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Management of upper extremity war injuries in the subacute period: A review of 62 cases

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A R T I C L E I N F O

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A B S T R A C T

Objective: In this study, we aimed to describe the relationship between the localization of rarely seen upper extremity war injuries and their complications in the subacute period, and define our preferences for surgery and antibiotic use.

Methods: Patients with an upper extremity war injury who presented to our institution between 2015 and 2018 were retrospectively evaluated. Data regarding demographics, time between injury and presentation, location of injury, type of damage, complications, treatment methods, infection rates and antibiotic use were recorded. Tissue defects, fracture fixation, neurovascular damage, infection development and treatment approaches were analyzed.

Results: Sixty-two male patients with isolated upper extremity injuries (mean age: 31.66 ± 8.28 years) were included in the study. The average time between trauma and hospitalization was 14 days. The mean hematocrit (Hct) level at presentation was 36.3 ± 6.8%. Patients had been followed up for an average period of 95.6 ± 32.1 days. Twenty-nine patients (46.8%) had nerve injury, eight (12.9%) had arterial injury that required repair, and 23 had infection (37.1%), of which five developed osteomyelitis. Infection was polymicrobial in nine cases and monobacterial in 14. A positive correlation was found between the presence of fracture and nerve injury ($p = 0.013$). The frequency of nerve injuries due to gunshot wounds was higher in the mid-section and lower part of the arms and in the proximal forearm when compared to other regions ($p = 0.011$). The infection rates were significantly higher in patients with fractures ($p = 0.033$). The mean hematocrit (Hct) level at presentation of the patients with infection (32.1 ± 6.3%) was significantly lower than that of those who did not have infection (38.8 ± 5.9%) ($p<0.001$).

Conclusion: Upper extremity war injuries require case-specific solutions. Microbiological samples should be taken prior to empirical antibiotic treatment for infection management and rational antibiotic use principles should be applied according to the culture and antibiogram results. The holistic and ambiguous character of nerve injuries often requires early exploration and combined reconstructive interventions. Arterial injuries can be overlooked by physical examination alone and thus routine angiography should be performed. Completion of the bone and soft tissue reconstructions in the same session using a holistic approach minimizes the possible risks.

Introduction

Gunshot wounds (GSWs) are an important cause of morbidity and result in serious socioeconomic problems [1,2]. High-energy injuries (HEIs) are caused by heavier weapons (military rifles) in

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war areas and create tissue damage over a large area with shock waves and cavitation mechanisms [3–5]. The wound is often contaminated with foreign materials such as fabric, soil, stones, bullets and shrapnel [6,7].

Studies on upper extremity GSWs are very few in the literature [8]. These injuries are complex due to their proximity to neurovascular structures and the concurrent involvement of tissue types with different functionalities (tendon, bone or nerve) require complex and meticulously planned treatments [5,9]. A consensus is still unavailable on the gold standard of antibiotic use and debridement policies for HEIs [10].

The first intervention to upper extremity war injuries is usually performed in peripheral hospitals under suboptimal conditions. The objective of the initial stages is to perform wound care by providing hemodynamics and immobilization of the fracture. Cases are often transferred to advanced centers for complicated wound management, definitive fracture treatment and advanced neurovascular interventions. The approach to these cases in the subacute period is problematic and open to complications [7].

In this study, we aimed to describe the relationship between the localization of rarely seen upper extremity war injuries and their complications in the subacute period, and define our preferences for surgery and antibiotic use.

Patients and methods

Our study was approved by our institution's ethics committee (date: May 11, 2020 and no: 2020/04-05). Adult cases (average age: 31.66 ± 8.28 years, range: 20 to 50 years) admitted to our center due to a war injury between 2015 and 2018 were retrospectively evaluated. Patients with isolated upper extremity injuries were included in the study. Cases with GSWs in different parts of the body were excluded due to possible complications and the necessity of changing antibiotic regimens. Included patients underwent their first interventions after injury in neighboring countries and were transferred to our hospital for a secondary intervention after stabilization. Data regarding demographics, time between injury and presentation, location of injury, type of damage, complications, treatment methods, infection rates and antibiotic use were recorded.

Due to the complex nature of the injury pattern, all cases were evaluated by a team of trauma surgeons, reconstructive surgeons and infectious diseases specialists, and we tried to produce case-specific solutions using a holistic approach.

For the purpose of this study, the upper extremity was defined as the area from the humeral head to the tip of the finger. The arm and the forearm were divided into three equal parts and defined as proximal, middle and distal locations.

Injuries were addressed under three different headings; soft tissue injuries, fractures and amputation. Soft tissue injuries consisted of superficial lacerations, contusions, hematoma formations and tissue defects (Fig. 1). General evaluation and circulatory and nerve examinations of the extremity were performed. During the first dressing, the wound was washed with saline under polyclinic conditions, superficial debridement was performed under local anesthesia and a sample was taken for culture. The patient was taken into surgery in the shortest time possible and necrotic soft tissue, bone particles and foreign material were removed while preserving tendons, nerves and arterial structures. All foreign materials, specifically in shrapnel and shotgun injuries, could not be removed in all cases. Extirpation was performed under fluoroscopy for less severe soft tissue damage.

On the first day, hemogram C-reactive protein (CRP) and routine biochemistry tests were conducted. Anti-staphylococcal antibiotic treatment for skin flora bacteria was initiated in all cases. For simple injuries, only 1 g of cefazolin sodium was given 3 times a day, whereas in severe injuries with tissue defects, fractures or vascular nerve damage or with peripheral signs of contamination, 1 g of cefazolin sodium, 160 mg of gentamycin and 500 mg of ornidazole were given 3 times a day, once a day and 2 times a day, respectively, for antibiotherapy. The wound was closed with wet dressing. Patients were kept under close supervision for findings of infection. Blood transfusion was performed when necessary. Liver and kidney functions were checked on a weekly basis.

Considering the possible presence of polymicrobial infection accompanied by microorganisms due to peripheral contamination other than skin flora bacteria, microbiological cultures including perioperative pus, sinus tract material and soft tissue and wound cultures were taken from the patients who showed symptoms of infection. Aerobic and anaerobic blood cultures were also taken for bacteremia and sepsis, especially from patients with fever. Antibiotherapy was rearranged according to the antibiotic susceptibility test results of microorganisms producing as a result of culture. Debridements were repeated until a healthy wound bed was obtained. Vacuum-assisted wound closure was performed in cases with large, exudative wounds, or wounds that required multiple debridement, whereas flap surgery was performed in wounds that could not be closed primarily. Depending on the size of the defect, the vitality of the soft tissue adjacent to the injury, and the presence of a broken bone exposure, defects were covered with local fasciocutaneous flaps, free flaps or muscle flaps.

In nerve injuries, neurolysis, primary nerve repair, nerve graft application, nerve and tendon transfers were performed after routine early period exploration, depending on whether the nerve integrity was preserved, the presence of nerve defects and the level of injury. Computed tomography angiography was performed for both the detection of vascular damage and the cases that would require a flap afterwards even in the event that distal pulses were present. Vascular injuries were repaired with primary or vascular grafting.

Systemic fever was considered to indicate infection in the presence of signs of inflammation, such as an increase in acute phase reactants and/or redness in the injury site or purulent discharge. Patients were examined for soft tissue infection, abscess, presence of osteomyelitis, concomitant bacteremia and possible sepsis.

