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Bone Infection after Open Fractures Caused by High-Velocity Gunshots and Ballistics in War-Related Injuries

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ABSTRACT

Introduction: High-velocity gunshot and explosive injuries cause severe open fractures with extensive soft tissue damage and contamination, leading to a high risk of infection. This study aimed to determine the incidence of and risk factors for bone infection in war-related open fractures.

Materials and methods: A retrospective cohort study was conducted at Al Thawra Modern General Teaching Hospital in Yemen from January 2015 to September 2022. The study included 1,034 adult patients who had high-velocity injuries. Data were collected from the medical files of the patients at the hospital's orthopaedic department. For each patient, parameters such as demographic features, time of injury, cause of injury, site and type of injury, time and type of antibiotics administered, characteristics of injury, intervention, surgeon experience, wound status, and need for plastic surgery were collected.

Results: The overall infection rate was 27.7%, with the highest incidence observed in patients with humeral fractures (38.6%) and the lowest in patients with tibial fractures (34%). Airstrikes had the highest infection rate (39%), followed by pump explosions (27.9%) and gunshot wounds (24.1%). Factors significantly associated with an increased risk of infection included the cause of the injury and delayed debridement (>6 hours). Multiple wound debridements, surgical interventions performed by specialists, and early bone coverage were independently associated with a reduction in the incidence of infection.

Conclusion: These results reveal delayed debridement, inadequate experience of the surgeon, and delayed bone coverage are pivotal for increasing infection rates, which highlights the detrimental effects of delayed surgical intervention and surgeon experience.

Keywords:
gunshot wounds, ballistic injuries, open fractures, debridement, infection risk factors

INTRODUCTION

Infection of open fractures caused by war-related injuries, such as high-velocity gunshot wounds (GSW) and explosive injuries, is a serious complication of trauma during warfare. The energy transferred from the bullet usually damages major soft tissues and pulverises bone, causing bacteria and debris to penetrate the wound, thereby increasing the severity of the injury[1]. The incidence of bone infection in war-related injuries is substantial, with reported rates ranging from 2.5% to 25%[2,3,4]. Knowledge about GSW injuries and care has been primarily obtained through experience accumulated during the great conflicts of the twentieth century. Guidelines were drafted at a time when military applications were the primary consideration for high-velocity weapons and deforming bullets, which cause more significant tissue damage. Clinical decision-making is made more difficult by the altered character of domestic GSW injuries brought about by advancements in weaponry technology and the greater availability of military-grade rifles to civilians[5,6].

Even at high-volume trauma hospitals, where GSWs are more common, anecdotal views still play a major role in treatment decisions. There is a frequent misconception that the heat generated when gunpowder ignites during gunshot discharge is enough to sterilise the bullet[7]. Wolf *et al* reported that there is an increasing number of bacteria in ballistic blocks when bullets coated with a small quantity of

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Staphylococcus aureus (S. aureus) are fired into the sterile ballistic blocks. These findings prove that the fired bullets can carry and transfer bacteria, leading to a potential source of infection in gunshot wounds[8]. A GSW results in an open entry tract, so particles and their constituents from the surrounding environment can enter a wound directly, carrying germs and detritus[9]. Notably, many factors make infections more difficult to treat and can exacerbate the problem of antibiotic resistance among wounded patients, such as poor hygiene, misuse of antibiotics, inadequate microbiology labs, and a lack of antibiotic stewardship within health facilities[7,8,10]. In addition, there is a lack of clear consensus on the use of antibiotics in GSWs, which is probably due in part to historical misunderstandings, despite the advancement of knowledge on potential infections[10]. Furthermore, a variety of risk factors, such as high-velocity gunshot wounds and explosive injuries, can lead to the development of bone infection in patients with open fractures. These include the kind of missile, the degree of injury, whether soft tissue damage is present, and the promptness and calibre of the first wound treatment[11,12]. Moreover, systemic conditions, such as diabetes, immunocompromised immune systems, and malnutrition, increase the likelihood of developing a bone infection[13]. Bone infection among affected patients can be disastrous and can result in several surgical procedures, extended hospital stays, and high rates of morbidity and mortality. Additionally, the financial strain of managing the infection is significant, with projected expenses for each patient ranging from $100,000 to more than $1 million[14].

