



Infectious profiles in civilian gunshot associated long bone fractures

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Abstract

Purpose There is a paucity of literature on infections in civilian gunshot associated with long bone fractures with the reported rates ranging from 0–15.7%. This study aimed to investigate the rates of infection associated with long bone fractures caused by civilian gunshots. The specific objectives were to determine if certain extremities were at a higher risk for infection and to identify the types of bacteria present in these infections by analyzing culture isolates.

Methods We conducted a retrospective review of consecutive patients aged 18–64 who sustained gunshot-associated long bone fractures at an urban Level I trauma centre from 2010 to 2017. Patient selection was based done through a institutional trauma centre database using international classification of diseases (ICD) 9 and 10 codes. We included patients who underwent surgical treatment, specifically fracture fixation, at our institution and excluded patients with fractures involving the pelvis, spine, foot, and hand. A total of 384 gunshot-associated long bone fractures in 347 patients were identified for analysis. Relevant patient-, injury-, and treatment-related variables were extracted from clinical records and radiographic reviews. Outcomes of interest included bony union, repeat operative procedures, and the development of deep infection.

Results 347 patients with 384 long bone fractures were included. 32 fractures in 32 patients developed an infection for an incidence of 9.3% of patients and 8.3% of fractures. Gram-positive bacteria were present in 23/32 (72.0%) culture isolates, gram-negative bacteria in 10/32 (31.3%) culture isolates, and six infections were polymicrobial. Staphylococcus 16/32 (50.0%) and Enterobacter 6/32 (18.8%) species were the most common isolates. Of the Staphylococcus species, 5/16 (31.3%) were MRSA. Lower extremity fractures had a greater risk for infection compared to the upper extremity (11.7% vs 3.7% $p < 0.01$) and fractures that developed an infection had a larger average zone of comminution (63.9 mm vs 48.5 mm $p < 0.05$).

Conclusion This study investigated the rates of infection associated with long bone fractures caused by civilian gunshots. The overall infection rate observed in our series aligns with existing literature. Gram-positive bacteria were the predominant isolates, with a notable incidence of MRSA in our patient population, highlighting the need for considering empiric coverage. Additionally, gram-negative organisms were found in a significant proportion of infections, and a notable percentage of infections were polymicrobial. Our findings emphasize the importance of carefully assessing highly comminuted lower extremity fractures and implementing appropriate antibiotic coverage and operative debridement for patients with gunshot-related long bone fractures. While current prophylaxis algorithms for open fractures lack specific inclusion of gunshot wounds, we propose incorporating these injuries to reduce the incidence of infections associated with such fractures.

Keywords GSW · Infection · Tibia · Femur · Micro · Antibiotics

Introduction

Gun violence is a major burden on the US healthcare system that has seen an increase in severity and cost over the past decade [1]. The healthcare costs related to firearm violence range from 740 million to 1 billion dollars. Among these, extremity injuries are among the most common non-fatal gunshot wounds [2–4]. Extremity injuries, particularly long bone fractures caused by civilian gunshots, are prevalent

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and often associated with complications such as infection and non-union. The reported incidence of infection in civilian gunshot associated with long bone fractures ranges from 0–15.7%.

Understanding the rates of infection and the types of bacteria involved in gunshot-associated long bone fractures is crucial for guiding antibiotic prophylaxis and therapy. Currently, there needs to be more consensus regarding the appropriate antibiotic regimen and duration for these fractures. There is also limited research on the risk factors, bacterial flora, and optimal treatment approaches for these injuries. By characterizing the bacteriology of infections, this study can provide valuable insights that will help optimize antibiotic coverage and improve patient outcomes. Additionally, identifying the risk factors associated with infection and non-union can aid in early identification and targeted management.

The main objectives of this study are to investigate the risk factors for infection in gunshot-associated long bone fractures, determine the bacteriology of these infections, and evaluate factors associated with poor bone healing. We hypothesized that patients with medical risk factors and higher energy injuries, as indicated by larger zones of comminution, will have a higher risk of infection and non-union. By addressing these objectives, we aim to enhance the understanding of the clinical implications of gunshot-associated long-bone fractures and provide evidence-based recommendations for their management, ultimately reducing the incidence of infections and improving patient outcomes.

