Gunshot-induced fractures of the extremities: a review of antibiotic and debridement practices

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Abstract The use of antibiotic prophylaxis and debridement is controversial when treating low- and high-velocity gunshot-induced fractures, and established treatment guidelines are currently unavailable. The purpose of this review was to evaluate the literature for the prophylactic antibiotic and debridement policies for (1) low-velocity gunshot fractures of the extremities, joints, and pelvis and (2) high-velocity gunshot fractures of the extremities. Low-velocity gunshot fractures of the extremities were subcategorized into operative and non-operative cases, whereas low-velocity gunshot fractures of the joints and pelvis were evaluated based on the presence or

absence of concomitant bowel injury. In the absence of surgical necessity for fracture care such as concomitant absence of gross wound contamination, vascular injury, large soft-tissue defect, or associated compartment syndrome, the literature suggests that superficial debridement for low-velocity ballistic fractures with administration of antibiotics is a satisfactory alternative to extensive operative irrigation and debridement. In operative cases or those involving bowel injuries secondary to pelvic fractures, the literature provides support for and against extensive debridement but does suggest the use of intravenous antibiotics. For high-velocity ballistic injuries, the literature points towards the practice of extensive immediate debridement with prophylactic intravenous antibiotics. Our systematic review demonstrates weak evidence for superficial debridement of low-velocity ballistic fractures, extensive debridement for high-velocity ballistic injuries, and antibiotic use for both types of injury. Intra-articular fractures seem to warrant debridement, while pelvic fractures with bowel injury have conflicting evidence for debridement but stronger evidence for antibiotic use. Given a relatively low number of studies on this subject, we recommend that further high-quality research on the debridement and antibiotic use for gunshot-induced fractures of the extremities should be conducted before definitive recommendations and guidelines are developed.

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Introduction

Non-fatal firearm injuries constitute a significant portion of the population's injuries and were estimated to occur 81,396 times in 2012 in the USA, as reported by the latest Centers for

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Disease Control [1]. These injuries are often associated with orthopedic complications such as fracture, compartment syndrome, infection, nerve-palsies, soft-tissue compromise, and lead toxicity given the extent of musculoskeletal involvement. The exact management of these injuries continues to remain a topic of debate. To establish consensus on treatment guidelines for ballistic injuries, we performed a review of current literature.

The purpose of this review is to summarize literature investigating the operative treatment and antibiotic use for ballistic fractures in the orthopedic trauma population. The focus of this review is to address the following:

- (1) Can low-velocity gunshot fractures of the extremities be definitively treated with antibiotics and with only superficial debridement for both operative and non-operative cases?
- (2) Should low-velocity gunshot fractures of the pelvis with associated bowel injuries be definitively treated with antibiotics and with extensive debridement?
- (3) Should high-velocity gunshot fractures of the extremities be treated with extensive debridement and prophylactic antibiotics?

Recommendations based on these findings will provide insight into treating low-velocity (extremities, joints, and pelvis) vs high-velocity gunshot wounds.

Methods: search strategy and inclusion criteria

The 58 articles included for analysis and review [2–38, 39•, 40–59] were identified through a systematic, multi-step process. Eight hundred primary articles describing gunshot-induced fractures of the extremities or pelvis were first identified using PubMed's MeSH term database (Fig. 1, Supplemental Table 1). MeSH terms included gunshot wounds and antibiotic or antibiotic prophylaxis, gunshot wounds of the upper extremity, lower extremity, humerus, radius, ulna, clavicle, carpal bones, metacarpal bones, finger phalanges, scapula, pelvis, femur, tibia, knee, metatarsal bones, tarsal bones, or toe phalanges. A list of all MeSH search terms used with articles found is provided in Supplemental Table 1.

Articles that investigated gunshot-induced injuries to soft tissues, vascular structures, or organs without the presence of extremity or pelvic fractures were excluded. Articles primarily investigating shotgun-induced injuries were excluded as these weapons may be characterized as either low-velocity or high-velocity without consistent identification in the literature. Fractures with axial bone involvement other than the pelvis, such as vertebral or cranial injuries, were also excluded. Only articles of the English language were chosen, and abstracts

without concurrent article publication were excluded due to difficulty in extracting high-quality data from the abstract without concomitant tables that would otherwise be present in the full manuscripts. The bibliographies of the articles meeting inclusion criteria were further investigated to search for additional applicable literature ($n=149$, Fig. 1). All articles underwent a primary screen to determine the applicability of the article to the three central questions of this review, with 241 articles meeting applicability criteria.

A secondary screen of these 241 articles selected only randomized controlled trials, retrospective and prospective cohort studies, case control studies, and case series studies that met, at minimum, the following criteria based on literature recommendations [60•]: high-quality data with patient populations, interventions, follow-up rates, and overall infection and complication rates clearly defined; confounding factors noted; type of operative fixation used if applicable; and methodology on how outcomes and results were collected and analyzed, respectively. Editorial opinions, case reports, and data that did not clearly or explicitly met the aforementioned criteria by not describing debridement and antibiotics protocols in study populations were excluded. Studies that investigated fractures secondary to gunshot wounds in addition to other mechanisms of injury were included if data related to the gunshot fractures were easily discernable. This stepwise screening methodology reduced the number of high-quality, usable references from 800 to 58. A diagram detailing the article selection process is provided in Fig. 1. Each article was further categorized based on the study design per protocols in the literature [61]: level I articles included randomized controlled trials, level II articles included prospective cohort trials, level III articles contained retrospective articles with a control group, and level IV articles contained case series.

