European Journal of Orthopaedic Surgery & Traumatology (2019) 29:295–305
https://doi.org/10.1007/s00590-018-2350-4

ORIGINAL ARTICLE • TRAUMA - MICROSURGERY

Gunshot and blast injuries of the extremities: a review of 45 cases

Ioannis A. Ignatiadis[1] · Andreas F. Mavrogenis[2] · Vasilios G. Igoumenou[2] · Vasilios D. Polyzois[3] · Vasiliki A. Tsiampa[1] · Dimitrios K. Arapoglou[1] · Sarantis Spyridonos[1]

Received: 22 October 2018 / Accepted: 25 November 2018 / Published online: 29 November 2018

Abstract

Gunshot wounds and blast injuries constitute a major public health problem, as the increasing availability of firearms and explosives in conjunction with increasing violence in the city setting have brought this reality into civilian life. Extremities are most commonly involved; therefore, orthopedic surgeons should be trained to manage these types of injuries. Complete and accurate assessment of the injury itself is of great importance, as it will determine the severity and the risk of patients. High-risk injuries from missiles and injuries from explosions are associated with moderate or poor outcomes, major complications, and increased need for multiple surgical procedures. On the other hand, low-risk injuries frequently present optimal results and rather low morbidity. The role of microsurgery is essential, especially in the high- and very high-risk injuries, since complex and multiple reconstructions have to be performed, which include the utilization of free flaps, nerve grafts, and tendon transfers.

Keywords Gunshot · Blast · Explosives · Fireworks · Microsurgery

Introduction

In 1998, there were 30,708 reports of fatal gunshot injuries and 64,484 reports of non-fatal gunshot injuries in the USA; in comparison, in the 10-year involvement in the Vietnam War, 58,156 soldiers died from gunshot war injuries [1]. The Global Burden of Disease 2016 Injury Collaborators and the Institute for Health Metrics and Evaluation used considerable expertise and resources to provide a sweeping view of the magnitude of firearm deaths in 195 countries and territories across the globe [2, 3]. The study estimated that 251,000 firearm-related deaths occurred outside of state-conflict settings in 2016, an increase from an estimated 209,000 firearm-related deaths in 1990. It was also shown that, in all but 1 year of the 27-year study period (1994; genocide in Rwanda), firearm deaths were more common outside war settings than within them [2, 3].

Explosions are not that common into civilian populations, but they are also not rare, with more than 1200 intentional bombings being reported annually in the USA since 1991 [4–6]. Whether accidental or intentional, explosions are an occurrence that can cause serious injury and death, having also the ability to inflict injuries on many people at the same time resulting in high levels of mortality and morbidity [7]. Therefore, any surgeon that is involved in trauma should have a thorough understanding of the mechanisms involved in both gunshot wounds and blast injuries, and the type of management of the patients.

This article presents an overview of the treatment of gunshot and blast injuries of the extremities. Injury patterns, methods of treatment, and patient outcomes are discussed, along with a systematic review of the current literature on the subject.

✉ Ioannis A. Ignatiadis
ignatioa@gmail.com

Andreas F. Mavrogenis
afm@otenet.gr; afmavrogenis@med.uoa.gr

1 Department of Upper Limb and Hand Surgery and Microsurgery, KAT Hospital, Athens, Greece

2 First Department of Orthopaedics, School of Medicine, National and Kapodistrian University of Athens, 41 Ventouri Street, Holargos, 15562 Athens, Greece

3 Third Department of Orthopaedics, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece

Materials and methods

We studied the files of patients with gunshot and blast injuries who were admitted and treated at the Department of Upper Limb, Hand Surgery and Microsurgery of a Tertiary Trauma Hospital through an 11-year period (2000–2010). Data were collected retrospectively; patients with incomplete files and/or lost to regular follow-ups were excluded from our analysis. This left 45 patients (43 men and 2 women) with a mean follow-up of 7.2 years (range 5–10 years) to be included in this study. At their admission, all patients gave written informed consent for their data to be included in a study. This study was approved by the Institutional Review Board/Ethics Committee of the authors' institution.

Forty-two patients were referred within 48 h from their injury to our department, and three patients were initially treated elsewhere and were referred to our Department for definitive care 1–5 weeks after their injury. All injuries were classified according to the SATT (Severity, Anatomy, Topography, and Type) evaluation system that is closely related to the prognosis of the injury [8]. We also classified injuries as "very high risk," "high risk," and "low risk" (Table 1) depending on whether or not a gunshot wound was likely to harm the patient; injuries caused by fireworks, grenades, bombs, and other explosives were "very high-risk" injuries. Twenty-one patients experienced a very high-risk blast injury (explosives and fireworks) involving the hand (15 patients), the forearm (three patients), and the leg and foot (three patients); 16 patients experienced a high-risk injury (hunting guns and military rifles) involving the arm (seven patients), the forearm (four patients), the hand (three patients), and the leg and foot (two patients); and eight patients experienced a low-risk injury (handguns) involving the hand (three patients), the arm (two patients), the forearm (two patients), and the leg and foot (one patient).

Associated injuries were recorded. Abdominal and/or thoracic trauma, multiple fractures, maxillofacial trauma, brachial plexus injuries, and burns were diagnosed in high-risk and very high-risk injury patients; no patient with a low-risk injury experienced associated injuries other than the primary wound.

