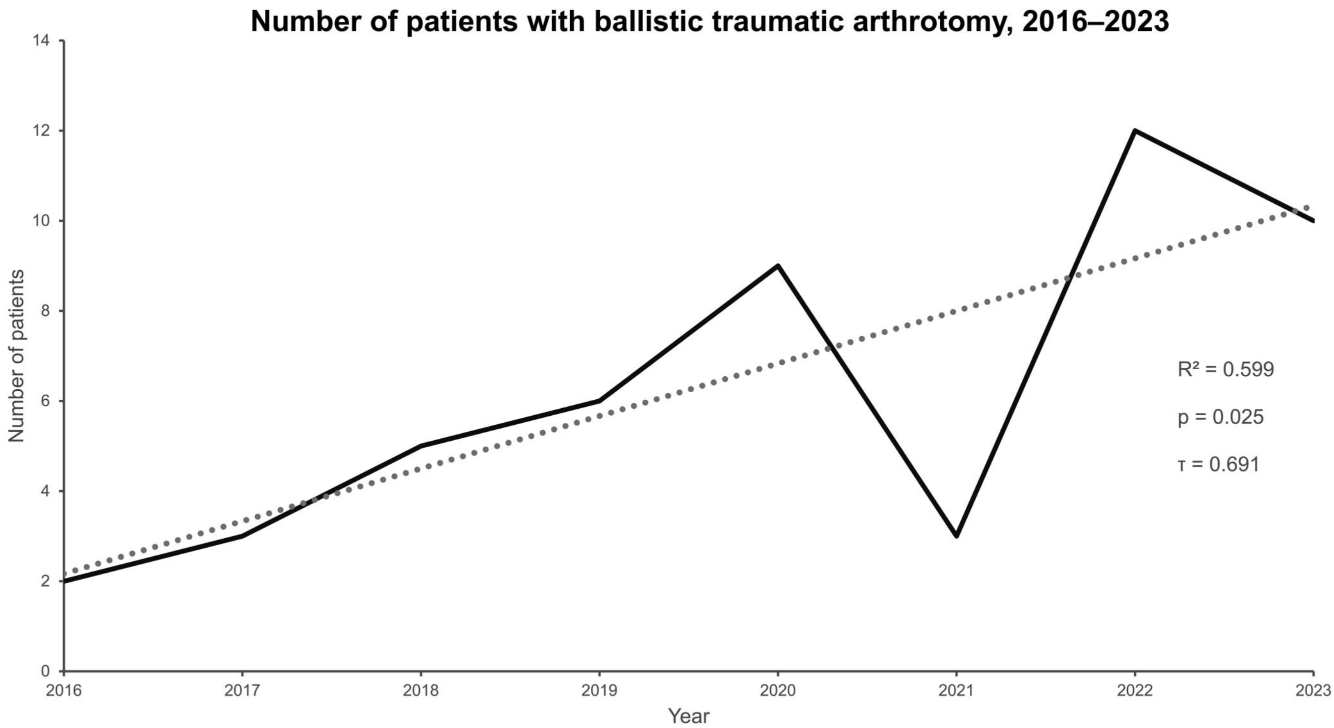

FIGURE 5. The number of patients presenting with a TA secondary to GSW for an 8-year period from January 1, 2016, to December 31, 2023. TAs increased at a compound annual growth rate of 25.8% for this period, with a peak of 12 patients in 2022 ($P = 0.025$, $\tau = 0.691$).

Before World War 1, TAs resulted in up to 100% rates of septic arthritis and frequent progression to amputation of the affected extremity.[7,8] Modern treatment including a combination of IV antibiotics and operative I&D has lowered this risk of progression to <5%, emphasizing the importance of treating these injuries appropriately. Without treatment, the progression of traumatic arthrotomy to intra-articular infection can be catastrophic. Among pediatric populations in developed countries, rates of dysfunction and complications secondary to septic joints are exceedingly high, ranging from 15% to 49%.[9] Long-term sequelae include destructive joint changes with limited range of motion, growth disturbance, joint contracture, limb length discrepancy, and amputation.[18]

Although the recommended treatment for most TAs continues to be formal I&D and antibiotics, recent data have shown that arthrotomy infection rates remain low with nonoperative treatment in the setting of GSW among adults.[11–13] On literature review, only 3 studies evaluate the rates of infection comparing operative to nonoperative treatment of these injuries. The earliest report on nonoperative treatment by Shultz et al[12] demonstrated no significant difference in risk of infection between operative I&D and local wound care among 46 adults, with no reported cases of septic arthritis.