Methods

A retrospective review of all consecutive patients between the age of 18–64 who sustained gunshot-associated long bone fractures at an urban Level I trauma centre from 2010–2017 was performed. Our institutional trauma centre database was queried using international classification of diseases (ICD) 9 and 10 codes to identify potential subjects. Individual records were then reviewed to confirm the diagnosis of gunshot-associated long bone fractures. We included for analysis patient ≥ 18 years of age with acute gunshot related fractures of the long bones who underwent surgical treatment including fracture fixation at our institution without minimum follow up. Fractures to the pelvis, spine, foot, and hand were excluded. In this review, we identified 384 gunshot associated long bone fractures in 347 patients.

Patient-, injury-, and treatment-related variables were extracted from clinical records and radiographic review. Patient-related factors included demographics, associated conditions including alcohol, tobacco, or substance use, and medical comorbidities such as diabetes, hypothyroidism, hepatitis C, and HIV status. Injury-related variables including open wound size, need for soft tissue and/or free flap

coverage. We used the extent of the zone of comminution as measured by millimeters as a surrogate measure of the energy imparted to the bone as the gunshot velocity was not able to be assessed. Zone of comminution was measured by taking the largest area of comminution as measured on the AP or Lateral X-ray, reviewed by a Board certified Orthopedic Surgeon. Associated injuries including additional extremity and non-extremity gunshot wounds, intra-abdominal or intra-thoracic injury requiring emergent laparotomy or thoracotomy were also recorded. Treatment-related variables included prophylactic antibiotic administration, timing and number of debridement procedures, type and timing of definitive surgical management, and any additional surgical procedures to achieve union. Our definition of union was based on radiographic evidence of resolution of the initial fracture line with bridging of bone cortices. As a standard protocol in our institution, all patients with GSW related fractures receive antibiotics within 24 h and are treated as an open fracture.

Outcomes examined included bony union, the need for repeat operative procedures, and the development of deep infection. Microbacterial results from intra-operative cultures obtained during operative debridement of infected cases were analyzed. Patients were stratified into cohorts for data analysis based on the presence or absence of infectious complications.

Categorical results are listed as counts with column percentages. Continuous data are listed as means standard deviations; standard errors are given where possible. Normally distributed data were compared with independent sample *t* tests. Non-normally distributed data were compared using the Wilcoxon rank-sum. Categorical variables were analyzed with Fisher's Exact Test or Chi Square with Kendall Tau. Odds ratios were also reported in our statistical analysis. Variables with $P < 0.05$ were considered statistically significant in our analysis.

Results

A total of 347 patients with 384 long bone fractures treated at our institution during the study period were included for analysis. The mean age was 30.1 and 30.4 years old respectively. The majority of patients in our study were males. Among these, 32 fractures developed an infection while 352 did not. 100% of all patients that developed an infection were male. Of the infected fractures, 12 were femurs, 13 were tibias, five were humeri, one was an ulna, and one was a fibula. Infection was more common in lower extremity fractures (26 out of 222 fractures, 11.8%) compared to upper extremity fractures (6 out of 162 fractures, 3.7%). The mean zone of comminution was significantly larger in the cohort of patients who developed infection (63.94 mm vs. 48.46 mm,

$P=0.032$). The remaining treatment-related variables did not differ significantly between cohorts. There were no significant differences in demographics, medical comorbidities or treatment-related variables between patients who developed infection and those who did not (Table 1). Duration of follow-up was significantly longer in the infection cohort (348.2 vs 157.7 days, $P<0.001$). The average follow-up time was 173 days.

Upper versus lower extremity fractures

Lower extremity fractures were significantly more likely to get infected than upper extremity fractures (81.3% vs 18.8%, $P=0.005$). Infections in the upper limb most commonly affected the humerus (3.1% $p<0.01$) while infection in the lower limb was most common in the tibia (5.9% $p<0.01$) (Tables 2 and 3).