Summary tables (Tables 1, 2, 3, 4, and 5) of the literature were created based on those articles (58 total) deemed to have high-quality, usable data. The summary tables contain information on the patient population, intervention used (i.e., antibiotic or debridement policies), study results (i.e., infection or complication rates), level of evidence adapted by orthopaedic literature, and the study authors' recommendations [60•]. The tables are further organized by fracture fixation method with studies investigating non-operative treatments appearing first when applicable. With extractable data from these studies, overall rates of infection and/or complications were calculated when possible if studies analyzed similar outcomes and had similar patient populations following methods previously used in the literature [60•]. Based on these summary tables and analyses, we subsequently provide our recommendations on debridement and antibiotic use as suggested by the literature.

Fig. 1 CONSORT diagram for article selection

Antibiotics in low-velocity, non-operative fractures

Low-velocity ballistic injuries include injuries from firearms with a muzzle velocity less than 2000 ft/s. Most common civilian injuries occur in urban areas, constitute low-velocity injuries, and result from handguns. Table 1 summarizes high-quality data in the literature on prophylactic antibiotic use secondary to low-velocity gunshot fractures: eight studies investigated non-operative management of gunshot-induced fractures [2–9] and 13 studies involved a combination of patients receiving either operative or non-operative treatment (6/13 studies) or all patients receiving operative stabilization of the fracture (7/13 studies) [10–22].

In the appropriate setting, superficial irrigation of the bullet wound without antibiotic administration and operative fixation has been proven to be a viable option [6, 7]. Out of the eight studies involving non-operative management of extremity fractures, 71 fractures were treated without antibiotics [6, 7] and 512 fractures were given some form of antibiotics [2–5, 8, 9]. Infection rates were 2.8 % (2/71) without antibiotics and 2.1 % (11/512) with antibiotics ($p=0.6835$). Data on the 71 fractures not treated with antibiotics were derived from two studies that each consisted of two cohorts: one arm in which patients were administered antibiotics and one arm in which patients did not receive any prophylaxis [6, 7]. In the Howland study [6], 42 patients with extremity fractures were treated of which 34 did not receive antibiotics; in the Dickey study [7]—a prospective randomized controlled trial—73 patients with extremity fractures were investigated of which 37 did not receive antibiotics. Both studies concluded that prophylactic antibiotics are not necessary for non-operative fractures secondary to low-velocity gunshots due to similar rates of infections between the cohorts. Furthermore, Marcus et al's study included a mixture of patients

treated operatively and non-operatively, and within the non-operative group ($n=18$), four patients were not given antibiotics [14]. The overall infection rate was 0 % in the study, prompting the authors to conclude that antibiotics are not necessary.

Multiple studies, however, have suggested that antibiotics should prophylactically be administered in non-operative cases [2–5, 8, 9]. Out of the eight studies in which all patients were treated non-operatively, four studies definitively recommended antibiotic use [2–5], with two additional studies providing no formal recommendations but contained data strongly suggesting the use of antibiotics [8, 9]. In the six studies with mixed operative and non-operative patients, four definitively recommended antibiotic use with one additional study containing data suggesting the use of antibiotics [10–13, 15]. When combining patients in the eight non-operative studies ($n=512$) with the non-operative patients in mixed studies ($n=282$), a total of 794 fractures of the extremities were treated with antibiotics [2–15]. The overall infection rate among this group was 1.8 % (14/794). The majority of studies recommending antibiotics advocate either a brief hospitalization with intravenous antibiotics or a course of oral antibiotics on an outpatient basis [2–5, 10–13]. For example, Dickson and colleagues demonstrated the ability to manage low-velocity, non-operative ballistic fractures in an outpatient setting by prospectively evaluating 41 patients [2]. These patients were administered a single dose of intravenous antibiotics, treated with local wound irrigation, and discharged from the emergency department with a 7-day course of oral antibiotics with only one patient developing a superficial infection (2.8 %) [2]. In contrast, Lenihan and associates investigated 30 patients who were given IV antibiotics for 72 h after presenting with ballistic fractures of the forearm that were cast-immobilized and found no evidence of infection in the entire cohort at follow-up [13].

Table 1 Prophylactic antibiotics in studies with low-velocity GSW fractures

Publication	Patients	Intervention	Results	Recommendations
All non-operative cases				
Dickson 2001 [2] IV (R)	44 ext fx	Cefazolin, cephalixin x7d	Infection rate 2.3 % (1/44)	Abx recommended
Hansraj 1995 [3] III (P)	59 ext fx	Ceftriaxone (IV) vs cefazolin (IV)	Infection rate 0 % (0/31): ceftriaxone 0 % (0/28): cefazolin	Abx recommended
Geissler 1990 [4] III (P)	50 ext fx	IM cephalosporin vs IV cephalosporin x48h	Infection rates 4 % (1/25): cephalosporin 4 % (1/25): IV abx	Abx recommended
Duncan 1974 [5] IV (R)	32 hand fx	Cephalosporin	Infection rate 3.1 % (1/32)	Abx recommended
Howland 1971 [6] III (R)	42 ext fx	Penicillin (IV) vs broad-spectrum vs no abx	Infection rates 0 % (0/18): penicillin 2.9 % (1/34): no abx 12.5 % (1/8): broad-spectrum	Abx not recommended
Dickey 1989 [7] I (P)	73 ext fx	Cefazolin (IV) vs no abx	Infection rates 2.8 % (1/36): cefazolin 2.7 % (1/37): no abx	Abx not recommended
Knapp 1996 [8] I (P)	222 ext fx	Cephapirin, gentamicin (IV) x3d vs ciprofloxacin x3d	Infection rates 1.7 % (2/120): cephapirin 2.0 % (2/102): cipro	None specified
Ryan 1981 [9]	43 femoral fx	Abx (not specified)	Infection rate 2.3 % (1/43)	None specified
Mixed non-operative and operative cases				
Victoroff 1994 [10] IV (R)	24 ext fx 5 op 19 non-op	Parenteral abx x48h	Infection rate 0 %	Abx recommended
Woloszyn 1988 [11] III (R)	132 fx 17 op 115 non-op	IV abx x3d vs cephalixin x7d	Infection rate 0 % (0/80): IV abx, inpt 3.8 % (2/52): cephalixin, outpt	Abx recommended
Brettler 1979 [12] III (R)	83 ext fx 2 op 81 non-op	Cefalotin x3d vs other abx vs no abx	Infection rate 1.3 % (1/79): cefalotin 50 % (1/2): other abx 0 % (0/2): no abx	Abx recommended
Lenihan 1992 [13] IV (R)	37 forearm fx7 op 30 non-op	IV abx x72h	Infection rate 0 % (0/37)	Abx recommended
Marcus 1980 [14] III (R)	44 ext fx 26 op 18 non-op	Penicillin/cephalosporin vs no abx	Infection rate 0 % (0/26): surgery 0 % (0/18): no surgery	Abx not recommended
Elstrom 1978 [15] IV (R)	29 forearm fx 23 non-op	IV cephalothin x72h, cephalexin x3d	Infection rate 0 % (0/29)	None specified
All operative cases				
Hollman 1990 [16] IV (R)	19 femoral fx	Cephalosporin x3d (+) IV abx	Infection rate 5.3 % (1/19)	Abx recommended
Cannada 2009 [17] IV (R)	74 femoral fx	IV abx	Infection rate 2.7 % (2/74)	Abx recommended
Hohmann 2007 [18] III (R)	15 tibial fx	IV cefazolin x3d	Infection rate 6.7 % (1/15)	Abx recommended
Nowotarski 1994 [19] IV (R)	39 femoral fx	IV cephalosporin	Infection rate 2.5 % (1/39)	Abx recommended