In the majority of the cases, a plaster splint, an external fixator or temporary osteosynthesis using intramedullary K-wires were applied in another center prior to admission to our center (Fig. 2). Following clinical evaluation, re-osteosynthesis was performed in patients with displaced or shortened fractures, double fractures of the forearm, neurovascular injuries, and in cases where osteosynthesis was believed to be not rigid. In infected cases, permanent osteosynthesis was performed at least 20 days after repeated debridements when no signs of infection were found in the clinical and laboratory parameters. In cases with an external fixator and where primary fixation materials were removed after debridements, permanent osteosynthesis was performed using intramedullary nails, plates and screws, screws or K-wires after a one week waiting period (Fig. 3).

When planning the postoperative treatment regimen, the revascularization of the bone, presence of residual infected bone or soft tissue, need for debridement and revision surgery and the type and virulence of the microorganism in the culture taken in the perioperative culture and its antibiotic susceptibility pattern were taken into consideration. Parenteral antibiotics with high penetration rates into the bone were preferred.

Data obtained during the retrospective evaluation were used in statistical analyzes conducted using SPSS v.17.0 software. Histogram graphics and the Kolmogorov-Smirnov test were used to determine whether the variables showed normal distribution. While presenting descriptive analyzes, mean, standard deviation, and median values were used. Categorical variables were compared using

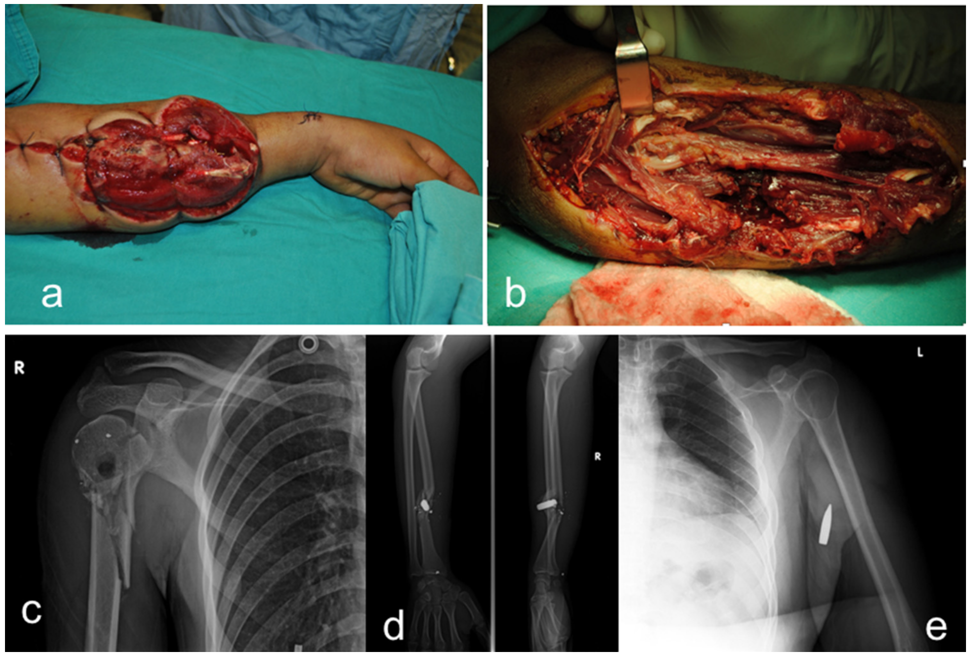

Fig. 1. (a) Segmental defective injury at the forearm level. (b) Segmental defective injury of the elbow and forearm. (c) Segmental fracture of the proximal humerus and entry point of the bullet. (d) Segmental bone fracture and appearance of the shrapnel fragment in the bone. (e) Gunshot wound in the axillary region.

Fig. 2. Gunshot wound cases treated with splints and external fixators.

the Pearson's chi-square test. When variables that were not normally distributed (nonparametric) were evaluated using the Mann-Whitney *U* test. *p* values below 0.05 were considered statistically significant.

Results

Sixty-two patients with isolated war injuries of the upper extremity who were admitted to our hospital in the subacute period were included in the study. All of the cases were male and approximately 80% were between the ages of 20 and 40 years. The average time between trauma and hospitalization was 14 days (range: 2 to 90 days). Fifty-one cases (82.3%) applied to our clinic three days or longer after injury. At presentation, the mean hematocrit level was 36.3 ± 6.8%, the average duration of antibiotic use was 8.6 ± 14.3 days and the average number of broken bones was 0.8 ± 0.6. According to the type of injury, 71% of the cases had fractures, 24% had soft tissue injuries and 5% had finger amputations. The mean follow-up time was 95.6 ± 32.1 days (range: 33 to 180 days).

There were a total of 52 fractures in 44 cases; eight cases had double fractures of the forearm (proximal in five cases, middle diaphysis in three cases), eight had fractures of the lower end of the humerus, five had humeral diaphyseal fractures, four had distal radius fractures, four had ulnar diaphyseal fractures, four had metacarpal fractures, three had fractures of the proximal ulna, three had radial diaphyseal fractures, two had distal fractures, two had phalangeal fractures and one case had an isolated radial proximal fracture.

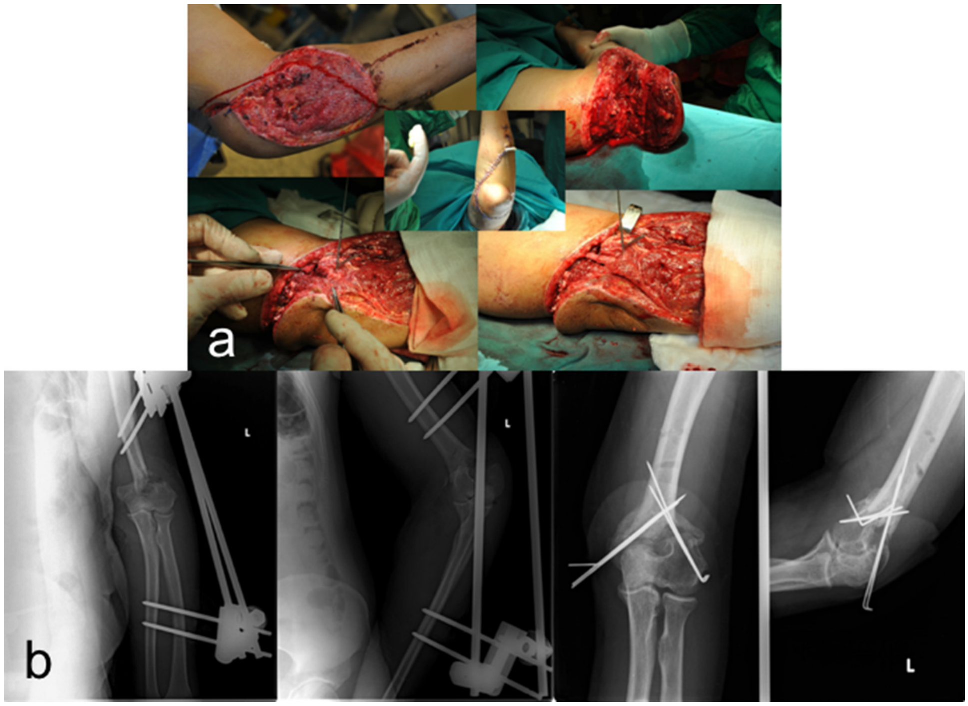

Fig. 3. (a) Wide soft tissue defect around the elbow. Wound dressing with fasciocutaneous flap after debridement. (b) Minimally invasive osteosynthesis performed using K-wires following the removal of the external fixator.