Surgical treatment

The surgical procedures varied depending on the risk of injury for the patient. In very high-risk injuries external fixations, revascularizations/replantations, amputations (Fig. 1a–c), reoperations or secondary reconstructions, vascularized locoregional/free flaps for wound coverage or revascularization, nerve repairs/grafting (Figs. 2a–g, 3a–c), bone lengthening, bone grafting, and tendon transfers were done. In high-risk injuries, external fixations, revascularizations/replantations, vascularized locoregional/free flaps, nerve repairs/grafting, reoperations, secondary reconstructions or amputations, bone lengthening, bone grafting, and tendon transfers were done (Fig. 4a–f). In low-risk injuries blister removal, direct closure and neurovascular microsurgical repair were done.

Clinical evaluation

Postoperative and at follow-ups clinical evaluation included the injured extremity's range of motion (ROM), muscle strength (using a JAMAR dynamometer for grip and pinch strength) and sensation (using a static and moving two-point discrimination test), [9–11] and by assessing patients' subjective feeling about the usefulness of their limb as previously described [12], as follows: Chen grade I, very good to excellent function (patient is able to resume original work, ROM exceeds 60% of normal, complete or nearly complete recovery of sensibility, muscle power of grades 4 and 5); Chen grade II, good function (patient is able to resume some suitable work, ROM exceeds 40% of normal, nearly

Table 1 Low- and high-risk gunshot injuries of the extremities (any type of injury caused by fireworks, grenades, bombs and other explosives is a "very high-risk" injury)

Variables	Low risk	High risk
Location of injury	City street	Battlefield/farmyard
Time to treatment	< 1 h	> 1–6 h
Weapon used	Handgun	Military, hunting, rifle, shotgun
Pathway of bullet/missile	Straight through, entrance and exit wounds at same level	Entrance and exit wounds at different levels, or no exit wound
Size of exit wound	Small	Large
Organ involvement	Skin, muscle	Solid organs, spine, central nervous system, vascular injury
Bone involvement	Small	Large, substantial
Number of projectiles	One	Many

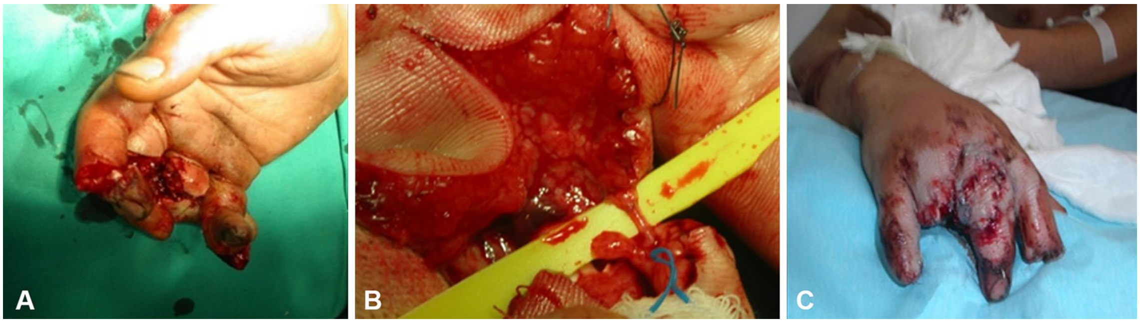

Fig. 1 **a** Intraoperative photograph of the right hand of an 11-year-old boy with amputation at the base of the ring finger, the middle finger and the distal phalanx of the index finger after a blast injury by fireworks. **b** Successful replantation of the middle finger with primary end-to-end anastomosis of the digital arteries and **c** coverage of the stumps of the index and ring fingers was done

complete sensibility, muscle power of grades 3 and 4); Chen grade III, medium function (patient is able to carry on daily life, ROM exceeds 30% of normal, partial or protective sensibility, muscle power of grade 3); and Chen grade IV, poor function (patient has almost no usable function of survived limb).

Results

As expected, the best outcomes were observed in the low-risk injury patients; seven patients experienced excellent (Chen grade I), and one patient experienced good (Chen grade II) function at the last follow-up (Table 2). Eleven high-risk injury patients experienced excellent or good function (11 patients), three patients experienced medium function, and two patients experienced poor function. In the very high-risk injury patients, one patient (a child) experienced excellent function, eight patients experienced good function, and 12 patients experienced poor and medium function.

Low-risk injury patients did not experience any complications and required no additional or revision surgery. In contrast, three high-risk injury patients were admitted to the Intensive Care Unit (ICU), two patients experienced osteomyelitis of the radius, and one patient experienced partial ischemic necrosis of the forearm. Five very high-risk injury patients were admitted to the ICU, one patient experienced osteomyelitis of the humerus, and another patient experienced compartment syndrome of the forearm.

Sixteen high-risk injury patients required 17 additional/revision surgical operations including tarsal bone arthrodesis, bone lengthening, bone grafting, open reduction internal fixation, bone excision/augmented grafts, ulnar/radial nerve grafts, flow-through free flap contralateral forearm to forearm, distant flap separation, tendon transfers, and skin grafts. Thirteen very high-risk injury patients required respective additional/revision surgical operations including revascularization (Fig. 5a–d), ankle arthrodesis, bone lengthening, bone excision/augmented grafts, tibial/peroneal/ulnar nerve grafts, muscle flap, distant flap separation, tendon transfers, and skin grafts.