There are few extensive guidelines or large datasets in the literature for managing retained bullets. Merely 14.5% of surgeons who participated in the study from 2022 stated that their institutions had bullet removal protocols[15]. Many medical professionals believe that complete debridement and bullet removal are necessary in every situation. The exact tissue involvement and damage presentation, however, differ greatly and determine the type and extent of intervention. Frequently, formal debridement and bullet removal are not required and can result in further difficulties or tissue damage, such as deep vein thrombosis, infection, and iatrogenic neurovascular injury. Lead intoxication is rare, despite popular perception, unless bullets have settled into synovial fluid or an intervertebral disc[16].

Despite the importance of this problem, more research specifically focused on the incidence of and risk factors for bone infection in open fractures caused by war-related injuries is needed. Most existing studies have investigated the epidemiology of bone infection among general trauma patients, with limited attention given to the unique characteristics of war-related injuries. This knowledge gap hinders the development of effective prevention and treatment strategies tailored to the wounded patient population.

The purpose of this study is to investigate the incidence of and risk factors for bone infection in open fractures caused by high-velocity GSWs and explosive injuries in war-related trauma.

MATERIALS AND METHODS

A retrospective cohort study was conducted at the Orthopaedic and Trauma Department of Al Thawra Modern General Teaching Hospital in Sana'a City, Yemen, a leading referral centre in Yemen with 880 beds. The study period spanned from January 2015 to September 2022. The study population consisted of 1,034 adult patients with war-related high-velocity gunshot and explosive injuries, including airstrikes and pump explosions (see clinical photos no. 1–3). Most of the patients were soldiers who were treated in the same department and hospital according to unified guidelines for the treatment of such cases. The inclusion criteria for the study were as follows: adult patients with war-related injuries such as high-velocity gunshot and ballistic injuries. The exclusion criteria were civilian gunshot wounds, patients referred from other hospitals who had undergone debridement or fixation, patients with isolated soft tissue injuries, and patients with vascular injuries. Data were collected from patient files, operation records, and nursing admission registries. The following variables were studied: time of injury, cause of injury, site and type of injury, time and type of antibiotics administered, time of debridement, orthopaedic intervention, timing of debridement, surgeon experience, wound state after debridement, need for second debridement and plastic surgery, and time to plastic surgery. Data analysis was performed using SPSS software, and the chi-square test of independence was applied to explore the association between infection and the factors affecting it.

Injuries were categorised according to the reported mechanism at the time of admission and verified through clinical assessment[17]. Gunshot wounds are defined as penetrating injuries caused by firearm projectiles and typically present as single-entry wounds, cavitation, and deep penetration[18]. Airstrike injuries are classified by patterns of high-energy polytrauma caused by aerial munitions, including blast overpressure, fragmentation, and blunt trauma. Pump explosion injuries are identified through primary to quaternary blast mechanisms (e.g., shrapnel fragment penetration, blunt impact from blast winds, structural collapse) and shallow, irregular cutaneous wounds[16,19,20].

RESULTS

The study population consisted of 1034 patients. Most patients (90%) were male, with a male (930)–to-female (104) ratio of 9:1. The mean age of the patients was 35.6

Table I: Relationship between various factors and incidence of infection.

Factor	Non-infected	Infected Number	P-value
Cause of Injury			
Gunshot	425 (76.0%)	134 (24.1%)	0.0005
Airstrikes	108 (61.0%)	69 (39.0%)	
Pump Explosion	215 (72.1%)	83 (27.9%)	
Antibiotic Administration			
< 6 hours	388 (85.8%)	64 (14.2%)	0.6108
> 6 hours	493 (84.7%)	89 (15.3%)	
Time of Debridement			
< 6 hours	382 (84.5%)	70 (15.5%)	0.0005
> 6 hours	441 (75.7%)	141 (24.2%)	
Number of Debridement			
One time	435 (64.5%)	239 (35.5%)	<0.00001
Two times and more	313 (86.9%)	47 (13.1%)	
Time of Debridement and Antibiotic Administration			
< 24 hours	566 (59.9%)	378 (40.0%)	<0.00001
> 24 hours	2 (2.2%)	88 (97.8%)	
Surgeon Experience			
Consultant/Specialist	277(87.1%)	41(12.9%)	<0.00001
Resident	471(65.8%)	245(34.2%)	
Timing of Debridement			
8 am morning shift	199(86.5%)	31(13.5%)	<0.00001
16 pm evening shift	549(68.3%)	255(31.7%)	
Type of Injury			
Isolated	559(75.8%)	179(24.3%)	0.00011
Multiple/Polytrauma	189(63.9%)	107(36.2%)	
Time of Bone coverage			
Early <48h	28(63.6%)	16(36.4%)	0.045
Late > 48h	31(43.1%)	41(56.9%)	