While three fractures (6.8% of the cases) were followed conservatively with plaster or splints, 25 fractures (56.8% of the cases) were treated with plates and screws, eight (18.2% of the cases) with K-wires, two (4.5% of the cases) with external fixators, two (4.5% of the cases) with intramedullary nails, two segmental defective wrist fractures (4.5% of the cases) with arthrodesis plate, one (2.3% of the cases) with the Zuggurtung (tension-band wiring) technique and one (2.3% of the cases) with headless cannulated screw. Ballistic extirpation was performed in 28 cases (45.2%).

Nerve injuries were detected in 29 cases (46.8%). The most frequently injured nerve was the ulnar nerve ($n = 12$) followed by the radial nerve ($n = 11$). The median nerve was damaged in four and brachial plexus in two. Although six patients had motor and sensory deficits, nerve continuity was detected and neurolysis was performed. The remaining patients had disrupted nerve continuity. Repair was performed with primary or nerve graft.

In five cases with high-level radial nerve lesions, after nerve grafting, two patients underwent primary tendon transfer from the pronator teres muscle to the extensor carpi radialis brevis (ECRB) muscle for internal splinting, while three patients underwent secondary tendon transfer due to wound problems. The transfer of the branch of the radial nerve to the ECRB muscle to the anterior interosseous nerve was performed in two patients with anterior interosseous nerve injury due to high-level median nerve injury. The motor branch of the ulnar nerve to the first web was transferred to the thenar motor branch in one patient. In two patients with high-level of ulnar nerve injuries, the branch of the anterior interosseous nerve to the pronator quadratus was transferred to the motor branch of the ulnar nerve using the end-to-side technique with the purpose of supercharge.

Arterial injury presented in the early period (first 10 days) and required repair in eight cases (12.9%). Three cases had brachial, two had radial, two had ulnar, and one had axillary artery injuries. All arterial injuries were repaired primarily or using vascular grafts.

Infection was detected in 23 cases (37.1%), five of which developed osteomyelitis.

Table 1
The relationship between nervous and vascular damage and the presence of fracture.

		Fracture				p*
		Absent		*Present*		
		n	%	n	%	
Nerve	*Absent*	14	42.4	19	57.6	0.013
	Present	4	13.8	25	86.2	
Vascular	*Absent*	17	31.5	37	68.5	0.269
	Present	1	12.5	7	87.5	

* Chi-square testSignificant p values are written in bold.

Wrist arthrodesis was performed in a patient with severe injury at the wrist level in addition to tendon transfer due to extensor tendon defect (flexor carpi radialis-extensor indicis proprius, extensor digitorum communis, extensor digiti minimi and palmaris longus - extensor pollicis longus tendon transfer). Two-stage tendon transfer was performed using a silicone tendon prosthesis in two patients with flexor digitorum profundus injuries.

In four cases with wide tissue defects (3 to 20 cm^2) local fasciocutaneous transposition flaps were used, while free flaps were used in two and muscle flaps in two other cases for wound closure.

A positive correlation was found between the presence of fracture and nerve injury ($p = 0.013$), whereas no correlation was detected between the presence of fracture and arterial injury (Table 1).

The frequency of nerve injuries due to GSWs was higher in the mid-section and lower part of the arm and the proximal forearm compared to other regions ($p = 0.011$). No relationship was detected between vascular injury frequency and injury site (Table 2).

The infection rates were higher in patients with fracture. No correlation was found between nerve and artery injury and infection development ($p = 0.033$) (Table 3).

In patients with infection, the mean Hct value at presentation (32.1 ± 6.3%) was lower than that in those without infection

Table 2
Nervous and vascular damage according to the site of injury.

		Region														p*
		Proximal arm		Middle arm		Distal arm		Proximal forearm		Middle forearm		Distal forearm		Hand		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	
Nerve	*Absent*	2	50.0	2	33.3	3	27.3	3	23.1	8	72.7	5	71.4	10	100	0.011
	Present	2	50.0	4	66.7	8	72.7	10	76.9	3	27.3	2	28.6	0	0	
Vascular	*Absent*	3	75.0	6	100	8	72.7	11	84.6	10	90.9	6	85.7	10	100	0.501
	Present	1	25.0	0	0	3	27.3	2	15.4	1	9.1	1	14.3	0	0	

* Chi-square testSignificant p values are written in bold.

Table 3
Relationship of fracture, nervous and vascular damage with infection.

		Infection				p
		Absent		*Present*		
		n	%	n	%	
Fracture	*Absent*	15	83.3	3	16.7	0.033*
	Present	24	54.5	20	45.5	
Nerve	*Absent*	20	60.6	13	39.4	0.689*
	Present	19	65.5	10	34.5	
Vascular	*Absent*	34	62.9	20	37.1	0.979†
	Present	5	62.5	3	37.5	

* Chi-square test
† Fisher's exact testSignificant p values are written in bold.

Table 4
Correlation between vascular injury and nerve injury.

		Vascular				p*
		Absent		*Present*		
		n	%	n	%	
Nerve	*Absent*	32	52.8	1	11.1	0.013
	Present	22	47.2	7	88.9	

* Fisher's exact testSignificant p values are written in bold.

Table 5
Distribution of microorganisms.

Distribution of microorganisms	(n)
Presence of microbiological reproduction	23
Polymicrobial	9
Monobacterial	14
Type of microorganism	
Gram-negative bacteria	
P. aeruginosa	8
E. cloacae	7
E. coli	4
A. baumannii	4
P. mirabilis	1
P. rettgeri	1
S. marcencens	1
E. gallinarum	1
P. stutzeri	1
P. stuartii	1
Gram-positive bacteria	
MSSA*	3
MRSA†	2
Bacillus spp.	2
MRCNS	2
E. faecium	1
E. faecalis	1
S. constellatus	1
MRCNS‡	1

* MSSA; methicillin-sensitive S. aureus
† MRSA: methicillin-resistant S. aureus
‡ MRCNS: methicillin-resistant coagulase negative staphylococci

(38.8 ± 5.9%) ($p<0.001$). A close correlation was found between artery injury and nerve injury ($p = 0.013$) (Table 4). Nine patients had polymicrobial reproduction. The most reproducing microorganism family were the *Enterobacteriaceae* group, followed by the *Pseudomonas* and *Staphylococci* groups (Table 5).

Discussion

To our knowledge there is limited information in the literature describing injury patterns, rates of neurovascular injury and early postoperative infection in war injuries of the upper extremities in

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the subacute period. Approximately 40% of war injuries affect the extremities [11]. Upper extremity GSWs is an important source of morbidity and poses serious difficulties in reconstructive surgeries [3,12]. Often, surgeons in war conditions have to deal with highly contaminated wounds and limited resources [13]. Acute cases hold some differences when compared to subacute cases, such as the uncertainties during the first interventions to the cases, the presence of frequently contaminated infected wounds, challenges in tracking due to the fact that the cases are usually treated in other centers and its effects on surgical indications.