Non-union

The overall rate of non-union was 25 of 384 fractures (6.5%). Incidence of non-union was significantly greater in the infection cohort (13 of 32 patients, 40.6%) compared to the uninfected cohort (12 of 352 patients, 3.4%) ($P<0.001$). The nonunion rate between upper vs lower extremity fractures overall was 8.7% vs 5.7%, respectively ($P=0.40$).

Culture results and antibiotics

Gram-positive bacteria were present in 23 culture isolates, and gram-negative bacteria in ten culture isolates. Six of the isolates were polymicrobial. The most common isolates were Staphylococcus (16) and Enterobacter (6). Of the 16 Staphylococcus isolates, 5/16 (31.3%) were Methicillin-resistant Staphylococcus aureus, as can be seen in Table 2. Several

Table 2 Organism cultures of all patients with positive cultures after sustaining a gunshot wound fracture

Culture growth	N (n)	N (%)
Bacillus, Enterobacter, Klebsiella	1	3.13%
Citrobacter	1	3.13%
Coagulase Negative Staph	1	3.13%
E Coli, Candida	1	3.13%
Enterobacter	4	12.50%
Enterobacter, Enterococcus	1	3.13%
Enterococcus, Corynebacterium	1	3.13%
MRSA	5	15.63%
MSSA	8	25.00%
MSSA, Corynebacterium	1	3.13%
MSSA, Pseudomonas	1	3.13%
Streptococcus mitis	1	3.13%
VRE	1	3.13%
No growth	5	15.63%

variables were analyzed and compared between the infectious and non-infectious groups. Only 20 out of 32 fractures (62.5%) that were later infected received antibiotics in the emergency department, while 275 out of 352 (78%) fractures of the non-infected group received antibiotics. 19 out of 32 (59%) infected fractures were treated with a single or combination antibiotic regimen that included vancomycin whereas only 146 out of 352 (41%) non-infected fractures were treated with a single or combination antibiotic regimen that included vancomycin ($P<0.05$).

Treatment

In terms of need for bone graft, four out of 28 (12.5%) fractures in the infected group required bone graft whereas ten

Table 1 general demographics of patients with and without an infection after sustaining a gunshot wound fracture

	No infection (n=352)	Infection (n=32)	P value
Male	323 (91.8%)	32 (100%)	0.091
Age	30.4 ± 11.0	30.1 ± 8.3	0.89
Diabetic	11 (3.1%)	1 (3.1%)	0.998
Hgb A1C	6.30 ± 1.5	5.325 ± .52	0.221
HIV positive	4 (1.1%)	0	0.544
Hepatis C positive	5 (1.4%)	0	0.497
Hypothyroidism	3 (0.9%)	0	0.6
Cocaine user	35 (10%)	5 (15.6%)	0.323
EtOH user	176 (51%)	20 (61%)	0.196
Tobacco user	168 (48.3%)	21 (65.6%)	0.06
Albumin	3.18 ± .72	2.99 ± 1.0	0.294
Pre-albumin	18.72 ± 7.8	17.63 ± 8.2	0.664
Hospital LOS (Days)	11.4 ± 34.5	15.5 ± 12.3	0.551
Zone of comminution (mm)	48.46 ± 38.9	63.94 ± 39.1	0.032

Table 3 Upper vs lower extremity fracture breakdown, union rates and follow up length of all patients with positive cultures after sustaining a gunshot wound fracture

		No infection (n = 352)		Infection (n = 32)		P-value
Upper or lower extremity	Lower	196	55.70%	26	81.30%	0.005
	Upper	156	44.30%	6	18.80%	
Known non-union	No union	12	3.40%	13	40.60%	< .001
Total follow up (Days)		157.7		348.2		< .001
		+/-185.1		+/-241.4		

out of 342 (2.8%) fractures in the noninfected group needed a bone graft ($P < 0.05$). Three out of 32 infected fractures needed a free flap whereas eight out of 352 noninfected fractures needed a free flap ($P = 0.55$). In terms of receiving antibiotics in the emergency center at arrival, 20 patients (62.5%) in the infected fracture group received antibiotics whereas 275 patients (78.1%) in the noninfected group received antibiotics in the emergency center ($P < 0.05$). 13 out of 32 patients in the infected fracture group had a formal incision and debridement in the operating room. The final antibiotics received during admission are broken down in Table 4 below.