TABLE 1. Number of Joints Which Sustained Ballistic TAs Between 2016 and 2023

Joint	Arthrotomies (with % of Total, n = 57)
Knee	12 (21.1%)
Hand	10 (17.5%)
Foot	9 (15.8%)
Elbow	7 (12.3%)
Shoulder	6 (10.5%)
Hip	4 (7.0%)
Ankle	4 (7.0%)
Sacroiliac	3 (5.3%)
Wrist (radiocarpal)	2 (3.5%)

Hand joints include all joints distal to the wrist, while foot joints include all joints distal to the ankle.

TABLE 2. Treatment of TAs Between 2016 and 2023

All joints
31 out of 57 total joints (54.4%) underwent formal operative I&D
18 (58.1%) ORIF/IMN with I&D
4 (12.9%) Foreign body removal with I&D
9 (12.9%) I&D alone
Major joints, excluding joints of the hands and feet
23 out of 38 joints (60.5%) underwent formal operative I&D
12 (52.2%) ORIF/IMN with I&D
3 (13.0%) Foreign body removal with I&D
8 (34.8%) I&D alone

The primary indication for surgical intervention is listed among those that went operative I&D.

I&D, irrigation and debridement; IMN, intramedullary nail fixation; ORIF, open reduction and internal fixation.

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TABLE 3. Average Duration of Antibiotic Treatment of TAs Between Cohorts

Group (Joints)	Average Total Doses of Inpatient Antibiotics	Average Length of Inpatient Antibiotic Treatment (d)	Average Length of Total Antibiotic Treatment (d)
Operative group (n = 30)	6.27 ± 4.3	3.00 ± 2.1	4.07 ± 3.1
Nonoperative group (n = 22)	4.59 ± 4.7	2.05 ± 1.2	3.82 ± 2.4

Prolonged antibiotic regimens (5 d or greater) for injuries to the head, chest, abdomen, or pelvic organs were excluded.

This study was followed by multiple larger retrospective reviews by Nguyen et al and Liu et al with 55 and 195 patients, respectively.[11,13] These analyses reported no incidences of deep infection or septic joint among the nonoperative groups. Infection was only seen among subjects who required operative fixation or vascular repair. All 3 studies concluded that formal operative irrigation and debridement was not necessary to prevent infection secondary to ballistic TAs. However, these studies focused on adult populations, with the average cohort age among the 3 studies: 32.6 ± 15.9 years (Shultz et al), 29.8 ± 10.0 years (Liu et al), and 30.6 ± 11.0 years (Nguyen et al).[11–13]

Several studies and reviews on the treatment of pediatric ballistic fractures secondary to GSW have suggested antibiotic treatment without the necessity of formal I&D.[14,15,18–22] However, these were limited regarding treatment of arthrotomies or rates of joint infection. Villegas et al did recommend I&D of affected joints for infection prevention, removal of metallic foreign bodies or loose bodies, and prevention of contractures. The rates of potential joint infection without I&D are otherwise unknown.[14,15]

The findings from this study help to extend the recommendations of adult ballistic arthrotomy studies to the vulnerable pediatric population, because nearly half (45.6%) of joints within this cohort were managed without formal operative washout, and none (0%) developed superficial infections or septic arthritis. Nevertheless, 54% of patients in this cohort still underwent operative treatment for multiple reasons. Ashby et al[23] originally described several indications for operative treatment with I&D of GSW injuries, including fractures requiring internal fixation, large intraarticular loose osteoarticular fragments, and large bullet fragments remaining in the joint. Intra-articular metallic foreign bodies remain a strong indication for acute operative management because these may lead to rapid chondral degradation in addition to bullet-induced synovitis or systemic lead absorption and toxicity.[4,24] Among the cohort, 12.9% (n = 4) of operative cases were primarily indicated for foreign body removal. Furthermore, 42% of operative patients (n = 15) underwent fracture fixation (including open reduction internal fixation and/or intramedullary nailing). The decision to pursue surgical management highlights the importance of individualized treatment plans tailored to the patient's clinical status while emphasizing the notion that surgical intervention remains necessary only in specific settings. A less invasive approach may mitigate the risks associated with general anesthesia and surgical intervention, particularly in younger patients.[25] Nonoperative management may also significantly reduce hospital length of stay and the associated economic burden on patients and their families.[26]