After a GSW, debridement of the wound with low pressure and surgical scrub is recommended. Preservation of the healthy tissues and avoidance of excessive debridement during the first debridement and between the 24^{th} and 48^{th} hours of evaluation of the borderline tissues for necrosis are recommended [14,15]. In an GSW, the wound should be carefully examined as it may be wider than it appears [3]. It has been reported that wounds in both the subacute and acute periods can be transformed into clean wounds through multiple debridements [16,17]. Negative pressure wound dressing systems prior to permanent wound closure provide closure and drainage, increase the blood flow, reduce tissue edema and reduces the wound size by stimulating the formation of granulation tissue [18,19]. Due to possible complications, primary wound closure should be avoided in HEIs, no matter how clean the wound is or how early the patient presented [20]. The wound may be left to heal primarily or may be closed secondarily in the first week. If the defect is large, it is recommended that additional procedures for closure should not be delayed in order to prevent colonization in the wound [21]. In HEIs, primary severe soft tissue losses or losses secondary to debridement increase the need for vascularized flaps [22]. If covering the bone in an open fracture is problematic, using muscle flaps instead of skin flaps in covering is more appropriate. Doing so contributes to the blood supply to the bone, thus the fracture unites better and the cavitary defects in the soft tissue are filled. Moreover, the bacterial resistance of muscle flaps is higher than fasciocutaneous flaps; they also positively affect antibiotic penetration into the tissue as they increase the blood supply to the tissue [23–25].

In our study, repeated debridements were performed depending on the condition of the wound. An average of three (range: 2 to 7) debridements were performed and negative pressure wound system was used in 11 cases. In four cases with tissue defects in which the bone was not exposed, closure could be achieved using local fasciocutaneous transposition flaps in four cases and using free flaps (anterolateral thigh flap) in two cases. Free flap was used in one and pedicled latissimus dorsi flap in another case with bone exposure.

As the liveliness of the area adjacent to the soft tissue defect is more affected in war injuries than other types of injuries, this region should be evaluated carefully before coverage. It should not be forgotten that a distant free flap may be needed if the extremity is widely affected [26].

Tendon repairs should be done in the early period after infection control. If there is a primary defect in the tendon or secondary defect after infection and repeating debridements, grafts from the palmaris longus, plantaris or tensor fascia lata can be utilized. If the possibility of adhesion is likely, silicon prostheses can be used in both extensor and flexor tendon injuries [19]. In our study, flexor tendon transfer was performed in one case with extensor tendon loss at the wrist level. In two cases with a deep flexor defect, a tendon sheath was created using a silicon prosthesis and then reconstruction was performed with a tendon graft.

If the metal article is located intraarticularly or in the adjacency of a vein or nerve, ballistic extirpation and through surgery are recommended as a part of debridement [12,27,28]. In our study, ballistic extirpation was added to debridement in approximately half of the cases. Extirpation of all foreign bodies was not possible as extirpation of all parts was difficult to obtain and ran the risk of causing soft tissue damage, especially in shrapnel and shotgun injuries. During the follow-up period, foreign bodies that became superficial due to regressed edema and swelling or migration, and could be felt under the skin by hand were extracted under local conditions. It should not be forgotten that foreign bodies may be sometimes hidden in important structures in GSWs with a large number of foreign bodies in particular and attempts to remove each foreign body may harm the patient. Therefore, attempt should be made only on those that can be safely removed. Although there is an effect of the presence of a foreign body on the development of infection in the early stages of the patients, this effect decreases in later periods.

Nerve tissue is very sensitive to GSWs because of its own plasticity. Pathologies ranging from neurapraxia to neurometesis can be seen in such cases [29]. In our study, the ulnar and radial nerves were frequently affected (Fig. 4). Mehta et al. detected nerve injury in all high-energy GSW cases ($n = 6$) [30], while we observed nerve injury in 46.8% of our cases. Engelmann et al. reported a 43.1% nerve injury rate after upper extremity civilian GSWs [31]. However, both studies included fracture cases only. In our study, a close relationship was found between nerve injury and the presence of fractures. Similarly, the proximal forearm, where the nerve's course remained close to the bone, was the location with the most frequent neurological injuries in our study [30].

Although peripheral nerve damage following GSW presents an uncertain clinical picture, defective damage in which nerve integrity is impaired occurs in war injuries [29,32]. In these injuries, the need for nerve grafts is high [33]. Irreversible changes may occur in the muscle motor unit during the course of anticipation of a spontaneous remission. Siemionow et al. questioned whether repair in nerve damage cases should be postponed until six months after injury and found that delays are ineffective in cases where nerve integrity is impaired [34]. In an experimental rat model, it has been reported that the number of Schwann cells decrease in pre-repair delays exceeding three months and that degeneration develops in Schwann cells and motor end plate between 18 to 24 months [35]. Early nerve exploration has some advantages, such as easy identification of the nerve without developing scar tissue, achieving decompression by performing neurolysis and allowing for repair with primary or short grafts since the nerve is not retracted [36,37]. Sural nerve graft is the gold standard with the advantage of length it provides in defective nerve injuries [38].

Due to possible functional losses, we recommend routine early nerve exploration in GSW fractures of the humerus or the forearm. In cases with no deterioration in nerve integrity, neurolysis was performed to regress the edema. Primary repair was preferred if there was disruption in the integrity, soft tissue loosening or approaching the nerve endings by transposition in case of a defect, or nerve graft if there was still a gap (Fig. 5). In ulnar nerve injuries at the elbow level, nerve endings were comfortably opposed to each other via nerve anterior transposition, and in two cases with partial injury, total excision of the nerve tissue affected by blast effect and primary neurorrhaphy were performed. In partial nerve injuries, in cases where damage due to the blast effect is observed in the section that exhibited continuity and there is a chance to perform primary neurorrhaphy, removing the damaged part completely and performing primary neurorrhaphy may be preferred.

In proximal-level nerve injuries of the upper extremity, sensory functions returns in the early term after nerve repair with sural graft. However, since the process of motor return is late and uncertain (due to the long reinnervation distance), we added nerve or tendon transfer to the treatment in these cases. Mathieu et al. stated that due to the indeterminate and variable healing pattern of nerve injuries of war and their irregular follow-up, nerve

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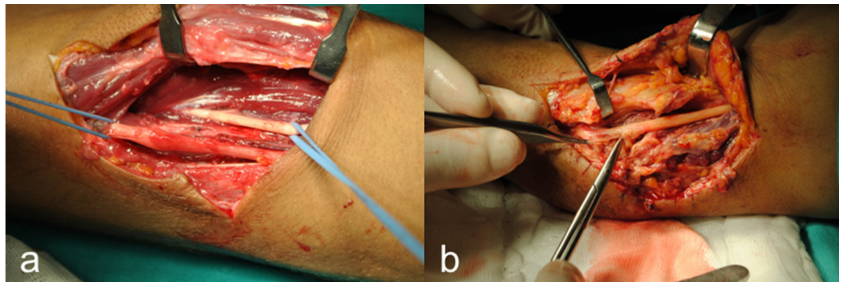

Fig. 4. (a) Normal appearance of the median nerve of the forearm and neurapraxia of the ulnar nerve. (b) Appearance of the partial damage of the ulnar nerve at the elbow level and the defect in the center of the nerve, caused by shrapnel shells.

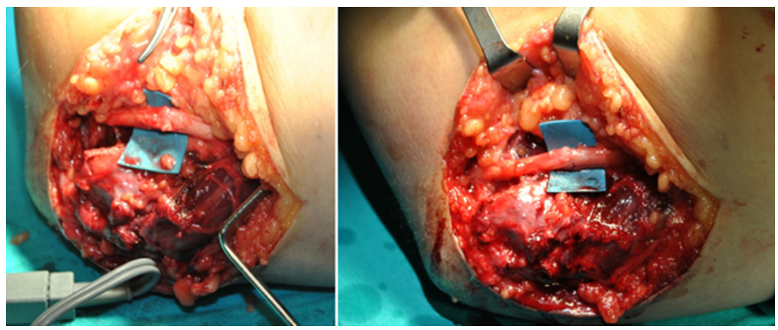

Fig. 5. Partial ulnar nerve injury; a view of the primary repair after debridement.