Table 1 (continued)

Publication	Patients	Intervention	Results	Recommendations
Wisniewski 1996 [20] II (P)	38 humeral fx	IV abx	Infection rate 21 % (8/38)	Abx recommended
Wiss 1991 [21] IV (R)	56 femoral fx	IV abx	Infection rate 0 % (0/56)	None specified
Levy 1993 [22] IV (R)	32 femoral fx	IV abx	Infection rate 0 % (0/32)	None specified

abx antibiotics, ext extremity, fx fractures, op operative, non-op non-operative, d days, h hours, IV intravenous, IM intramuscular, R retrospective, P prospective

Within the group of studies advocating for antibiotic use, several studies have investigated differences in specific antibiotic use and coverage, and any difference in route of antibiotic administration [3, 4, 6, 8, 11, 12, 15]. Six out of the eight non-operative studies used a cephalosporin antibiotic alone or in combination with other antibiotics [2–5, 7, 8], and four out of six mixed operative and non-operate studies used a cephalosporin antibiotic [11, 12, 14, 15]. Out of 512 (66.7 %), 341 fractures in the eight non-operative studies were treated with a cephalosporin [2–9]. When adding non-operative patients from combined operative and non-operative studies, a total of 555 fractures out of 794 (69.9 %) were treated with a cephalosporin [2–15]. Knapp and colleagues showed equal efficacy between oral ciprofloxacin ($n=102$, 2 infection) and IV cephalosporin plus gentamicin ($n=120$, 2 infections) in extremity gunshot fractures [8]. Hansraj et al. investigated different generations of cephalosporins for greater gram-negative coverage and found no difference between IV cefazolin (first generation, $n=31$, 0 infection) and IV ceftriaxone (third generation, $n=28$, 0 infections) [3]. Geissler et al. demonstrated similar efficacy between intramuscular cephalosporin ($n=25$, 1 infection) and intravenous cephalosporin ($n=25$, 1 infection) in a group of patients with extremity fractures [4].

Antibiotics in low-velocity, operative fractures

Seven studies included patients who were all treated operatively for definitive stabilization of the fracture secondary to a low-velocity gunshot (Table 1) [16–22]. All seven studies involved the use of antibiotics, with five out of seven studies recommending antibiotic use [16–20] and two studies demonstrating low infection rates with antibiotics without any definitive recommendations [21, 22]. In all, 273 fractures were treated with antibiotics resulting in an infection rate of 4.8 % (13/273) [16–22]. The seven studies all involved intravenous antibiotics, with three specifically mentioning use of a cephalosporin [16, 18, 19]. Six out of the seven studies involved lower extremity fractures [16–19, 21, 22], with five specifically focusing on cohort of patients with femoral fractures [16, 17, 19, 21,

22]. Cannada et al's study had the largest cohort, with 74 femoral fractures undergoing retrograde intramedullary nailing and receiving IV antibiotics [17]. Only two patients (2.7 %) developed an infection under this protocol.

Debridement in low-velocity, non-operative fractures

Debridement of necrotic tissue and irrigation of detritus and foreign particles are important steps in treatment of ballistic injuries. Several studies have investigated the need for debridement of low-velocity injuries with an underlying non-operative fracture pattern (Table 2) [2, 4, 6–10, 12, 13, 23–25]. Seven studies specifically described patients who were treated non-operatively for their gunshot-induced fractures and provided details on debridement policies [2, 4, 6–9, 23]. Of these seven studies, three studies employed superficial debridement [2, 7, 9], one study used extensive debridement on all subjects [4], two studies used a mixture of superficial and extensive debridement [6, 23], and one study used no debridement [8]. Interestingly, six out of the seven studies recommended debridement for non-operative gunshot fractures [2, 4, 6, 7, 9, 23]: with four recommending superficial debridement [2, 6, 7, 9] and two recommending extensive debridement [4, 23]. In all, 57 fractures underwent extensive debridement [4, 6], 225 fractures had superficial debridement [2, 6, 7, 9, 23], and 222 fractures had no debridement [8]. Infection rates were 3.5 % (2/57) for extensive debridement, 2.7 % (6/225) for superficial debridement, and 1.8 % (4/222) for no debridement ($p=0.6652$). In terms of mixed studies incorporating operative and non-operative treatment, Marcus et al. conservatively managed 18 patients with non-operative debridement and showed a 0 % infection rate [10], and Woloszyn treated 115 out of 132 fractures non-operatively but with superficial debridement and found a 1.7 % (2/115) infection rate [12]. Out of the five studies that included mixed operative and non-operative patients [10, 12, 13, 24, 25], four recommended superficial debridement [10, 12, 24, 25] with the last study from Brettler et al. advocating for lavage in lieu of formal debridement [13].