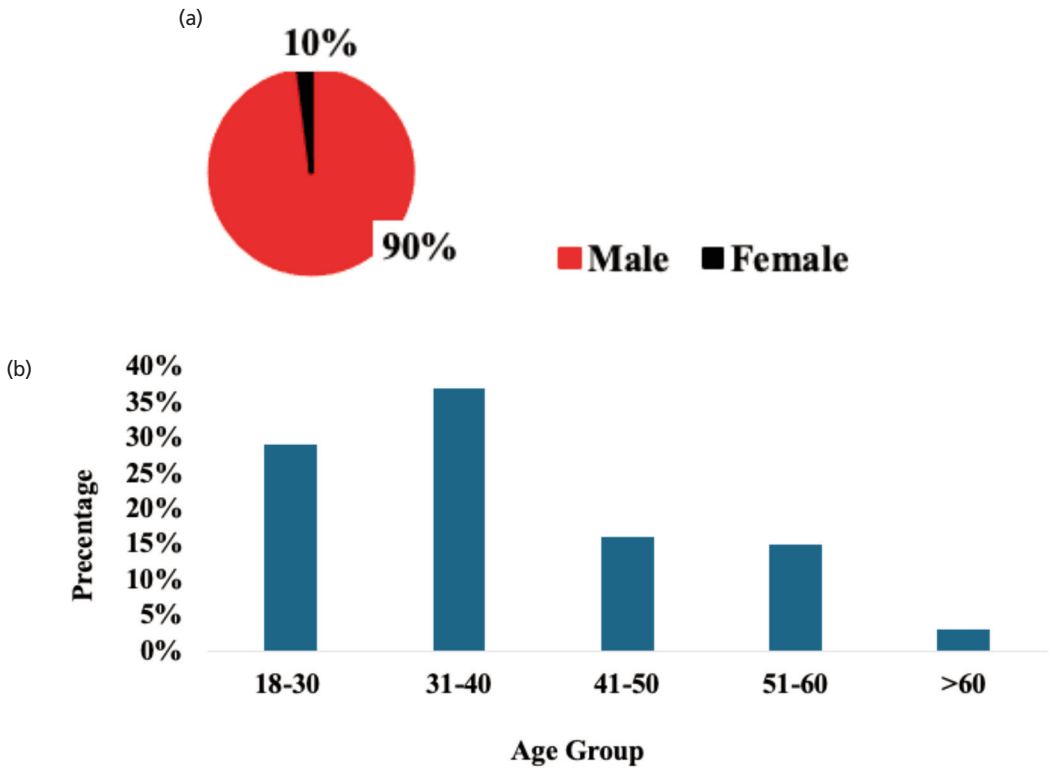

Fig. 1: Demographic profile of patients (a) distribution of participants by gender, (b) distribution of participants by age groups.