Fig. 6. Gunshot wound in the axillary region. The forearm was performed fasciotomy in the war zone.

and/or tendon transfers are necessary [39]. Nerve transfers have many advantages; unlike nerve grafts, the waiting period for reinnervation is not long, the procedure is performed outside of the trauma region with healthy tissues, and unlike tendon transfers nerve transfers do not disrupt the natural anatomy. In this way, biomechanics are not changed and joint motion opening is not affected while at the same time reinnervation of the natural muscle is provided. However, while the desired clinical outcome can be obtained within weeks in tendon transfer, the process lasts for months in nerve transfer [40,41]. In our study, nerve repair in high-level nerve injuries was combined with tendon and nerve transfers. Nerve graft was applied with tendon transfer in five cases and with nerve transfer in five cases.

While the risk of arterial injury in low-energy GSWs has been reported at rates of 1.5 to 4%, this rate is higher in HEIs [42]. In a study involving high-energy civil GSW cases, arterial injury was reported by CT angiography in 66% [30]. The 12.9% of arterial injury rate in our study is lower compared to HEI studies in the literature. However, it should not be forgotten that, in the current study, patients presented in the subacute period and some patients with vascular injuries may have been treated prior to presentation in their home country. Two patients with axillary artery injury previously underwent repair with saphenous vein grafts in their home countries (Fig. 6). In this case, it will not be correct to give a real proportional number for arterial injury. We believe that the lack of a correlation between arterial injury and the presence of fracture and location of injury is due to the fact that our cases were subacute and not acute.

The indication for angiography in the absence of physical examination findings is controversial [43]. Anderson et al. found 25% positive angiography findings in the absence of physical examination findings in forearm GSW cases [44]. As physical examination alone may cause some vascular damage to be overlooked, angiography or exploration is recommended to minimize this risk [3]. In our study, we frequently used CT angiography and observed its effectiveness in high-energy GSW cases. We believe that angiography is valuable, especially in terms of arteriovenous (AV) fistula diagnosis in subacute injuries. In two of our patients, AV fistula was detected by angiography and operated by cardiovascular surgeons. In our case approach, after the assessment of arterial damage, the damaged part was resected and repaired without tension, otherwise (in presence of tension) the repair of the arterial damage was performed using a vein graft. One of the points to be considered here is the placement of the vein graft away from the wound area and covering the graft [45].

Gunshot wounds have one of the highest wound contamination rates among the causes of Type 3 open fractures. This increases the risk of infection in HEI [46]. Bullets are not sterile and wounds are often contaminated with fabric and skin flora [47]. For this reason, it is recommended to debride the wound in the early period (first 6 to 8 hours). The bacterial load in the wound can reach 10 times the original quantity after 24 hours [20]. Engelmann et al. reported an 11.8% of infection rate after civil GSW of the upper extremity and stated that there was a relationship between the complexity of the fracture and the risk of infection [31]. Quality information on debridement practices in HEIs is insufficient. Nikolić et al. observed soft tissue infection in 17% and bone infection in 15% of cases despite debridement and antibiotic treatment in femoral fractures with HEIs [48]. Among their cases of war injury, Hinsley et al. observed a 48% infection rate after debridement and primary closure [4]. These studies reveal the importance of not only debridement but also delayed closure. Omoke defined a time of over 6 hours to reach the hospital, a time of 12 hours or more before debridement, low hematocrit value, and the injury of war as risk factors for infection after GSW [49]. Similarly, in our study, lower hematocrit values were observed in infectious cases.

In one third of our cases, infection was detected during the first presentation or clinical follow-up. Performing the first interventions before the hospital, performing emergency surgical interventions in environments with adverse conditions such as field hospitals and not following adequate infection control measures may result in peripheral contamination of the injured area. In war injuries, factors such as deterioration of tissue integrity, presence of necrotic tissues, insufficient vascularization and development of dead space, which cause antibiotics to fail reaching adequate tissue concentration, in addition to both local flora and peripheral contamination in the skin all result in the development of both endogenous and exogenous infections.

We believe that the relatively high rate of infection in our study is due to the fact that our cases were war injuries that underwent first intervention in other centers that possessed inadequate infection control practices before referral to our institution.

In patients in whom presence of an infection is suspected and antibiotic treatment is planned, microbiological cultures should be taken before treatment and empirical treatment should be initiated. In the initial empirical treatment approach, quinolone and cephalosporin groups of antibiotics may be preferred, considering the possibility of polymicrobial reproduction. Preferably, an antipseudomonal beta-lactam antibiotic can be administered, since gram-negative bacteria are more commonly a factor. Especially in cases with osteomyelitis, antistaphylococcal antibiotics can be combined to address gram-positive bacteria. For a rational antibiotic use, after initial empirical antibiotic treatment, treatment should be reorganized according to culture results. According to the culture-antibiogram result, microbiological cultures should be repeated in case of no response to treatment despite proper antimicrobial treatment management.

Planning for long term antibiotics for 2 to 4 weeks in wound infection and a minimum 6 weeks in the presence of osteomyelitis requires strict monitoring of the side effects of antibiotics. Frequent and high-dose analgesic use for pain management also requires monitoring of drug interactions.

In recent years, the rate of infections developed with multiple resistant microorganisms has increased. In patients presenting with war injuries, an increase in the frequency of infections with drug-resistant strains has been observed, probably due to inadequate infection control measures and frequent revision surgery. Nephrotoxic and neurotoxic side effects for colistin and hepatotoxic and gastrointestinal side effects for tigecycline, antibiotics used in infections developed with multiple resistance gram-negative bacteria strains, should be monitored closely. In gram-positive bacterial infections, follow-up is required for nephrotoxicity and ototoxicity in vancomycin use and for hematological side effects in linezolid treatment.

The risk of osteomyelitis is higher in war injuries than in other GSWs. Ignatiadis et al. observed osteomyelitis in three of 37 cases with HEI (8.1%), while, similar to the literature, we detected osteomyelitis in five cases (8.1%) in our series [21].

The presence of fractures emerged in our work as another risk factor for infection. This situation is associated with the size of the soft tissue damage caused by the injury force that caused the fracture in high-energy GSWs [20,50].

Although antibiotherapy is known to be important in the treatment of GSWs, there is no consensus on its duration and administration. What is known is the need for a longer period of treatment (minimum 48 to 72 hours) in HEIs [51,52]. However, short-term treatments can be applied with the clinical, laboratory and radiological proofs of the absence of a soft tissue or bone infection.

When determining the duration of treatment in the presence of infection, 4 to 6 weeks of parenteral and oral sequential antibiotherapy after final debridement should be planned in the presence of residual infected bone, soft tissue or foreign body and in the case of growth of a microorganism in culture that is difficult to treat. Additionally, that revascularization of the bone needs four weeks. The duration of treatment should be planned as 8 to 12 weeks, especially in patients diagnosed with osteomyelitis. Treatment times may be extended in certain conditions; the presence of gram-negative bacteria and polymicrobial factors; in cases with a high risk of reinfection; cases in which no benefit would be obtained from revision surgery; insufficient, immobile and difficult to treat bone and soft tissue reserves; and the presence of comorbid diseases. It should be remembered that antibiotherapies terminated in the early period can result in the recurrence of infection.