Discussion

Trauma and hand surgeons should be familiar to treating gunshot and blast injuries. In a review of battle casualties from NATO coalition forces in Iraq and Afghanistan, the most common wounds in more than 18,000 patients were those to the extremities (approximately 40%) [13]. In civilian life, extremity and hand trauma from bullets are becoming more common with increasing gang violence and availability of firearms [14, 15].

Bullets and missiles/gunshot injuries

The wounding effects of missiles are determined by their physical properties (mass, shape, composition), flight characteristics (velocity, stability, yaw, and tumbling), and reaction of the differing types of tissue (elasticity–density) [16]. Velocity is an important factor in creating a wound; it is usually classified as low-velocity (< 600 m/s, more common in civilian and practice guns), and high-velocity (> 600 m/s, more commonly seen in military guns) [15]. According to the equation of the kinetic energy ($E = 1/2\ mv^2$), energy is directly related to velocity; therefore, the higher the velocity of a missile, the greater the damage it produces. While it is true that high-energy guns have greater wounding capacity than lower-energy guns, this knowledge by itself does not help the surgeons to treat their patients [15]. The amount of tissue damage and patient's injury has mostly to do with the rate of energy transfer and the area over which the energy is transferred [15, 17–20]. If surgeons focus only on the energy or the velocity of the guns, they may be deceived, since the amount of energy transferred from the missile to the tissues varies significantly, and so does the effect of a given amount

Fig. 2 **a** Intraoperative photograph of the right arm of a 30-year-old man with open comminuted fracture of the humerus and radial nerve transection after a gunshot injury by a military rifle. **b** External fixation for bone stabilization, followed by **c** bridging of the bone defect with iliac crest autologous bone graft, and **d** microsurgical repair of the radial nerve defect with **e** a sural nerve autograft was done. Two years after the injury **f** hand function was good; **g** radiographs showed fracture healing

of energy on specific tissues [15, 17, 20]. Therefore, it is recommended that surgeons should further assess the characteristics of the specific injury, and look for findings that may lead to a suspicion of occult injuries [21]. In this practice, classifying the risk of injury, as in the present study, is the most useful concept [20]. Additionally, the amount of tissue damage from a gunshot wound is related to multiple factors including the weapons' velocity, type of bullets and tissues involved. Therefore, in contrast to traditional teaching, a simplistic view of gunshot wounds, based only on either bullet velocity or energy transfer may lead to mistakes in management. For instance, a shotgun is technically not a high-velocity gun, but it can create substantial rates of soft tissue, nerve, vascular, bone, and joint injury. For that reasons, a classification based on the energy of injury, as used in the present study, should be considered more appropriate to describe a gunshot and blast injury [15].

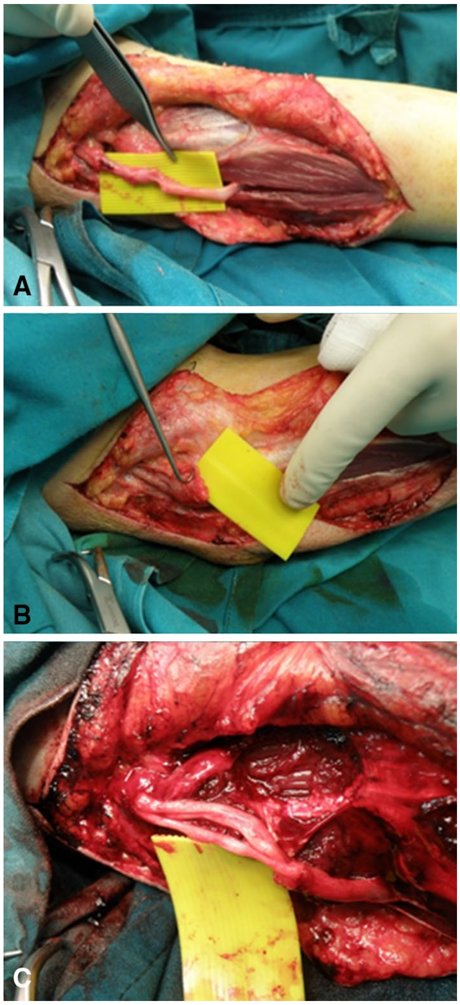

Fig. 3 **a** Intraoperative photograph of the left elbow of a 39-year-old man with ulnar nerve partial transection and neuroma-in-continuity formation at the elbow after an explosion injury. **b** Excision of the neuroma-in-continuity and **c** microsurgical ulnar nerve repair with a sural nerve autograft was done. Six months after the injury hand function was good

The energy transferred from a bullet/missile may result into tissue crush (leaving a permanent cavity) or tissue stretch (causing a temporary cavity) [17]. Tissue stretch is generally fairly well tolerated by many parts of the body, and the energy is dissipated without much damage [17]. Cavitation (the temporary cavity that is created as the bullet travels through tissue) has not only been significantly exaggerated in the literature, suggesting that it can be 30–100 times the diameter of the bullet but has been also mainly associated with high-velocity bullets. However, both speculations have been questioned; even with high-powered rifles, the maximal temporary cavity is only 12.5 diameters of the bullet, while cavitation occurs with both high and low-velocity weapons [17]. This is very important in the clinical scenario, as during debridement there is no need to remove viable tissue that has been only stretched by temporary cavitation and is not permanently damaged [17].