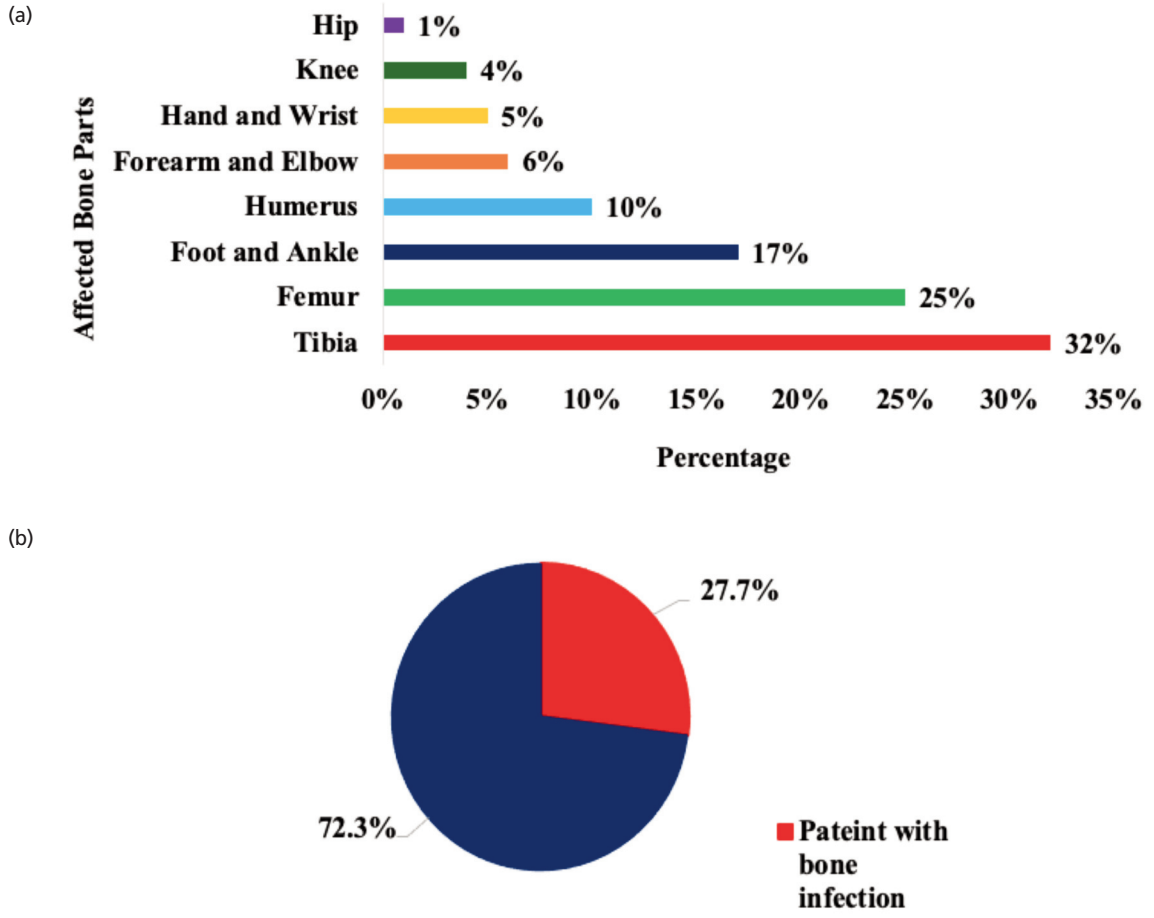

Fig. 2: Affected bone parts of patients and incidence of bone infection. (a) distribution of affected bone parts among patients, (b) incidence of bone infection among patients.

years, and the most affected age group was 31–40 years (37.7%). The most commonly affected bone was the tibia (32%), followed by the femur (25%) and the humerus (10%). The overall infection rate among the patients was 27.7% (286/1034). Most patients (72.3%) did not have an infection (Fig. 1 and Fig. 2). The highest infection rate among the patients, according to the cause of injury, was airstrikes (39%), followed by pump explosions (27.9%) and gunshots (24.1%). The affected bone associated with the highest infection rate among the patients was the humerus (38.6%), followed by the tibia (34%), the femur (26%) and other remaining bones (1.4%).