Table 2 Debridement in studies with low-velocity GSW fractures

Publication	Patients	Intervention	Results	Recommendations
All non-operative cases				
Geissler 1990 [4] III (P)	50 ext fx	Debridement (extensive)	Infection rate 4 % (2/50)	Debridement recommended (extensive)
Howland 1971 [6] III (R)	72 ext fx	Debridement (superficial vs extensive)	Infection rates 0 % (0/7): extensive 3.1 % (2/65): superficial	Debridement recommended (superficial)
Stromberg 1978 [23] III (R)	41 hand fx	Debridement (superficial vs extensive)	Secondary debridement rate 57.1 % (16/28)	Debridement recommended (extensive)
Dickson 2001 [2] IV (R)	44 ext fx	Debridement (superficial)	Infection rate 2.3 % (1/44)	Debridement recommended (superficial)
Dickey 1989 [7] I (P)	73 ext fx	Debridement (superficial)	Infection rates 2.7 % (2/73)	Debridement recommended (Superficial)
Ryan 1981 [9] IV (R)	43 femoral fx	No debridement vs superficial	Infection rate 2.3 % (1/43)	Debridement recommended (superficial)
Knapp 1996 [8] I (P)	222 ext fx	No debridement	Infection rates 1.8 % (4/222)	No recommendations
Mixed non-operative and operative cases				
Marcus 1980 [10] III (R)	44 ext fx 26 op 18 non-op	Debridement (superficial vs extensive)	Infection rates 0 % (0/26): extensive 0 % (0/18): superficial	Debridement recommended (superficial)
Woloszyn 1988 [12] III (R)	132 ext fx 17 op 115 non-op	Debridement (superficial vs extensive)	Infection rate 0 % (0/17): extensive 1.7 % (2/115): superficial	Debridement recommended (superficial)
Brettler 1979 [13] III (R)	83 lower ext fx 2 op 81 non-op	Debridement vs lavagae	Infection rate 2.4 % (2/82): lavage 0 % (0/1): debridement	No debridement recommended
Joshi 1998 [24] III (R)	14 humeral fx 7 op 7 non-op	Debridement (superficial vs extensive)	Time to union 6 weeks: superficial 9 weeks: extensive	Debridement recommended (superficial)
Chappell 1999 [25] IV (R)	121 hand fx 60 op 56 non-op	Debridement (superficial)	Infection rate 0.8 % (1/121)	Debridement recommended (superficial)
All operative cases				
Rodrigues 2006 [26] IV (R)	11 below elbow fx	Debridement (multiple extensive)	Infection rate 0 % (0/11)	Debridement recommended
Parisien 1981 [27] IV (R)	61 ext fx	Debridement (superficial)	Complication rate 3.3 % (2/61)	Debridement recommended (superficial)
Gonzalez 1993 [28] IV (R)	64 hand fx	Debridement (superficial)	Infection rate 3.1 % (2/65)	Debridement recommended (superficial)
Gonzalez 1998 [29] IV (R)	35 hand fx	Debridement (superficial)	Infection rate 0 % (0/35)	Debridement recommended (superficial)
Hohmann 2007 [18] III (R)	15 tibial fx	Debridement (extensive)	Infection rate 6.7 % (1/15)	Debridement recommended (extensive)
Nowotarski 1994 [19] IV (R)	39 femoral fx	Debridement (superficial)	Infection rate 2.5 % (1/39)	Debridement recommended (superficial)
Wisniewski 1996 [20] II (P)	38 humeral fx	Debridement (superficial)	Infection rate 21 % (8/38)	Debridement recommended (superficial)
Tometta 3rd 1994 [30] IV (R)	36 femoral fx	No debridement	Infection rate 0 % (0/36)	Debridement not recommended
Hollman 1990 [16] IV (R)	19 femoral fx	No debridement	Infection rate 5.3 % (1/19)	Debridement not recommended
Nicholas 1995 [31] IV (R)	14 femoral fx	Debridement (extensive)	Deep infection rate 0 % (0/14)	None specified

Table 2 (continued)

Publication	Patients	Intervention	Results	Recommendations
Wright 1993 [32] IV (R)	18 femoral fx	Debridement (ER: superficial)	Infection rate 0 % (0/18)	None specified
Bergman 1993 [33] IV (R)	65 femoral fax	Debridement (ER: superficial)	Infection rate 3.1 % (2/65)	None specified
Komurcu 2008 [34] III (R)	92 hand fx	Debridement (superficial)	Infection rates 10.5 % (8/92)	None specified
Bach 2006 [35] IV (R)	10 hand fx	Debridement (extensive)	Failure rate 10 % (1/10)	None specified

ext extremity, *fx* fractures, *op* operative, *non-op* non-operative, *R* retrospective, *P* prospective

Debridement in low-velocity, operative fractures

Low-velocity gunshot injuries requiring operative fixation of underlying fractures can present challenges for debridement. Specifically, formal operative and aggressive debridement may be decided upon amidst fear of introducing hardware into potentially contaminated tissue. Despite such concerns, the literature

provides examples of “semi-conservative” treatment, whereby the ballistic fracture is operatively fixed but only superficially debrided with adequate results (Table 2) [18–20, 26–29]. Out of 14 studies that treated all patients operatively for fracture stabilization, eight used superficial debridement [19, 20, 27–29, 32–34], four incorporated extensive debridement in the operating room [18, 26, 31, 35], and two used no debridement as part

Table 3 Debridement and antibiotics in studies with joint and/or pelvic fractures