Another common myth is that bullets are sterile due to the immense heat and pressure generated with firing [22]. This is totally false according to experimental data [22, 23]. Current recommendations suggest at least a short duration of antibiotic prophylaxis, or longer duration of antibiotics administration if significant soft tissue disruption, contamination from hollow viscera, or involvement of joint, bone or the central nervous system has occurred [17]. The administration of antibiotics for low-risk gunshot injuries is controversial; even in the setting of a fracture, there is no obvious benefit to longer antibiotic administration or even to the use of antibiotics per se [24, 25], and infection rates are independent of the route of administration (intravenously or orally) [25]. In contrast, high and very high-risk injuries should be treated with 48–72 h of antibiotic adjuvant treatment [15].

The misconception that bullet removal is vital due to potential lead poisoning should be addressed, since it is frequently proved an unnecessary procedure [26, 27]. Lead poisoning is considered a potential concern and bullet removal should be attempted only if the bullet is in contact with synovial fluid or within an intervertebral disk and the spinal canal causing neurologic deficits, or to address complications [28]. Other indications to remove retained bullets exist include the risk of thromboembolism from bullets within a blood vessel or the myocardium [17].

Gunshot injuries of the extremities present a challenge for the treating physician. Penetration alone is a problem, but the energy transferred to the soft tissues is particularly destructive [29, 30]. Injury to the various tissue types complicates the initial treatment, the subsequent rehabilitation, and expected functions. To preserve or regain those functions, the appropriate tissue type must be addressed. For example, injury to joints and cartilage leads to loss of motion, and injury to tendons and retinacula leads to reduced or complete loss of motion and weakness. Injury to sensory nerves may cause loss of sensibility, apprehension, stereognosia and locognosia, pain and dysesthesia, and injury to motor nerve may lead to weakness or loss of muscle function. Injury to blood vessels may lead to ischemia and necrosis, and loss of skin coverage may result in infection and total destruction of underlying tissues. When a patient presents with a gunshot injury to the extremities, and especially to the hand, the above essential tissues must be considered [15, 19].

The ideal clinical scenario after a gunshot injury to the hand is involvement of only one tissue type. This would allow for a logical specific treatment strategy. However, unfortunately in most cases, gunshot injuries to the hand cause combined injuries that affect more than one tissue type [31]. Combined injuries constitute a major problem because different tissue types may require opposing modes

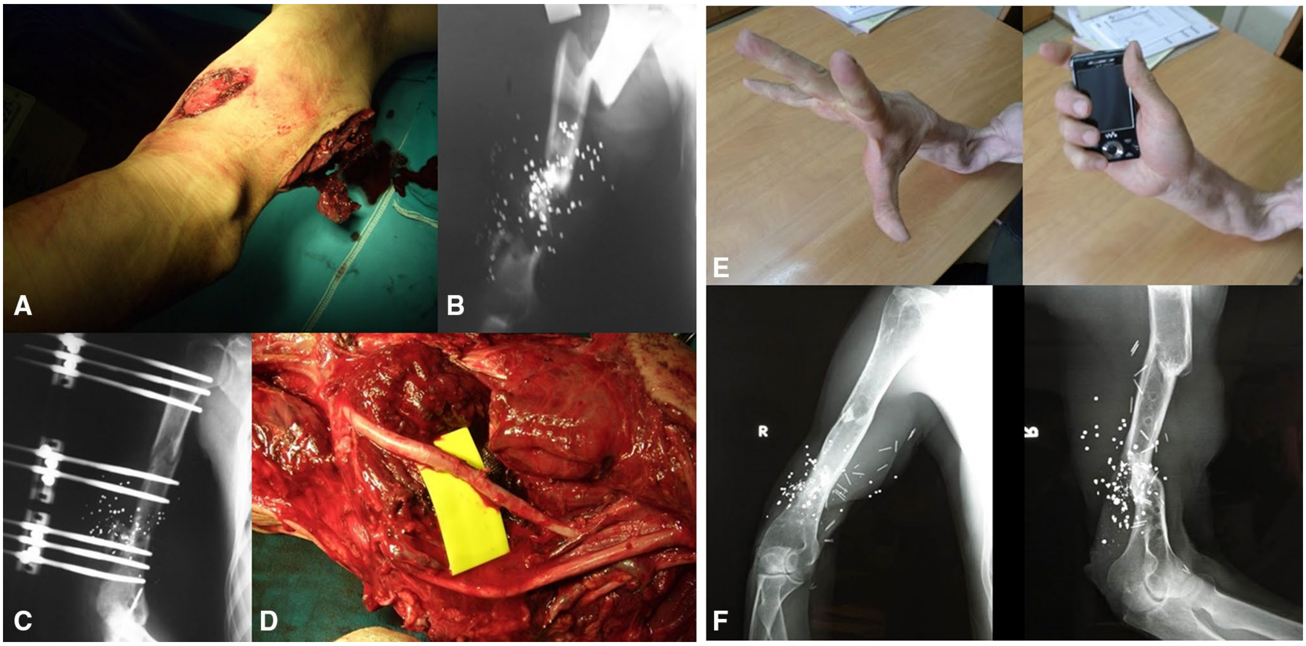

Fig. 4 **a** Intraoperative photograph and **b** radiograph of the right humerus of a 33-year-old man with open comminuted fracture of the humerus, brachial artery tear and radial nerve transection after a gunshot injury by a hunting gun. **c** External fixation for bone stabilization, followed by **d** microsurgical repair of the brachial artery with a venous graft, and late (at 6 months) tendon transfers for the radial nerve palsy was done. Two years after the injury (**e**) hand function was good; **f** radiographs showed fracture healing

of treatment. For instance, a patient with an injury to a flexor tendon generally is treated with early surgical repair and mobilization. However, a patient with a flexor injury with concomitant nerve damage may require a period of rest to allow for decreased tension for healing of the nerve repair. Additionally, injuries to tendons on flexor and extensor sides of the hand may pose a rehabilitation [32].