The present study revealed no significant difference in the infection rate between patients who received antibiotics within 6 hours and those who received antibiotics 6 hours after the time of injury (14.2% vs. 15.3%, $p>0.05$). However, a significant difference in the infection rate was detected between the patients who underwent debridement within 6 hours and those who underwent debridement 6 hours after the time of injury (15.5% vs. 24.2%, $p<0.05$). In addition, there was a significant difference in the infection rate between the patients who underwent a single debridement procedure and those who underwent multiple debridement procedures from the time of injury (35.5% vs. 13.1%, $p<0.05$). Next, a significant difference in the infection rate was detected between the patients who underwent debridement and received antibiotics within 24 hours and the patients who underwent debridement and received antibiotics after 24 hours (40.0% vs. 97.78%, $p<0.05$). Additionally, a significant difference in the infection rate was detected between the patients whose surgery was performed by a consultant or a specialist and the patients whose surgery was performed by an orthopaedic resident (12.9% vs. 34.2%, $p<0.05$). In addition, a significant difference in the infection rate was detected between the patients whose debridement procedure was performed on the morning shift and those whose debridement procedure was performed on an evening shift (13.5% vs. 31.7%, $p<0.05$). Finally, the current study revealed a significant difference in the infection rate between the patients with an isolated injury and the patients who had multiple or polytrauma injuries (24.3% vs. 36.2%, $p<0.05$) (Table I), and a significant difference was found between early coverage of the open fracture via plastic surgery

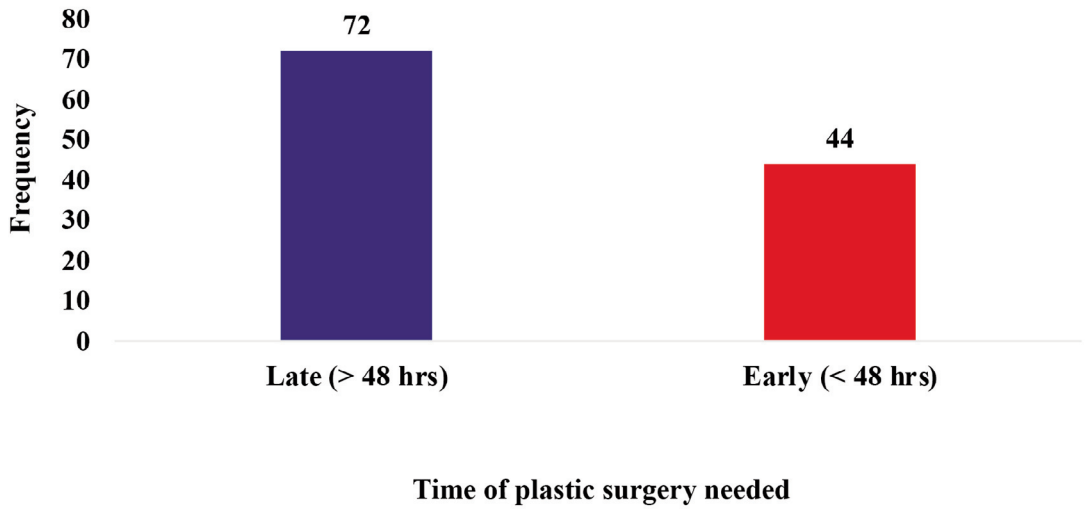

Fig. 3: Early versus Late exposed bone coverage.

procedures within 48 hours and later coverage of the open fracture via plastic surgery after more than 48 hours (36.4% versus 56.9%, $p<0.05$) (Fig. 3).

Various factors influence the incidence of infection in patients with war-related injuries, such as the cause of injury, time of debridement, surgeon experience, and type of injury. Early debridement, antibiotic administration, and bone coverage may reduce the risk of infection in these patients.

DISCUSSION

Close-range injuries are wounds caused by a weapon, especially those involving a firearm or explosion. They are associated with an increased risk of wound contamination and infection, and large-scale tissue loss from high-velocity bullet wounds increases the likelihood of infection. The results of the current study revealed that the overall infection rate caused by the three types of war injuries (gunshot, airstrikes, and pump explosions) was 27.7%. Additionally, the incidence of gunshot wound infection among military trauma patients (46.6%) was higher than the incidence of wound infection reported for civilian trauma patients, with a range of 15.0% – 29.6% reported in some low-income countries[21-30].

The present study revealed that the percentage of males (90%) was greater than the percentage of females, with a mean age of 35.6 years. The most affected age group was 31 – 40 years (37.7%). These findings are consistent with earlier published research, which revealed a percentage of males (98%), with a mean age of 34.8 years and a range of ages from 18 to 66.