In the literature, the use of external fixators with limited number of pins and a simple reduction is frequently reported in GSWs with open fractures or bone loss [18,47]. After the resolution of wound problems, delayed internal fixation is recommended in displaced fractures of the forearm [53]. In high-energy open fractures of the forearm, Smith and Cooney reported good and excellent results with the initial use of an external fixator and later use of plates and screws [54]. Here, the placement of the fixation pins away from the fracture line is important for the plate that will be placed later [55]. It has been reported that plate and screw fixation performed in open complex forearm fractures after a good debridement is advantageous in arterial anastomosis, allows early rehabilitation and facilitates the union, thanks to the anatomical, stable and permanent fixation it provides [56]. Due to the fact that most of our cases had displaced segmental fractures of the forearm or distal humerus fractures, the necessity of providing the anatomical radius and ulna length and joint anatomy was decisive in our implant preference. In addition, anatomical reduction was aimed in forearm fractures by considering them as intraarticular fractures. However, in patients with multi-segmental double bone fracture of the forearm due to blast effect, plates and screws were used for rigid fixation after excision of excessive fragment bone fragments and after equal amount of bone shortening in both the radius and the ulna. Bone graft application was preferred in defective single bone fractures of the forearm. Bone shortening can be applied more easily in defective humerus fractures. We believe that bone shortening procedures performed in necessary cases can be beneficial in providing fracture union. Due to the different anatomic location and configurations of the fractures we encountered, implants were chosen based on each case. We used external fixators for definitive treatment in a limited number of cases ($n = 2$), and in a larger number of cases ($n = 10$) before internal fixation and during the wound care period. Headless screws or K-wires were used in distal intraarticular fractures of the humerus, while K-wires were used in minimally displaced distal radius and hand fractures, plates and screws in distal humerus fractures with intraarticular extension, and arthrodesis plates in multi-segmental distal radius fractures affecting the carpal bones (Fig. 7). Due to the nature of the segmental fracture caused by ballistic injury and due to soft tissue problems (need for debridement), conservative protocols could be followed in a limited number of cases (two cases of ulna fractures and one case of humeral diaphysis fracture). Osteosynthesis using plates and screws was achieved in all of the forearm double fractures, 46% of ulna fractures and 75% of radius fractures (Fig. 8). Before plate-screw application, cleanliness of the wound should be ensured and debridement should be performed to revive the ends of the fractures. If the defects are smaller than 6 cm, use of free bone grafts is sufficient. Bone grafting was performed in eight cases with defect in our series; with six of them being il-

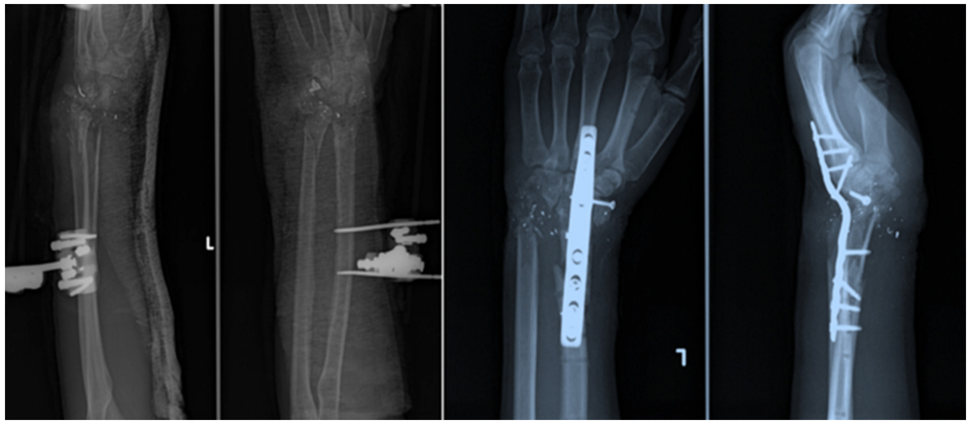

Fig. 7. Bone defect in the wrist joint and the arthrodesis application.

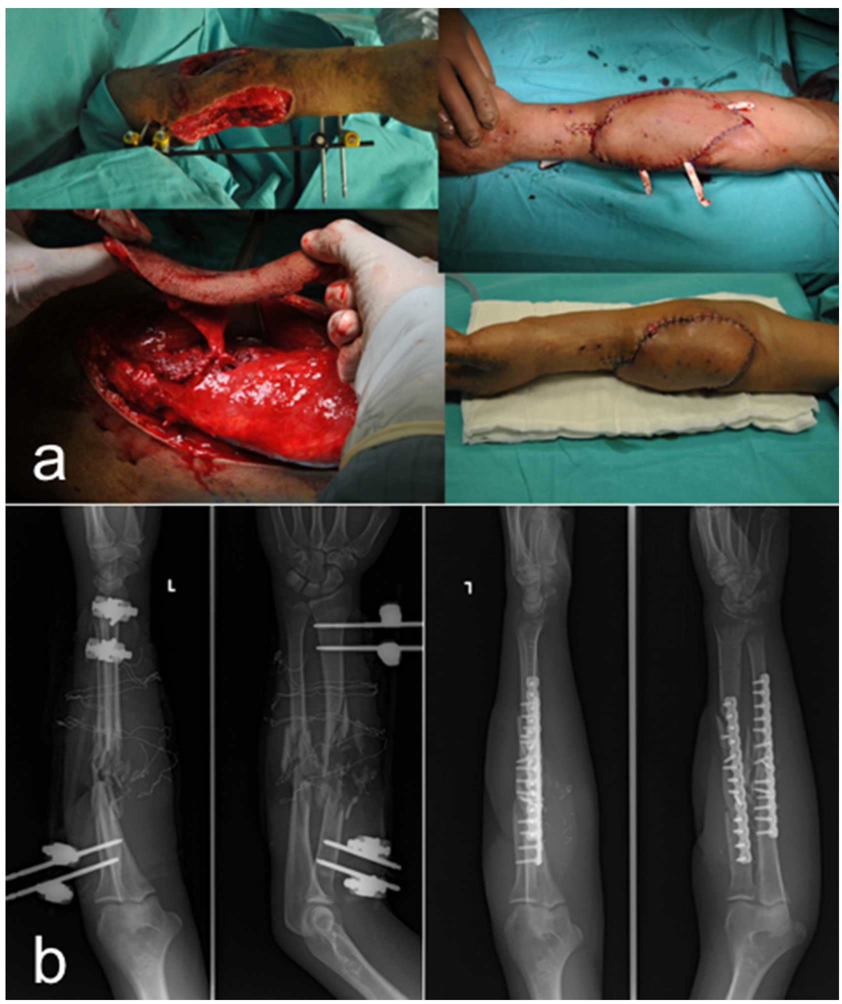

Fig. 8. (a) Defective gunshot wound of the forearm. Application of free flap (anterolateral thigh flap) after debridement. (b) Following the removal of the external fixator and bone shortening, plate and screw osteosynthesis was performed.

iac and two of them being olecranon grafts. A patient with a wide humerus defect underwent vascular fibula grafting.

The retrospective design of our study and the absence of a control group are its limitations. Since the patients returned to their home countries after completion of their treatment, we cannot present long-term functional results. However, with the remote connection established with most patients, we were able to determine that fracture union was achieved. Although it is not possible to follow up for a long time in this type of injury etiology, we aimed to share our experience with the subacute period approach to GSWs. Although nerve transfer is a promising technique in penetrating injuries of the upper extremity, it is still not considered as the standard treatment method; more evidence is required to develop an algorithm [41]. Future studies that include a large number of cases with a control group and that evaluate standard outcome measures are needed. We believe that the data we have obtained will be useful both in new studies and in the approaches of trauma surgeons who will treat such complex cases.