Explosives/blast injuries

An explosive is a material capable of producing an explosion (blast) by its own energy. Explosions, in fact, are caused by the rapid conversion of a liquid or solid material (chemical, gaseous, mechanical or even nuclear means) into gas, with the release of considerable energy (heat), while propellants burn by a process of deflagration, resulting in a blast wave extending out from the point of detonation [4, 6, 33]. The initial shock wave following an explosion is a special form of high-pressure wave; the surrounding atmosphere is heated by the passage of this shock wave and then forced outwards by the expansion of gases formed within the explosion. The blast wave is then produced, which travels supersonically and contains the products of the explosion (gas and fragments) [19, 34].

Explosives are categorized as high-order explosives or low-order explosives. High-order explosives (dynamite, trinitrotoluene (TNT) and cyclotrimethylene trinitramine) have a strong supersonic pressure wave, and low-order explosives (pipe bombs, gunpowder, and petroleum-based bombs) have a subsonic explosion, lacking the high-order explosive blast wave [7]. High explosive detonation occurs almost instantaneously and results in extremely high-pressure blasts, with initial pressures of sometimes more than four million pounds per square inch (30 GPa) and speeds as high as 8000 m/s. [4, 6, 35]. In addition to the blast wave, an explosion can cause blast wind that is the flow of superheated air that can interact with people and objects and cause injury or damage [7].

Victims of explosions present complex injuries, either immediately or at longer term, directly or indirectly related to the shock wave (blast) of the explosion [19]. The location and the distance from the epicenter of explosion are primordial elements for the early diagnosis of blast injury in the individual. The pressure characteristics of the shock wave generated by the explosion and the type of injuries created depend on the nature of the explosive device, its packaging, the environment in which the explosion occurs, and the location of the victim at the time of the explosion [19].

Blast injuries are classified into four grades: primary (the interaction of the initial shock wave with the body and air containing structures such as the ear, lungs and gastrointestinal tract); secondary (the result of the blast wave and explosive fragments causing penetrating or non-penetrating wounds); tertiary (the result of gross body displacement including crush and avulsion injuries); and quaternary (a

Table 2 Details of the patients included in this series

Details	Mechanism of injury		
	Low-risk injuries (city guns/pistols, $n=8$)	High-risk injuries (shotguns/hunting guns, $n=10$; military rifles, $n=6$)	Very high-risk injuries/blast injuries (explosives, $n=21$)
Site			
Shoulder and arm	2	7	–
Forearm and wrist	2	4	3
Hand and digits	3	3	15
Leg and foot	1	2	3
Gender			
Males	7 (three adolescents)	15 (one child)	21 (two children; one adolescent)
Females	1	1	–
SATT score	S1A1T1Ty1, four patients	S1A2T2Ty2, 10 patients	S2A2T3Ty2, 14 patients
	S1A1T2Ty1, two patients	S1A2T1Ty2, one patient	S2A2T2Ty3, four patients
	S1A2T1Ty2, one patient	S2A2T2Ty2, five patients	S1A2T2Ty2, three patients
	S1A2T2Ty1, one patient	–	–
Surgical treatment	Blister removal, direct closure, and neurovascular microsurgical repair	External fixations, revascularizations/replantations, vascularized locoregional/free flaps, nerve repairs/grafting, reoperations, secondary reconstructions or amputations, bone lengthening, bone grafting, and tendon transfers	External fixations, revascularizations, replantations, amputations, reoperations or secondary reconstructions, vascularized locoregional/free flaps for wound coverage or revascularization, nerve repairs/grafting, bone lengthening, bone grafting, and tendon transfers
Complications	–	Intensive Care Unit (three patients), osteomyelitis of the radius (two patients), partial ischemic necrosis of the forearm (one patient)	Intensive Care Unit (five patients), osteomyelitis of the humerus (one patient), forearm compartment syndrome (1 patient)
Additional procedures/reoperations	–	16 patients (17 reoperations): tarsal bone arthrodesis, bone lengthening, bone grafting, open reduction internal fixation, bone excision/augmented grafts, ulnar/radial nerve grafts, flow-through free flap contralateral forearm to forearm, distant flap separation, tendon transfers, and skin grafts	13 patients/reoperations: ankle arthrodesis, bone lengthening, bone excision/augmented grafts, tibial/peroneal/ulnar nerve grafts, muscle flap, distant flap separation, tendon transfers, and skin grafting
Outcome			
Excellent (Chen I)	7	2	1
Good (Chen II)	1	9	8
Medium (Chen III)	–	3	4
Fail-Poor (Chen IV)	–	2	8