The most frequently infected bone was the humerus (38.6%), followed by the tibia (34%) and femur (26%). Among the published scientific studies, there was also a notable similarity in high infection rates. In earlier studies, the infection rates for the tibia, femur, and humerus were 38%, 34%, and 26%, respectively. The advantages of numerous debridements and early bone covering in reducing infection rates were also emphasised in both studies. The current study showed that a significantly association with decreasing the infection rate among patients who had two or more times of debridements. According to the findings of an earlier scientific study, patients who underwent several debridements had a much lower infection rate (13% vs. 35.5%, $p<0.05$)[31]. War-related trauma often results in orthopaedic injuries, which negatively impact a person's health, well-being, and livelihood. However, their scope, treatment, and outcomes in Yemen are poorly understood[32,33]. The management of orthopaedic injuries in war settings poses many challenges for health care providers. These include limited resources, inadequate infrastructure, a lack of trained personnel, frequent infections, delayed presentations, and poor follow-up. Moreover, ongoing violence and insecurity can hamper access to health facilities and the delivery of humanitarian assistance[32,34].

The current study revealed that the incidence of infection varied significantly depending on the cause of injury. Airstrikes had the highest infection rate (39%), followed by pump explosions (27.8%) and Gunshots (24.1%). Low-velocity projectiles, which are typically fired from handguns, generally cause localised tissue damage. In contrast, high-velocity bullets from military-grade rifles are associated with extensive injury, such as comminuted fractures, vascular disruption, and damage to internal organs[35]. Being open, a gunshot fracture is more likely to become infected. For Gustillo type III fractures, the risk of wound infection can reach 50%. This rate increases with increasing fracture severity[36]. When gunshot fractures of the lower extremities were treated with an interlocking nail, Olasinde *et al*

reported an infection incidence of 15%; in contrast, Kaimkhani *et al* and Hutaif et al reported a deep infection rate of 30% in gunshot fractures treated with external fixators/intramedullary nails[28,32,37]. Compared with the rates in these earlier findings, the infection rate among fracture patients in this series was greater. Therefore, it is important to highlight the role of treatment-related factors, particularly the time interval between injury and wound debridement, that might contribute to the relatively elevated infection rates observed in gunshot-related fractures.

The present study revealed that the incidence of infection caused by explosive injuries was 29%. This might indicate that blast waves from explosives can cause severe damage to bone and soft tissues. The severity of the injury depends on the energy of the explosion and the proximity of the victim. Although there is no published paper revealing the incidence of the infection associated with explosive injuries exclusively from Yemen or from nearby countries, we did find only one published scientific paper from Yemen that revealed that explosive injuries had a high incidence rate (70%), followed by gunshot injuries (15%). This finding aligns with the finding that explosive injuries and gunshot wounds were the main causes of injuries among wounded patients, as reported by Amir Khorram-Manesh *et al*[21,38]. There is a lack of information on the incidence of infection with respect to the cause of war-type injuries in the literature. A review of the literature revealed a lack of published scientific papers clearly discussing the relationships between different war injuries and the incidence of wound infection among orthopaedic military patients. This is reflected by the fact that war injuries are mostly severe and complex types of trauma and pose many challenges to study. Our study is the first to discuss the relationship between the type of war injury and the incidence of wound infection among the studied patients. We recommend performing more research on this relationship in the future.