Discussion

Our study of 384 patients who underwent treatment for acute gunshot-related fractures of the long bones aimed to identify differences in infection rates, to characterize infection profiles and to assess factors that may affect outcomes. We found that 1) lower extremity fractures were more likely to develop infection; 2) the extent of the zone of comminution was a significant risk factor for infection; 3) patients that received antibiotics in the emergency center upon arrival were less likely to develop an infection; and 4) although gram-positive organisms were the most common infecting organisms based on deep cultures, gram-negative bacteria were isolated in a notable proportion of cases.

In our study, 59% of the infections were gram-positive (either isolated or polymicrobial). Gram-positive bacteria were present in 23 culture isolates, gram-negative bacteria

in ten culture isolates, and six infections were polymicrobial. Staphylococcus (16) and Enterobacter (6) species were the most common isolates. Of the Staphylococcus species, 31.3% were MRSA. Specifically, Staphylococcus was the most cultured bacteria, and 5/16 were MRSA isolates. Furthermore, gram-negative organisms were the second most isolated bacteria, followed by polymicrobial infections. Although our results focus on gunshot-associated long bone fractures, these results build on existing evidence that suggests Staphylococcus and Enterobacter are the most common cause of surgical site infection after open fracture [5–10]. There is an increased risk of infection associated with open fractures due to the open communication between environmental contaminants and the fracture site. There are varying rates of infections associated with open fractures depending on the Gustilo-Anderson classification of the open fracture. This classification has guided prophylactic antibiotic coverage in open fractures secondary to high-energy trauma [11]. While there are well-established antibiotic regimens for open fractures secondary to blunt trauma, there are no standard treatment algorithms, to our knowledge, for the type and duration of antibiotic prophylaxis in gunshot-associated fractures [2, 10, 12]. In 2016, a questionnaire was given to the Orthopedic Trauma Association (OTA) members regarding prescribing antibiotics for gunshot-related fractures. 85% of respondents said they prescribe antibiotics for bacteria coverage in gunshot-related fractures. Unsurprisingly, respondents reported that antibiotic use was based on personal preference, educational influence, and fear of litigation [13]. Correspondingly, 70% of the OTA respondents stated that they do not use the Gustilo-Anderson classification to guide their treatment choice in gunshot-related fractures [4]. In a later questionnaire, 69% of the OTA respondents suggested that their institution did not have an established antibiotic protocol for gunshot-associated fractures or were unaware of the respected protocol [4]. However, according to the survey, most clinicians treat gunshot-related gunshot fractures similarly to established principles surrounding blunt trauma-related open fractures. We suggest the inclusion of open gunshot-related fractures in the already established institutional guidelines for blunt trauma related open fractures. This would streamline the treatment protocols and reduce the overall incidence of infections in open fractures secondary to high-impact trauma.

Table 4 Antibiotic breakdown for infected fractures and noninfected fractures

Infectious	N	%	Non-infectious	N	%
Ancef	11	34%	Cefazolin	155	44%
Vancomycin	19	59%	Vancomycin	129	37%
piperacillin / tazo-bactam	3	9%	piperacillin / tazo-bactam	13	4%
Clindamycin	3	9%	Clindamycin	27	8%
Cefepime	15	47%	Cefepime	114	32%