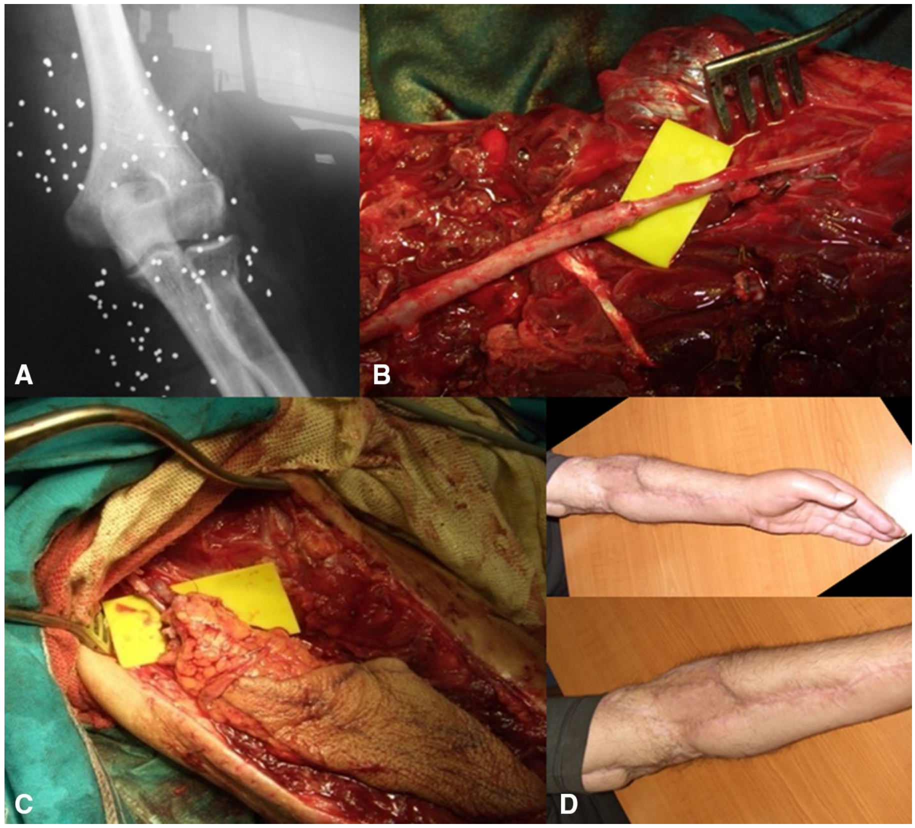

Fig. 5 **a** Radiograph of the left elbow of a 27-year-old man with brachial artery tear and median nerve neurapraxia after a gunshot injury by a hunting gun. **b** Microsurgical repair of the brachial artery with a 40-cm saphenous vein graft was done. **c** Because of venous autograft thrombosis, a reoperation using a contralateral forearm through-flow flap transfer was done. **d** Six months after the injury hand function was moderate

miscellaneous collection of all other mechanisms including thermal injury, methemoglobinemia, acute septicemic melioidosis, and other) [7, 19, 34].

Principles of treatment

Indications for surgery in bullet wounds include the presence of considerable tissue damage, major vascular injury, progressive neurologic deficits, obvious contamination, joint involvement, compartment syndrome, unstable fractures, tendon injuries, superficial fragments in the palm, and patients presenting at least 8 h after injury [15, 36]. Most patients with gunshot and blast injuries of the extremities benefit substantially from early treatment [37], including initially meticulous wound care, immobilization, and antibiotics [38]. Because of its abundant blood supply, it is very rarely necessary, and at times detrimental, to debride questionable tissues at the time of injury [29]. It is preferable to cleanse the wound thoroughly and observe recovery or necrosis of the remaining soft tissue. Although antibiotics are crucial for the treatment of injuries, there is no consensus on the length of treatment and mode of administration [15, 25]. Limited use of antibiotics is acceptable in the low-risk injuries, but liberal use of antibiotics is necessary for the high and very high-risk injuries [15, 25, 39].

Initial wound care for gunshot wounds should be done with a surgical scrub brush and copious low-pressure irrigation. Immediate reconstructive treatment is recommended. If the injury cannot be addressed at presentation, all injured segments should be immobilized with removable plaster splints to control pain and prevent secondary infection [19]. The hand should be immobilized in a functional position that is the metacarpophalangeal joints in flexion and the wrist in slight dorsiflexion. The wounds should be covered with non-adherent dressings that be well padded but not bulky. Plaster easily conforms to dressings and a well-positioned hand. Ace bandages have a tendency to be placed overly tight. If available, a non-elastic bandage is preferable. If there is bone loss or open fractures, immobilization is best provided by external fixators according to the principles of damage control (simple assembly, limited number of pins, fracture reduction is not mandatory) rather than ideal definitive reduction and fixation [19].