Prior research revealed a significant relationship between increased wound infection rates ($p<0.001$) and surgical debridement performed more than 12 hours after injury. In that research, most of the patients (79.2%) who had gunshot fractures required debridement after the 12-hour mark, which was linked to a noticeably elevated risk of infection[22,29,30]. The importance of prompt debridement is further emphasised by our findings. According to our research, the infection rate increased considerably when debridement was delayed beyond six hours (24.2% vs. 15.5%, $p<0.05$). Although the studies' time thresholds are different (12 hours in the prior research versus 6 hours in this study), both demonstrate the negative effects of postponing surgical intervention on the course of infection. Additionally, the results of the current study revealed that there was a significant association between the combined timing of debridement and antibiotic administration (<24 hours vs. >24 hours) and the incidence of infection. These findings emphasise that the rate of infection increases when surgical debridement of the fracture is performed more than 24 hours after injury. In conflict zones such as Yemen, where the health care infrastructure is often compromised, trauma surgeons typically manage patients who have delayed open fractures, usually accompanied by extensive soft tissue damage and contamination, caused by gunshots, airstrikes, and explosions[38,39]. Although early debridement within 6 hours has historically been advised to reduce infection rates, timely surgical intervention and prompt antibiotic administration are frequently hampered by logistic issues such as delayed patient evacuation, limited medical facility access, and security constraints[32,39,40]. This delay increases the risk of deep infections and associated problems because the best debridement window is missed and the start of antibiotics is considerably delayed. Some published research has shown that the early administration of intravenous antibiotics significantly reduces the incidence of infection among those with open fractures, and ideally, postinjury antibiotics should be given within three hours of injury[39,41,42]. Antimicrobial resistance (AMR) is very high in conflict zones; with each successive conflict, infected pathogens become more resistant, making the management of infections among casualties increasingly challenging[43,44]. War injuries, poor hygiene, misuse of antibiotics, inadequate microbiology labs, and a lack of antibiotic stewardship make infections more difficult to treat and can exacerbate the problem of antibiotic resistance[43]. Multiple open wounds, which are common in war areas, health facilities, or nursing homes, can also result in increasing acquired hospital infections if they are not treated properly[43]. Clinicians are forced to rely on extrapolated data from civilian trauma care, which may not fully address the particular difficulties of war injuries because of a significant lack of established standards regarding the timing, selection, and duration of antibiotic therapy in combat contexts. Evidence-based practices, such as perioperative care bundles, antimicrobial stewardship, infection prevention and control measures, and a focus on prompt antibiotic administration at the point of first medical contact and surgical debridement as soon as possible, regardless of the initial delay, must therefore be tailored to the realities of war zones. These practices can help rationalise the use of antimicrobial agents, stop the increasing incidence of wound infection and the dissemination of resistant bacteria, and enhance the outcomes of wounded patients[43,44]. Prior research in this context revealed that patients frequently received unconventional fracture therapy rather than orthodox orthopaedic care, which frequently led to a delay in informed consent for surgery[45]. It is unclear how many of these things are at play in this situation. Consequently, research to determine all the contributing elements is needed, as a policy intended to lower the risk of wound infections by promoting early surgical intervention in gunshot fracture patients is needed.

There are several limitations of this research that need to be considered when the findings are analysed. First, the retrospective design creates limited possibilities for controlling the collection of data and can lead to selection and information biases. This study was conducted in one referral hospital in Yemen; therefore, its findings may not be generalisable to other settings, especially other regions with different health care systems and practices. Furthermore, the study was based on hospital records that might have records with missing or inconsistent data, especially on prehospital care and the exact time of initial wound management. The variation in acute injury characteristics, management strategies, or surgeon experience might also influence the reliability of the results. Second, the study did not control for variables such as the socioeconomic status of the patients or the different patterns of care that patients may require after being discharged, which could affect the infection outcomes. Finally, as the study focuses solely on high-velocity gunshot injuries, generalisations about other types of trauma or civilian populations cannot be made without a control group. In addition, the results of this study clearly demonstrate the importance of ensuring that surgeons perform debridement within a reasonable time after an individual sustains a high-velocity gunshot wound because the timing of debridement does impact infection rates. It emphasises the need for better protocols and training for quick actions, especially in areas of conflict. The conclusions also emphasise the need for further research to establish standardised, detailed protocols for managing such injuries, such as debridement and the use of antibiotics to enhance treatment outcomes and decrease infection rates, with the goal of applying the findings in military and civilian practice.

CONCLUSION

These results reveal delayed debridement, inadequate experience of the surgeon, and delayed bone coverage are pivotal for increasing infection rates, which aligns with the findings in the literature and highlights the detrimental effects of delayed surgical intervention and surgeon experience. Despite the study's limitations, such as its retrospective nature and single-centre design, the findings contribute valuable knowledge to the field of trauma management. Future research should focus on refining treatment protocols and addressing gaps in care to improve outcomes for patients with high-velocity gunshot injuries, particularly in conflict-affected regions.

CONFLICT OF INTEREST

The authors declare that there are no potential conflicts of interest.

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