TABLE 4. Antibiotic Regimen Between the Operative and Nonoperative Groups

Antibiotic Treatment Method	Number of Joints (%)
Operative group (n =31 joints)	
Single dose of IV abx	3 (9.7%)
IV abx 8–24 h	2 (6.5%)
IV abx ≤24 h and d/c on oral regimen	3 (9.7%)
IV abx 24–72 h and d/c on oral regimen	1 (3.2%)
IV abx 24–72 h	12 (38.7%)
IV abx >72 h	9 (29.0%)
Prolonged abx for polytrauma	1 (3.2%)
Nonoperative group (n = 26 joints)	
Single dose of IV abx	3 (11.5%)
IV abx 8–24 h	1 (3.8%)
IV abx ≤24 h and d/c on oral regimen	6 (23.1%)
IV abx 24–72 h and d/c on oral regimen	1 (3.8%)
IV abx 24–72 h	8 (30.8%)
IV abx >72 h	3 (1.5%)
Prolonged abx for polytrauma	4 (15.4%)

Polytrauma includes a minimum of 5 d of broad antibiotic coverage for injuries to head/chest/abdomen/pelvic organs.
abx, antibiotics; d/c, discharge.

Although this study evaluated the need for acute prophylactic operative management of ballistic TAs, further surgical intervention on a nonemergent basis may still be indicated. Tornetta et al[27] found that rates of meniscal and chondral damage to the knee were much higher than suspected on plain radiographs. The potential for future surgical intervention beyond prophylactic I&D should not be disregarded.

All patients included in this study received at least 1 dose of IV cefazolin, consistent with current guidelines recommending antibiotic treatment for open fractures and joint injuries.[4,14,28] After exclusion of patients with polytrauma on prolonged antibiotic regimens, the average total duration of antibiotic treatment among the nonoperative group was only 3.8 ± 2.4 days. However, only 11.5% of these joints only received a single dose of IV cefazolin treatment. Because no patients developed postinjury infections, this may be indicative that longer antibiotic regimens may hold less utility. Overall, 26.9% (n = 7) of the nonoperative joints were sent home on an oral antibiotic regimen (average 6.4 ± 1.9 days), though it is unclear whether this made a substantial impact on infection prevention for the patients on shorter regimens.

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Although the findings of this study are encouraging, they are not without limitations. The transition to ICD-10 codes in 2015 limited the study period to maintain consistent data collection. A longer study period may have further empowered the observed trends noted above. Detailed information regarding the type of firearm used for these injuries was unavailable, which is relevant given the association between high-velocity projectiles (>2000 fps) and higher infection rates.[29] Although most injuries in the civilian urban setting of the study were likely caused by low-velocity handguns, the exact distribution remains unknown. Furthermore, detailed descriptions of size and level of contamination of GSW wounds were not consistently available and, therefore, could not be compared between groups.

A standardized GSW antibiotic protocol does not currently exist at the institution where this study was conducted, which may have introduced variability in treatment practices and outcomes. However, the observed range of antibiotic durations does provide justification for using shorter antibiotic regimens because no patients developed infections regardless of duration. The follow-up period of 1 month was consistent with other similar studies, because postinjury extremity infections typically present within 2 weeks,[8,13,28] However, a longer follow-up duration could have provided more comprehensive data on long-term complications, functional outcomes, and the need for further surgical intervention, though this was not the focus of this study. Finally, the cause of the GSWs in this study was subjective and relied on information provided by patients or their families, which may not accurately reflect the true circumstances of the injury.

CONCLUSIONS

This study supports the notion that operative I&D is not mandatory for infection prevention in the setting of GSW-related TAs in children. A combination of a short-term antibiotic regimen along with local wound care was found to be sufficient in preventing infections after these injuries. Operative debridement should be reserved only for cases requiring additional interventions, namely fracture fixation or removal of intra-articular foreign bodies.

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