Publication	Patients	Intervention	Results	Recommendations
Non-hip joint involvement				
Oladipo 1999 [36] IV (R)	13 knee fx	Debridement (arthroscopic)	Infection rate 0 % (0/13)	Debridement recommended (arthroscopic)
Tometta 3rd 1997 [37] IV (R)	33 knee fx	Debridement (arthroscopic)	Infection rate 0 % (0/33)	Debridement recommended (arthroscopic) Abx recommended
Hip fractures +/- abdominal injuries				
Brien 1992 [38] IV (R)	5 hip fx 5 bowel injury	Debridement No antibiotics	Infection rates: 40 % (2/5)	Debridement recommended Abx recommended
Rehman 2011 [39••] III (R)	15 hip fx 2 bowel injury 13 no bowel injury	Debridement vs no debridement	Infection rate 14.3 % (1/7): debridement 0 % (0/8): no debridement	Debridement recommended (if intra-articular)
Najibi 2012 [40] IV (R)	39 acetabular fx 19 bowel injury 20 no bowel injury	Cefazolin vs cefotetan Debridement	Infection rate 0 % (0/20): no bowel inj 21 % (4/19): bowel inj	Debridement recommended Abx recommended
Pelvic fractures +/- abdominal injuries				
Bartkiw 2010 [41] III (R)	42 pelvic/hip fx 15 bowel injury 27 no bowel injury	Debridement (superficial vs extensive) Cefazolin, gentamicin x48h	Infection rate 0 % (0/5): extensive 0 % (0/37): superficial	Debridement recommended Abx recommended
Watters 2011 [42] III (R)	47 pelvic fx 17 bowel injury (7,10) 30 no bowel injury (7, 23)	Extensive debridement vs no debridement	Infection rate 7 % (1/14): debridement 6.1 % (2/33): no debridement	No debridement recommended
Becker 1990 [43] IV (R)	5 pelvic fx 5 bowel injury	Debridement (extensive) Antibiotics (unspecified)	Infection rate 80 % (4/5)	Debridement recommended Abx recommended
Navsaria 2011 [44] III (P)	25 pelvic fx No bowel injury	Cefazolin	Infection rate 12 % (3/25)	Abx recommended
Rehman 2011 [39••] III (R)	50 pelvic fx 50 bowel injury	IV abx	Infection rate 2 % (1/50)	Abx recommended

abx antibiotics, *fx* fractures, *h* hours, *R* retrospective, *P* prospective

Table 4 Debridement in studies with high-velocity GSW fractures

Publication	Patient population	Intervention	Results	Recommendations
All operative cases				
Leffers 1985 [45] IV (R)	8 tibial fx	Debridement (extensive)	Infection rate 75 % (6/8)	Debridement recommended (extensive)
Atesalp 2002 [46] IV (R)	163 ext fx	Debridement (extensive)	Infection rates 47.2 % (77/163)	Debridement recommended (extensive)
Zinman 1997 [47] IV (R)	26 type III fx	Debridement (extensive: multiple)	Infection rate 19.2 % (5/26)	Debridement recommended (extensive)
Dar 2009 [48] III (P)	37 femoral fx	Debridement (extensive)	Infection rate 0 % (0/37)	Debridement recommended (extensive)
Yildiz 2003 [49] IV (R)	13 tibial plafond fx	Debridement (extensive)	Infection rate 46.2 % (6/13)	Debridement recommended (extensive)
Long 2003 [50] II (P)	7 femoral fx	Debridement (extensive)	Infection rate 43 % (3/7)	Debridement recommended (extensive)
Miric 2002 [51] IV (R)	17 femoral fx	Debridement (extensive)	Infection rate 5.9 % (1/17)	Debridement recommended (extensive)
Jorgenson 1995 [52] IV (R)	5 lower ext fx	Debridement (extensive: multiple)	Infection rate (secondary) 0 % (0/5)	Debridement recommended (extensive)
Operative and non-operative cases				
Rowley 1996 [53] IV (R)	200 ext fx	Debridement (extensive)	Successful fixation rate 26 % (52/200)	Debridement recommended (extensive)
Keller 1995 [54] IV (R)	37 humeral fx	Debridement (extensive)	Non-union rate 27 % (10/37)	Debridement recommended (extensive)
Hinsley 2006 [55] IV (R)	21 ext fx	Debridement (extensive)	Infection rate 48 % (10/21)	Debridement recommended (extensive)
Boucree 1995 [56] IV (R)	3 ft fx	Debridement (multiple: extensive)	Secondary infection rates 33 % (1/3)	Debridement recommended (extensive)
Nikolic 1998 [57] IV (R)	29 femoral fx	Debridement (extensive)	Infection rate 47.5 % (19/41): all patients	None specified

ext extremity, fx fractures, R retrospective, P prospective

of the treatment algorithm [16, 30]. In all, 517 fractures comprised these 14 studies, with 50 fractures treated with extensive debridement, 412 treated with superficial debridement, and 105 fractures treated without debridement [16, 18–20, 27–35]. Infection rates for these groups are 4 % (2/50) for extensive debridement, 5.6 % (23/412) for superficial debridement, and 1.8 % for no debridement.

Six of the 14 studies specifically dealt with femoral fractures secondary to low-velocity gunshots [16, 19, 30–33], and debridement policies in these six studies ranged from no debridement [16, 30] to superficial [19, 32–34] and extensive debridement [31]. For example, Wright and colleagues retrospectively investigated 18 patients with femoral fractures who were treated with immediate intramedullary nailing and superficial, preoperative debridement and found a 0 % infection rate [32]. In contrast, Nicholas described 14 femoral fractures that were also treated with immediate intramedullary nailing but instead with extensive debridement and also found a 0 % infection rate [31]. Similar disagreements on debridement policies were seen with hand fractures, which comprised four out of the 14 studies involving operative patients [28, 29, 34, 35].