In case of articular involvement, capsular debridement should be performed sparingly, in order to allow closure of the joint capsule over a suction drainage. Negative pressure wound dressing changes is an interesting therapeutic modality that allows drainage, while assuring temporary coverage of the wound and limiting secondary tissue edema [19]. Ideally, surgical wound revision should be performed within 24–48 h, as "borderline" ischemic zones at the time of initial debridement can progress to necrosis [19]. Definitive wound closure can be achieved by either directed healing, or secondary closure (5–7 days later), or plastic surgical procedures (1 week later), depending on the size of the cutaneous defect [19]. Definitive surgical repair should be done before tendon retraction, loss of fracture reduction, or colonization of open wounds. As in all hand surgery, binocular loupes magnification is necessary for wound exploration of the hand, and an operating microscope is paramount for vessels and nerves reconstruction [40, 41]. Injuries such as blast and high-velocity gunshots translate unpredictable forces and may result in ongoing loss of soft tissue following initial debridement. Soft tissue coverage via vascularized flaps might be necessary for definitive treatment and to achieve both functional results and some degree of cosmesis [42]. Associated injuries should be screened, diagnosed and carefully evaluated and treated [19]. Damage control principles should be adapted and management of the hemorrhage is a priority. Extensive debridement should be abandoned, in order to shorten the initial operative time. At a later time point, during secondary damage control, further debridement and removal of objects, which present a risk to life or function can be performed [19, 43, 44].

Neurovascular injuries/amputations

Blast injuries represent the most destructive trauma, followed by the high-risk gunshot injuries (hunting guns and military rifles), and low-risk injuries (city and practice pistols and handguns) [45–47]. Replantations/revascularizations are recommended in partial amputations and compound injuries in low and high-risk gunshot injuries, but very rare in blast injuries and mangled extremities. An amputation secondary to a very high-risk blast injury is performed when replantation is not feasible, as these injuries are crash type injuries with deep thermal injury at the level of the stumps [48]. Additionally, the presence of thoracic and/or abdominal trauma in these patients is a relative contraindication for microsurgical reconstructions. In children and adolescents, despite the fact that blast injuries represent contraindication for replantation attempt, replantation of the limb should be always attempted, even with a small shortening of the bone as function is often satisfactory [49, 50]. In high-risk gunshot injuries from hunting guns, shotguns and military rifles neurovascular injury may not be complete for early amputation. Often the limb is salvaged at the initial management, but numerous reconstructions may be necessary. The outcome is usually poor, but if nerve injury is restricted, good to excellent results can be expected. In contrast, low-risk gunshot injuries from handguns, pistols and practice guns are usually not associated with amputations (except for injuries to the fingers); however, in these cases, the indications for revascularization/replantation are stronger [20].

Neurovascular injuries are common, especially among patients with high- and very high-risk gunshot injuries, and determine the outcome when the skeleton has been reconstructed. Pseudoaneurysm and aneurysm have been reported in association with gunshot wounds. Nerve palsy is a common finding in gunshot wounds and is usually temporary. A transected nerve should not be repaired primarily but only after the acute inflammation has subsided; early nerve repair has been associated with very low functional recovery in such injuries ranging up to 25% [20]. Direct nerve repair using nerve grafts or looping techniques could give satisfactory results, especially in young patients; occasionally, acute long bone shortening (followed by subsequent bone lengthening) could facilitate a nerve end-to-end repair, which offers better nerve regeneration, rehabilitation, and function. Overzealous repair of all injured tendons might undermine functional recovery; priority should be given to repair the most important tendons and strive for compliance from patients with rehabilitation [15, 51].