In conclusion, there is still no standard approach in upper extremity GSWs. War injuries in this region are complicated and are one of the more challenging areas of orthopedic trauma. 'Such injuries necessitate solutions specific to each individual case. Contaminated infected wounds frequently turn into large soft tissue defects after repeated debridements in such cases, and reconstructive microsurgical interventions are needed. With utilization of vacuum assisted closure, smaller defects can be covered with less complicated reconstructive interventions. Microbiological samples should be taken prior to empirical antibiotic treatment for infection management, antibiotherapy should be reviewed according to culture-antibiogram results, and rational antibiotic use principles should be followed. The holistic and uncertain character of nerve injuries often requires early exploration and combined reconstructive interventions. As arterial injuries can be missed by physical examination alone, routine angiography should be performed. Completion of bone and soft tissue reconstructions in the same session in a holistic approach minimizes the possible risks. In the treatment of these cases, surgical teams are needed that can master the entire treatment.

Declaration of competing Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

[1] Naghavi M, Marczak LB, Kutz M, Shackelford KA, Arora M, et al., Global Burden of Disease 2016 Injury Collaborators Global Mortality from Firearms, 1990-2016 [published correction appears in JAMA. 2018 Sep 25;320(12):1288]. JAMA 2018;320(8):792-814. doi:10.1001/jama.2018.10060.

[2] Gonzalez T, Briceno J, Velasco B, Kaiser P, Stenquist D, Miller C, et al. Gunshot-related injuries to the foot & ankle: review article. Foot Ankle Int 2020;41(4):486-96. doi:10.1177/1071100720901712.

[3] Bakhach J, Abu-Sitta G, Dibo S. Reconstruction of blast injuries of the hand and upper limb. Injury 2013;44(3):305-12. doi:10.1016/j.injury.2013.01.024.

[4] Hinsley DE, Phillips SL, Clasper JS. Ballistic fractures during the 2003 Gulf conflict–early prognosis and high complication rate. J R Army Med Corps 2006;152(2):96-101. doi:10.1136/jramc-152-02-06.

[5] Sathiyakumar V, Thakore RV, Stinner DJ, Obremskey WT, Ficke JR, Sethi MK. Gunshot-induced fractures of the extremities: a review of antibiotic and debridement practices. Curr Rev Musculoskelet Med 2015;8(3):276-89. doi:10.1007/s12178-015-9284-9.

[6] Petersen K, Riddle MS, Danko JR, Blazes DL, Hayden R, Tasker SA, et al. Trauma-related infections in battlefield casualties from Iraq. Ann Surg 2007;245(5):803-11. doi:10.1097/01.sla.0000251707.32332.c1.

[7] Celiköz B, Sengezer M, Işik S, Türegün M, Deveci M, Duman H, et al. Subacute reconstruction of lower leg and foot defects due to high velocity-high energy injuries caused by gunshots, missiles, and land mines. Microsurgery 2005;25(1):3-15. doi:10.1002/micr.20049.

[8] Patel NM, Yoon RS, Cantlon MB, Koerner JD, Donegan DJ, Liporace FA. Intramedullary nailing of diaphyseal femur fractures secondary to gunshot wounds: predictors of postoperative malrotation. J Orthop Trauma 2014;28(12):711-4. doi:10.1097/BOT.0000000000000124.

[9] Buchler U, Hastings H. Combined injuries. In: Green DP, Hotchkiss RN, Pederson WC, editors. Green's operative hand surgery. Philadelphia: Churchill Livingstone; 1999. p. 1631–50.

[10] Marecek GS, Earhart JS, Gardner MJ, Davis J, Merk BR. Surgeon preferences regarding antibiotic prophylaxis for ballistic fractures. Arch Orthop Trauma Surg 2016;136(6):751-4. doi:10.1007/s00402-016-2450-8.

[11] Hoencamp R, Vermetten E, Tan EC, Putter H, Leenen LP, Hamming JF. Systematic review of the prevalence and characteristics of battle casualties from NATO coalition forces in Iraq and Afghanistan. Injury 2014;45(7):1028-34. doi:10.1016/j.injury.2014.02.012.

[12] Omid R, Stone MA, Zalavras CG, Marecek GS. Gunshot wounds to the upper extremity. J Am Acad Orthop Surg 2019;27(7):e301-10. doi:10.5435/JAAOS-D-17-00676.

[13] Coulet B, Lacombe F, Daussin PA, Chammas M. Mains de "blast": stratégie thérapeutique [treatment of blast injuries of the hand]. Chir Main 2004;23(5):215-23. doi:10.1016/j.main.2004.08.009.

[14] Hafertepen SC, Davis JW, Townsend RN, Sue LP, Kaups KL, Cagle KM. Myths and misinformation about gunshot wounds may adversely affect proper treatment. World J Surg 2015;39(7):1840-7. doi:10.1007/s00268-015-3004-x.

[15] Lerner A, Yaffe B, Soudry M. Functional limb salvage in severe war injuries to limbs. Eur J Orthop Surg Traumatol 2010;20(5):381–8. doi:10.1007/s0059-0-009-0571-2.

[16] Yaremchuk MJ, Brumback RJ, Manson PN, Burgess AR, Poka A, Weiland AJ. Acute and definitive management of traumatic osteocutaneous defects of the lower extremity. Plast Reconstr Surg 1987;80(1):1-14. doi:10.1097/00006534-198707000-00001.

[17] Francel TJ, Vander Kolk CA, Hoopes JE, Manson PN, Yaremchuk MJ. Microvascular soft-tissue transplantation for reconstruction of acute open tibial fractures: timing of coverage and long-term functional results. Plast Reconstr Surg 1992;89(3):478-89.

[18] Prat NJ, Daban JL, Voiglio EJ, Rongieras F. Wound ballistics and blast injuries. J Visc Surg 2017;154(Suppl 1):S9 12. doi:10.1016/j.jviscsurg.2017.07.005.

[19] Ng ZY, Askari M, Chim H. Approach to complex upper extremity injury: an algorithm. Semin Plast Surg 2015;29(1):5-9. doi:10.1055/s-0035-1544165.

[20] Bartlett CS, Helfet DL, Hausman MR, Strauss E. Ballistics and gunshot wounds: effects on musculoskeletal tissues. J Am Acad Orthop Surg 2000;8(1):21-36. doi:10.5435/00124635-200001000-00003.

[21] Ignatiadis IA, Mavrogenis AF, Igoumenou VG, Polyzois VD, Tsiampa VA, Arapoglou DK, et al. Gunshot and blast injuries of the extremities: a review of 45 cases. Eur J Orthop Surg Traumatol 2019;29(2):295-305. doi:10.1007/s00590-018-2350-4.

[22] van Waes OJ, Halm JA, Vermeulen J, Ashford BG. "The Practical Perforator Flap": the sural artery flap for lower extremity soft tissue reconstruction in wounds of war. Eur J Orthop Surg Traumatol 2013;23(Suppl 2):S285 9. doi:10.1007/s00590-012-1133-6.

[23] Guzman-Stein G, Fix RJ, Vasconez LO. Muscle flap coverage for the lower extremity. Clin Plast Surg 1991;18(3):545-52.

[24] Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and random-pattern flaps. Plast Reconstr Surg 1982;70(1):1-10. doi:10.1097/00006534-198207000-00001.

[25] Richards RR, McKee MD, Paitich CB, Anderson GI, Bertoia JT. A comparison of the effects of skin coverage and muscle flap coverage on the early strength of union at the site of osteotomy after devascularization of a segment of canine tibia. J Bone Joint Surg Am 1991;73(9):1323-30.