Specifically, Gonzalez reviewed 49 patients with 64 fractures of the metacarpus that underwent early irrigation and superficial debridement in the emergency room with subsequent definitive internal fixation and bone-grafting 1–7 days later with primary closure of wound [28].

Results showed two superficial infections resolving with oral antibiotics [28]. The authors felt that given the appearance of wounds at the time of definitive fixation and long-term results showing no deep infections, an early non-operative irrigation and debridement were appropriate. Bach et al. treated 10 ballistic metacarpal fractures with extensive debridement instead and subsequent locked intramedullary nailing within 7 days, with no patients developing an infection [35].

Antibiotics and debridement for low-velocity joint and pelvic fractures

Although the majority of examples in the literature dealing with gunshot injuries to joints consist of case reports, the literature does provide agreement for extensive irrigation and debridement

Table 5 Prophylactic antibiotics in studies with high-velocity GSW fractures

Publication	Patients	Intervention	Results	Recommendations
Hinsley 2006 [55] IV (R)	21 ext fx	Benzyl penicillin	Infection rate 48 % (10/21)	Abx recommended
Atesalp 2002 [46] IV (R)	163 ext fx	Cephalosporin + amino x 72 h	Infection rate 47.2 % (77/163)	Abx recommended
Dar 2009 [48] III (P)	37 femoral fx	Cefazolin + amikacin or tobramycin x5d	Infection rate 0 % (0/37)	Abx recommended
Yildiz 2003 [49] IV (R)	13 tibial plafond fx	Parenteral abx x3d	Infection rate 46.2 % (6/13)	Abx recommended
Washington 1995 [58] IV (R)	11 ext. fx	Cefazolin x24h	Infection rates 14 % (5/37); total pts	Abx recommended
Boucree 1995 [56] IV (R)	3 ft fx	IV broad-spectrum abx	Infection rates 33 % (1/3)	Abx recommended
Patzakis 1974 [59] II (P)	78 ext fx	Penicillin + streptomycin vs cephalothin vs non	Infection rates 4.9 % (4/78)	Abx recommended
Long 2003 [50] II (P)	7 femoral fx	Cefazolin or broad spectrum	Infection rate 43 % (3/7)	Abx recommended
Jorgenson 1995 [52] IV (R)	5 lower ext fx	Cefazolin	Infection rate 0 % (0/5)	Abx recommended
Keller 1995 [54] IV (R)	37 humeral fx	Penicillin x5d	Non-union rate 27 % (10/37)	Abx recommended
Zinman 1997 [47] IV (R)	26 type III fx	Penicillin x6h + gentamicin x8h	Infection rate 19.2 % (5/26)	None specified

abx antibiotics, ext extremity, d days, fx fractures, h hours, P prospective, R retrospective

in low-velocity ballistic injuries involving joints, especially in cases with retained intra-articular foreign bodies [36–38, 39•, 40]. Intra-articular debris has potential to develop septic arthritis and lead toxicity [62–69]. Tornetta and Hui arthroscopically evaluated 33 gunshot injuries to the knees and found a 42 % incidence of meniscal damage and 15 % incidence of cartilage damage all in the absence of radiographic evidence [37]. Damage to the articular architecture and the presence of loose bodies have potential to create a shift in weight-bearing dynamics with subsequent acceleration of arthritis. Although rare, systemic lead toxicity can result because synovial fluid acts as a lead solvent leading to non-specific symptoms of fatigue, anemia, headaches, peripheral neuropathy, abdominal pain, and encephalopathy as systemic lead concentrations rise [62–69]. In light of such articular damage, potential for loose bodies, and risks for local infection and systemic plumbism, the literature suggests articular irrigation and debridement [36–38, 39•, 40]. Debridement in these situations can be done using either traditional open or arthroscopic techniques [36, 37]. The two cohort studies by Oladipo et al. [36] and Tornetta et al. [37] demonstrated success in performing arthroscopically assisted debridement of foreign bodies and osteochondral fragments from the knee with no infections following gunshot injuries. Tornetta and Hui further recommended at least 24 to 48 h of intravenous antibiotics following a gunshot wound to a major joint [37].

Injuries to the hip joint and pelvic girdle warrant special evaluation to determine injuries to the surrounding gastrointestinal

tract [38, 39•, 40–44]. When a missile enters the gastrointestinal tract, concerns of adjacent musculoskeletal tissue contamination arise secondary to spilled content [38, 39•, 40–43]. Three high-quality studies investigating fractures of the hip joint—with one study specifically focusing on acetabular fractures—all suggested immediate debridement as treatment protocol [38, 39•, 40]. Two out of the three studies further recommended antibiotics [38, 40]. A total of 49 fractures were reviewed among the three studies, with 26 fractures associated with concomitant bowel injury [38, 39•, 40]. Overall infection rate was 14 % out of these 49 fractures. Brien et al. [38] and Najibi et al. [40] provided infection rates for fractures associated with bowel injury, and higher infection rates resulted (40 % Brien et al., 21 % Najibi et al.) in cases with bowel injury compared to cases without bowel injury (0 % Najibi et al.). Najibi et al. further investigated differences in antibiotics in the presence of bowel injury; all patients without a bowel injury received a first generation cephalosporin, while those with a bowel injury received a third-generation cephalosporin for an unspecified duration [40]. In the non-operatively managed group without bowel injury, no patients developed infections. Among the operative group with bowel injury, results showed that despite irrigation and debridement, four cases of hip septic arthritis developed. Rehman et al. interestingly split patients into two groups: those receiving debridement ($n=7$) vs those who did not ($n=8$) [39•]. Among the debridement group, two patients had associated bowel injury, and one of these patients developed an infection

compared to no infections in the non-debrided, no bowel injury group [39••].