Our results provide insight into the relationship between empiric antibiotics and gunshot-related infections [14, 15]. It has been well established that narrow antibiotic coverage, such as first-generation cephalosporins, have significantly reduced the risk of infection in high-energy open fractures [16, 17]. More recently, broader antibiotic coverage, such as monobactams and glycopeptides, have been recommended [11]. Based on the Gustillo-Anderson classification, many guidelines recommend using narrow-based antibiotics for grade 1 and 2 open fractures and broader gram-negative coverage for grade 3 open fractures secondary to high-impact trauma [17, 18]. The majority of the guidelines recommend the use of intravenous antibiotics with continued administration for two to three days [19]. A recent study by Nguyen et al. reported that a single dose of intravenous antibiotics in their emergency department was associated with a lower infection rate than no antibiotics in soft tissue injuries, (6.1% vs. 25.9%, respectively, $P=0.07$). Furthermore, the study also indicated that multiple doses of antibiotics did not significantly reduce the infection rate compared to a single dose of antibiotics (14.6% vs. 12.5%, respectively, $P=1.00$) [4]. This study suggests that empiric antibiotics could potentially reduce the risk of infection in gunshot-related infections. Due to the high incidence of MRSA and gram-negative infections, our results suggest that empiric MRSA and gram-negative antibiotic coverage should be considered in the setting of gunshot-associated long bone fractures.

As expected, lower extremity fractures had a greater infection incidence than the upper extremity (11.7% vs 3.8% $p<0.01$). These results build on existing evidence suggesting lower extremity fractures have a higher risk of infection than upper extremity fractures [10]. A recent meta-analysis and systematic review, including seven prospective studies, 18 retrospective studies, two randomized control trials, and 6,425 fractures, analyzed the infection rate of upper extremity fractures vs. lower extremity fractures [20]. Consistent with our results, the review revealed that lower extremity fractures had a higher risk of generating an infection (11.8% versus 5.4% (RR 1.94, $p=<0.0001$) [20]. This is relevant because open lower extremity fractures are some of the most common long bone injuries [21]. Our results should be considered when contemplating the empiric treatment of gunshot-associated fractures.

Our overall nonunion rate was 6.5% in all long bone fractures. The nonunion rate was significantly higher in the group that had positive infection cultures (40.6% vs 3.4%, $p<0.001$), independent of the fracture mechanism. These patients also followed up significantly longer due to their complications (348.2 ± 241.4 days vs. 157.7 ± 185.1 days, $P<0.001$). In their retrospective review, Metcalf et al. found that nonunion and infection rates were high in GSWs with large wounds, exposed tibia, and comminution when

compared to blunt injuries. The zone of comminution was significantly higher in our study for those with positive cultures than negative cultures [22–24].

This study is not without limitations. The retrospective nature of this study may bias the results and their interpretation. This can be minimized with high level evidence randomized control trials. In addition, patients were extracted from a single trauma centre who were all treated by different surgeons which limits the external validity of our study as opposed to multi-centre studies. Changes in our institutional ER antibiotic protocols over the years are another external limitation that may impact long term union and infection rates. These are potential confounders, and we recommend future studies take these into account in their statistical analysis.

Fracture grading is an imprecise tool, but highly comminuted lower extremity fractures due to GSWs should have a higher index of suspicion for infection. Our data suggest that antibiotic coverage and operative debridement should be prioritized in patients with lower extremity long bone fractures secondary to a gunshot. Because of the increased incidence of MRSA and gram-negative culture isolates, empiric MRSA and gram-negative antibiotic coverage should be considered in gunshot-associated long bone fractures, especially in lower extremity long bone fractures.

Conclusion

Although there is no definitive inclusion of infectious prophylaxis for open fractures secondary to gunshot wounds within prophylaxis algorithms in various health centers, these injuries are treated similarly to all-cause infectious prophylaxis for open fractures. We would suggest including gunshot wound open fractures within these algorithms to reduce the frequency of infections secondary to these injuries.

Authors' contributions All authors have contributed significantly to all vital and important stages of the manuscript.

Data availability (data transparency) The analyzed data is available and attached to this manuscript.

Code availability (software application or custom code) Not applicable.

Declarations

Ethical approval This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of Baylor College of Medicine approved this study.

Consent for publication Consent to publish was obtained based on our institutional IRB protocol.

Informed consent Informed consent was obtained based on our institutional IRB protocol.

Conflict of interest The authors do not declare any conflict of interest regarding the publication of this manuscript.

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