[26] Tintle SM, Gwinn DE, Andersen RC, Kumar AR. Soft tissue coverage of combat wounds. J Surg Orthop Adv 2010;19(1):29-34.

[27] Dienstknecht T, Horst K, Sellei RM, Berner A, Nerlich M, Hardcastle TC. Indications for bullet removal: overview of the literature, and clinical practice guidelines for European trauma surgeons. Eur J Trauma Emerg Surg 2012;38(2):89-93. doi:10.1007/s00068-011-0170-x.

[28] Deitch EA, Grimes WR. Experience with 112 shotgun wounds of the extremities. J Trauma 1984;24(7):600-3. doi:10.1097/00005373-198407000-00009.

[29] Dubuisson A, Kline DG. Indications for peripheral nerve and brachial plexus surgery. Neurol Clin 1992;10(4):935-51.

[30] Mehta SK, Dale WW, Dedwylder MD, Bergin PF, Spitler CA. Rates of neurovascular injury, compartment syndrome, and early infection in operatively treated civilian ballistic forearm fractures. Injury 2018;49(12):2244-7. doi:10.1016/j.injury.2018.10.009.

[31] Engelmann EWM, Roche S, Maqungo S, Naude D, Held M. Treating fractures in upper limb gunshot injuries: the Cape Town experience. Orthop Traumatol Surg Res 2019;105(3):517-22. doi:10.1016/j.otsr.2018.11.002.

[32] Pannell WC, Heckmann N, Alluri RK, Sivasundaram L, Stevanovic M, Ghiassi A. Predictors of nerve injury after gunshot wounds to the upper extremity. Hand (N Y) 2017;12(5):501-6. doi:10.1177/1558944716675294.

[33] Evriviades D, Jeffery S, Cubison T, Lawton G, Gill M, Mortiboy D. Shaping the military wound: issues surrounding the reconstruction of injured servicemen at the Royal Centre for Defence Medicine. Philos Trans R Soc Lond B Biol Sci 2011;366(1562):219-30. doi:10.1098/rstb.2010.0237.

[34] Siemionow M, Brzezicki G. Chapter 8: current techniques and concepts in peripheral nerve repair. Int Rev Neurobiol 2009;87:141- 72. doi:10.1016/S0074-7742(09)87008-6.

[35] Furey MJ, Midha R, Xu QG, Belkas J, Gordon T. Prolonged target deprivation reduces the capacity of injured motoneurons to regenerate. Neurosurgery 2007;60(4):723-33. doi:10.1227/01.NEU.0000255412.63184.CC.

[36] Dicpinigaitis PA, Koval KJ, Tejwani NC, Egol KA. Gunshot wounds to the extremities. Bull NYU Hosp Jt Dis 2006;64(3-4):139-55.

[37] Houdek MT, Shin AY. Management and complications of traumatic peripheral nerve injuries. Hand Clin 2015;31(2):151-63. doi:10.1016/j.hcl.2015.01.007.

[38] Jones PE, Meyer RM, Faillace WJ, Landau ME, Smith JK, McKay PL, et al. Combat injury of the sciatic nerve - an institutional experience [published correction appears in Mil Med. 2018 Sep 1;183(9-10):246]. Mil Med 2018;183(9-10):e434-41. doi:10.1093/milmed/usy030.

[39] Mathieu L, Bertani A, Gaillard C, Chaudier P, Ollat D, Bauer B, et al. Surgical management of combat-related upper extremity injuries. Chir Main 2014;33(3):174-82. doi:10.1016/j.main.2014.02.003.

[40] Ozcelik IB, Yildiran G, Mersa B, Sutcu M, Celik ZE, Ozalp T. A novel nerve transfer: The first palmar interosseous motor branch of the ulnar nerve to the recurrent motor branch of the median nerve [published online ahead of print, 2020 Feb 24]. Injury 2020;S0020-1383(20):30193–5. doi:10.1016/j.injury.2020.02.119.

[41] Karamanos E, Rakitin I, Dream S, Siddiqui A. Nerve Transfer surgery for penetrating upper extremity injuries. Perm J 2018;22:17 156. doi:10.7812/TPP/17-156.

[42] Lenihan MR, Brien WW, Gellman H, Itamura J, Kuschner SH. Fractures of the forearm resulting from low-velocity gunshot wounds. J Orthop Trauma 1992;6(1):32-5.

[43] Lynch K, Johansen K. Can Doppler pressure measurement replace "exclusion" arteriography in the diagnosis of occult extremity arterial trauma? Ann Surg 1991;214(6):737-41. doi:10.1097/00000658-199112000-00016.
[44] Anderson RJ, 2nd HRW, Lee BC, Manno J, Swan KG, Padberg Jr FT, et al. Reduced dependency on arteriography for penetrating extremity trauma: influence of wound location and noninvasive vascular studies. J Trauma 1990;30(9):1059-65.
[45] Weber MA, Fox CJ, Adams E, et al. Upper extremity arterial combat injury management. Perspect Vasc Surg Endovasc Ther 2006;18(2):141-5. doi:10.1177/1531003506293451.
[46] Howland WS Jr, Ritchey SJ. Gunshot fractures in civilian practice. An evaluation of the results of limited surgical treatment. J Bone Joint Surg Am. 1971;53(1):47-55.
[47] Atesalp AS, Yildiz C, Başbozkurt M, Gür E. Treatment of type IIIa open fractures with Ilizarov fixation and delayed primary closure in high-velocity gunshot wounds. Mil Med 2002;167(1):56-62.
[48] Nikolić D, Jovanović Z, Turković G, Vulović R, Mladenović M. Subtrochanteric missile fractures of the femur. Injury 1998;29(10):743-9. doi:10.1016/s0020-1383(98)80174-5.
[49] Omoke NI. Analysis of risk factors for gunshot wound infection in a nigerian civilian trauma setting. World J Surg 2016;40(8):1885-91. doi:10.1007/s00268-016-3475-4.
[50] Volgas DA, Stannard JP, Alonso JE. Current orthopaedic treatment of ballistic injuries. Injury 2005;36(3):380-6. doi:10.1016/j.injury.2004.08.038.
[51] Turker T, Capdarest-Arest N. Management of gunshot wounds to the hand: a literature review. J Hand Surg Am 2013;38(8):1641-50. doi:10.1016/j.jhsa.2013.02.011.
[52] Papasoulis E, Patzakis MJ, Zalavras CG. Antibiotics in the treatment of low-velocity gunshot-induced fractures: a systematic literature review. Clin Orthop Relat Res 2013;471(12):3937-44. doi:10.1007/s11999-013-2884-z.
[53] Elstrom JA, Pankovich AM, Egwele R. Extra-articular low-velocity gunshot fractures of the radius and ulna. J Bone Joint Surg Am 1978;60(3):335-41.
[54] Smith DK, Cooney WP. External fixation of high-energy upper extremity injuries. J Orthop Trauma 1990;4(1):7-18. doi:10.1097/00005131-199003000-00002.
[55] Mathieu L, Bazile F, Barthélémy R, Duhamel P, Rigal S. Damage control orthopaedics in the context of battlefield injuries: the use of temporary external fixation on combat trauma soldiers. Orthop Traumatol Surg Res 2011;97(8):852-9. doi:10.1016/j.otsr.2011.05.014.
[56] Ugurlar M, Kabakas F, Sonmez M, Erturer E, Mersa B, Ozcelik I. The plate fixation in the treatment of complex forearm open fractures. Hand Microsurg 2017;6:1–8. doi:10.5455/handmicrosurg.214642.