Four additional studies in conjunction with the Rehman study involved fractures through the pelvic girdle [39••, 41–44], with three studies providing information on debridement policies [41–43] and three studies clearly delineating antibiotic policies [39••, 41, 44]. The overall infection rate in these studies was 6.5 % (11/169) [39••, 41–44]. Of these 169 fractures, 87 or 51.4 % were associated with bowel injury. The higher aggregate infection rate in these studies when compared to the lower infection rates in low-velocity gunshot-induced fractures of the extremities further highlights the importance of identifying injuries to the surrounding GI tract. In the three studies providing information on debridement policies, 70 fractures either had superficial or no debridement compared to 24 fractures that underwent extensive debridement [41–43]. All cases of extensive debridement were associated with bowel injury. Infection rates were 2.9 % (2/70) for superficial or no debridement [41, 42] compared to 20.8 % (5/24) for cases that included extensive debridement and concomitant bowel injury [42, 43]. Despite higher infection rates, two out of the three studies recommended debridement for pelvic fractures [41, 43]. Watters et al. did not recommend debridement in their study, which investigated 47 pelvic fractures of which 14 underwent extensive debridement due to bowel injury compared to 33 fractures that did not have debridement [42]. Infection rates in this study were 7 % (1/14) for cases undergoing debridement compared to 6.1 % (2/33) for cases that did not have debridement [42]. Due to statistically similar infection rates, these authors concluded that debridement is not necessary. In terms of antibiotics, all three studies providing information on antibiotics specifically suggested the use of antibiotics for gunshot-induced pelvic fractures [39••, 41, 44]. Forty-two fractures from these studies did not have bowel injury and were treated with either cefazolin or cefazolin with gentamicin, resulting in an infection rate of 7.1 % (3/42) [39••, 41, 44]. A total of 65 pelvic fractures from these studies included concomitant bowel injury, and the overall infection rate was 7.7 % (5/65). No specifics on what type of antibiotic to use were provided.

Author recommendations for low-velocity gunshot wounds

Based on the current state of the literature and the available high-quality data, we believe the literature suggests that in the absence of surgical necessity for fracture care with concomitant absence of gross wound contamination, vascular injury, large soft-tissue defect, or associated compartment syndrome, superficial debridement for low-velocity ballistic fractures is a satisfactory alternative to extensive irrigation and debridement. When the ballistic fracture mandates operative fixation,

we cannot recommend for or against extensive debridement given equally satisfactory outcomes with superficial debridement. Furthermore, we cannot recommend for or against extensive debridement for pelvic or hip fractures associated with bowel injuries given the low number of studies on this topic. Based on the literature, periarticular fractures with joint involvement and injury seem to warrant arthroscopic or open operative debridement to remove joint debris or contamination, but only a handful of high-quality studies were identified to support these claims. Overall, we cannot definitively make recommendations on debridement policies for low-velocity gunshot fractures given the relatively few number of high-quality studies, although the literature suggests the aforementioned trends.

With regard to antibiotic administration for infection prophylaxis, the literature overall suggests low infection rates both for non-operative fractures treated with antibiotics and without antibiotics. However, given the relatively few patients in the aggregate group treated without antibiotics compared to a much larger, aggregate cohort treated with antibiotics, we recommend a short course of oral antibiotics for non-operative fractures. A first generation cephalosporin seems to be an appropriate choice based on the available data. For the treatment of fractures that have concomitant bowel injury, we believe the literature points to the use of broad-spectrum antibiotics for 48 to 72 h. However, given the few studies on this subject, we believe further high-quality studies should be conducted to definitively provide guidelines.

Antibiotics and debridement in operative, high-velocity gunshot wound fractures

High-velocity firearm injuries (muzzle velocity greater than 2000 ft/s) are primarily military injuries although it is not uncommon to increasingly see the use of such weapons in the civilian population. Studies in which low-velocity and high-velocity weapons are fired into soap blocks show the significant temporary cavity that is created with high-velocity weapons [70, 71].

With such extensive cavitation, high-velocity projectiles have a greater propensity to produce infection due to soft-tissue injury [45–49, 72, 73]. These injuries often result in significant damage and are more analogous to open fractures given the amount of traumatized soft tissue [45, 47–49, 52–54, 57]. Consequently, these fractures often require multiple rounds of irrigation and debridement [47, 52, 56]. Upon presentation, these fractures are typically treated according to algorithms associated with the management of open fractures to include extensive debridement and broad-spectrum antibiotic use. Principles of managing high-velocity injuries continue to be through debridement, removal of foreign bodies and devitalized tissues, irrigation, immobilization, and delayed primary closure [45–57]. Despite such protocols, high-velocity ballistic injuries nevertheless have a higher rate of

infectious complications despite debridement and antibiotic administration. For example, Nikolic et al. reported on soldiers who sustained high-velocity ballistic subtrochanteric femur fractures [57]. All patients underwent operative debridement and received intravenous antibiotics for an unspecified amount of time. Seven (17 %) patients developed soft-tissue infections, and six (15 %) patients developed bone infections.

High-quality data regarding debridement practices is lacking when describing the management of high-velocity ballistic fractures (Table 4). The minimal data however does consistently advocate extensive debridement with delayed primary closure [45–56]. Thirteen studies met the inclusion criteria for this review in which debridement policies of high-velocity gunshot wound (GSW) fractures were described [45–57]. Of these, 12 studies recommended extensive debridement for patients presenting with high-velocity GSW fractures [45–56]. These studies incorporated a protocol consisting of extensive debridement—often multiple rounds—with no study opting for superficial or no debridement. Furthermore, all 13 studies included patients who were operatively treated for stabilization of their gunshot-induced fractures, with eight studies consisting only of patients treated by operative means [45–52]. A total of 566 fractures comprised these 13 studies, with an overall infection rate of 41.4 % (109/263) when only including those studies that provided infection rates [45–56]. This infection rate significantly differed ($p=0.0001$) from the overall infection rate for patients who underwent either superficial or extensive debridement for treatment of low-velocity gunshot fractures (9.5 %, 25/262) [26–35, 45–56]. This combination of immediate extensive debridement followed by delayed closure is seen with a variety of fractures caused by high-velocity fractures [45–56]. For example, Hinsley et al. described their experience in the first Gulf War treating gunshot-associated fractures [55]. Of 21 gunshot-associated extremity fractures, 10 (48 %) infections resulted despite operative debridement. Of note, 80 % of wounds that were closed primarily became infected, demonstrating the importance of delayed primary closure of these high-velocity ballistic injuries.

Atesalp et al. described their 10-year results of treating high-velocity ballistic injuries using a protocol that included early debridement with Ilizarov fixation and delayed primary closure [46]. Of 163 extremity fractures, only five (3.1 %) developed osteomyelitis. This method was also demonstrated to be effective for high-velocity gunshot-associated tibial plafond fractures by Yildiz et al. [49], whose protocol consisted of extensive debridement and circular external fixation. There were no cases of osteomyelitis in the 13 patients studied. Two (15 %) developed superficial wound infections that resolved with a 5-day course of oral antibiotics [49].

Relatively fewer studies in the literature provided high-quality data on administration of antibiotics (Table 5). Eleven total studies provided information on antibiotic use,

of which 10 studies ultimately recommended the use of antibiotics [46, 48–50, 52, 54–56, 58, 59]. A total of 353 fractures were identified from these studies that provided antibiotic protocols and subsequent infection rates, and 106 fractures subsequently were infected (30.0 %) despite the use of antibiotics [46–50, 52, 54–56, 58, 59]. All studies again included patients who were operatively treated for fracture stabilization, and the 30.0 % infection rate among these patients differed significantly compared to the infection rate for the low-velocity operative patient population treated with antibiotics (4.8 %, 13/273; $p=0.0001$) [16–22, 46–50, 52, 54–56, 58, 59]. The types of antibiotics used differed among these studies. Due to the infrequent development of gas gangrene, the addition of penicillin is discouraged by the Surgical Infection Society and the Prevention of Combat-Related Infections Guidelines Panel [74]. However, four studies specifically used penicillin by itself or in combination with other antibiotics [47, 54, 55, 59]. For example, Zinmann and colleagues retrospectively reviewed 26 patients with Gustilo type III ballistic humeral fractures undergoing external fixation [47]. All injuries were operatively debrided within 3 h of presentation, and all patients were given IV crystalline penicillin plus gentamicin at admission until wound closure. No cases of osteomyelitis resulted, and five patients developed pin-tract infections (19.2 %) [47]. In contrast, several studies have reported success with a short duration of parenteral antibiotics or cephalosporins [46, 48–50, 52, 58]. For example, Atesalp et al. had succeed treating all patients with an IV first-generation cephalosporin and aminoglycoside for 3 days, reporting only a 3 % (5/163) rate of osteomyelitis [46]. Similarly, Dar and colleagues reported no infections in a prospective study using a protocol of IV cefazolin and amikacin/tobramycin, which were started on admission and were continued for 4–5 days post-operative [48].

Author recommendations for high-velocity gunshot wounds

Based on studies that met our inclusion criteria, we believe the literature suggests extensive debridement for all high-velocity gunshot fractures. However, due to the relatively few studies on this subject and the lack of prospective, randomized controlled trials, we believe further high-quality research should be conducted to fully elucidate debridement policies for high-velocity fractures. In terms of antibiotics, the literature again suggests the use of antibiotics given the high infection rates present in patients. Policies aimed at treating high-velocity GSW fractures seem to mirror treatment algorithms for open fractures, and therefore, antibiotics seem to be favored. However, there are no prospective, randomized controlled trials investigating two cohorts of patients where one group receives antibiotics and one group does not

as seen with the low-velocity gunshot studies. Such a study would really help determine whether antibiotics should be administered prophylactically to all patients presenting with a high-velocity GSW fracture to the extremity. Despite the literature suggesting the use of antibiotics, in light of an absence of high-quality studies, we cannot provide definitive recommendations on antibiotic use.

Conclusion

The data surrounding the management of gunshot-induced extremity fractures remains incomplete. High-quality randomized, controlled trials are needed to establish recommendations and guidelines. Specifically, a prospective trial for extensive versus superficial debridement of bowel-contaminated ballistic fractures is needed. Furthermore, data is limited on sequelae of retained extra-articular bullet fragments in ballistic injuries. Although it is known that high-velocity ballistic injuries have a higher rate of infectious complications, further study is needed to investigate whether serial debridements, placement of antibiotic bead pouches, negative pressure wound vacuums, or other adjuncts can help lower already high infection rates.

Gunshot-induced fractures can significantly tax orthopedic trauma resources and have significant social and economic implications on society, as patients are predominantly male, unemployed, and uninsured [75–77]. Treatment costs for ballistic fractures have risen faster than the medical care inflation rate by a factor of 300 % [75–77]. As such, the efficient use of orthopedic resources is increasingly important considering that the incidence of gunshot fractures in the USA is increasing. Further, high-quality research on the topics of debridement and antibiotic use for gunshot-induced fractures will help develop evidence-based guidelines focusing on patient-centered care in cost-effective manner.

Compliance with ethics guidelines

Conflict of interest Vasanth Sathiyakumar, Rachel V. Thakore, Daniel J Stinner, James R. Ficke, and Manish K. Sethi declare that they have no conflict of interest.

William T. Obremskey has previously consulted for biometrics, provided expert testimony in legal matters, and had a grant from the Department of Defense.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Human studies done by authors (but no animal studies) This article does not contain any studies with animal subjects performed by any of the authors. With regard to the authors' research cited in this paper, all procedures were followed in accordance with the ethical standards of the

responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Animal studies done by authors (but no human studies) This article does not contain any studies with human subjects performed by any of the authors.

With regard to the authors' research cited in this paper, all institutional and national guidelines for the care and use of laboratory animals were followed.

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- Of importance
- Of major importance

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