Conclusions

Gunshot wounds and blast injuries constitute a major public health problem, as the increasing availability of firearms and explosives in conjunction with increasing violence in the city setting have brought this reality into civilian life. Extremities are most commonly involved; therefore, orthopaedic surgeons should be trained to manage these types of injuries. Complete and accurate assessment of the injury itself is of great importance, as it will determine the severity and the risk of patients. High-risk injuries from missiles and injuries from explosions are associated with moderate or poor outcomes, major complications, and increased need for multiple surgical procedures. On the other hand, low-risk injuries frequently present optimal results and rather low morbidity. The role of microsurgery is essential, especially in the high- and very high-risk injuries, since complex and multiple reconstructions have to be performed, which include the utilization of free flaps, nerve grafts, and tendon transfers.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Gotsch KE, Annest JL, Mercy JA, Ryan GW (2001) Surveillance for fatal and nonfatal firearm-related injuries—United States, 1993–1998. In: CDC surveillance summaries. MMWR 50, No. SS-2, pp 1–34
2. Global Burden of Disease Injury C (2018) Global mortality from firearms, 1990–2016. JAMA 320(8):792–814. https://doi.org/10.1001/jama.2018.10060
3. Rivara FP, Studdert DM, Wintemute GJ (2018) Firearm-related mortality: a global public health problem. JAMA 320(8):764–765. https://doi.org/10.1001/jama.2018.9942
4. Byard RW (2018) Lethal explosions in a non-terrorist civilian setting. Med Sci Law 58(3):156–158. https://doi.org/10.1177/0025802418767797
5. Center FBoIBD (1996) General Information Bulletin 96-1: 1996 Bombing Incidents. US Department of Justice, Washington, DC
6. Wightman JM, Gladish SL (2001) Explosions and blast injuries. Ann Emerg Med 37(6):664–678. https://doi.org/10.1067/mem.2001.114906
7. Jorolemon MR, Krywko DM (2018) Blast injuries. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK430914. Accessed 10 Oct 2018
8. Ignatiadis IA, Yiannakopoulos CK, Mavrogenis AF, Nomikos GN, Spyridonos SG, Gerostathopoulos NE, Soucacos PN (2008) Severe upper limb injuries with or without neurovascular compromise in children and adolescents—analysis of 32 cases. Microsurgery 28(2):131–137. https://doi.org/10.1002/micr.20464
9. Antonopoulos DK, Mavrogenis AF, Megaloikonomos PD, Mitsiokapa E, Georgoudis G, Vottis CT, Antonopoulos GK, Papagelopoulos PJ, Pneumatikos S, Spyridonos SG (2017) Similar 2-point discrimination and stereognosia but better locognosia at long term with an independent home-based sensory reeducation program versus no reeducation after low-median nerve transection and repair. J Hand Ther Off J Am Soc Hand Ther. https://doi.org/10.1016/j.jht.2017.10.008
10. Galanakos SP, Mavrogenis AF, Vottis C, Macheras GA, Ignatiadis I (2018) Epineural sleeve reconstruction technique for median nerve complete transection. Arch Bone Jt Surg 6(2):140–145
11. Mavrogenis AF, Spyridonos SG, Antonopoulos D, Soucacos PN, Papagelopoulos PJ (2009) Effect of sensory re-education after low median nerve complete transection and repair. J Hand Surg 34(7):1210–1215. https://doi.org/10.1016/j.jhsa.2009.04.014
12. Chen ZW, Yu HL (1987) Current procedures in China on replantation of severed limbs and digits. Clin Orthop Relat Res 215:15–23
13. Hoencamp R, Vermetten E, Tan EC, Putter H, Leenen LP, Hamming JF (2014) Systematic review of the prevalence and characteristics of battle casualties from NATO coalition forces in Iraq and Afghanistan. Injury 45(7):1028–1034. https://doi.org/10.1016/j.injury.2014.02.012
14. Bartlett CS, Helfet DL, Hausman MR, Strauss E (2000) Ballistics and gunshot wounds: effects on musculoskeletal tissues. J Am Acad Orthop Surg 8(1):21–36
15. Turker T, Capdarest-Arest N (2013) Management of gunshot wounds to the hand: a literature review. J Hand Surg 38(8):1641–1650. https://doi.org/10.1016/j.jhsa.2013.02.011
16. Rhee PM, Moore EE, Joseph B, Tang A, Pandit V, Vercruysse G (2016) Gunshot wounds: a review of ballistics, bullets, weapons, and myths. J Trauma Acute Care Surg 80(6):853–867. https://doi.org/10.1097/TA.0000000000001037
17. Hafertepen SC, Davis JW, Townsend RN, Sue LP, Kaups KL, Cagle KM (2015) Myths and misinformation about gunshot wounds may adversely affect proper treatment. World J Surg 39(7):1840–1847. https://doi.org/10.1007/s00268-015-3004-x
18. Karaca MA, Kartal ND, Erbil B, Ozturk E, Kunt MM, Sahin TT, Ozmen MM (2015) Evaluation of gunshot wounds in the emergency department. Turk J Trauma Emerg Surg TJTES 21(4):248–255. https://doi.org/10.5505/tjtes.2015.64495
19. Prat NJ, Daban JL, Voiglio EJ, Rongieras F (2017) Wound ballistics and blast injuries. J Visc Surg 154(Suppl 1):S9–S12. https://doi.org/10.1016/j.jviscsurg.2017.07.005
20. Volgas DA, Stannard JP, Alonso JE (2005) Current orthopaedic treatment of ballistic injuries. Injury 36(3):380–386. https://doi.org/10.1016/j.injury.2004.08.038
21. Clasper J (2001) The interaction of projectiles with tissues and the management of ballistic fractures. J R Army Med Corps 147(1):52–61
22. Santucci RA, Chang YJ (2004) Ballistics for physicians: myths about wound ballistics and gunshot injuries. J Urol 171(4):1408–1414. https://doi.org/10.1097/01.ju.0000103691.68995.04
23. Wolf AW, Benson DR, Shoji H, Hoeprich P, Gilmore A (1978) Autosterilization in low-velocity bullets. J Trauma 18(1):63
24. Dickey RL, Barnes BC, Kearns RJ, Tullos HS (1989) Efficacy of antibiotics in low-velocity gunshot fractures. J Orthop Trauma 3(1):6–10
25. Papasoulis E, Patzakis MJ, Zalavras CG (2013) Antibiotics in the treatment of low-velocity gunshot-induced fractures: a systematic literature review. Clin Orthop Relat Res 471(12):3937–3944. https://doi.org/10.1007/s11999-013-2884-z
26. Mazotas IG, Hamilton NA, McCubbins MA, Keller MS (2012) The long-term outcome of retained foreign bodies in pediatric gunshot wounds. J Trauma Nurs Off J Soc Trauma Nurses 19(4):240–245. https://doi.org/10.1097/JTN.0b013e31827757a7
27. Vaidya R, Sethi A, Oliphant BW, Gibson V, Sethi S, Meehan R (2014) Civilian gunshot injuries of the humerus. Orthopedics 37(3):e307–e312. https://doi.org/10.3928/01477447-20140225-66
28. Tosti R, Rehman S (2013) Surgical management principles of gunshot-related fractures. Orthop Clin North Am 44(4):529–540. https://doi.org/10.1016/j.ocl.2013.06.006
29. Fackler ML, Burkhalter WE (1992) Hand and forearm injuries from penetrating projectiles. J Hand Surg 17(5):971–975
30. Jabaley ME, Peterson HD (1973) Early treatment of war wounds of the hand and forearm in Vietnam. Ann Surg 177(2):167–173
31. Buchler U, Hastings H (1999) Combined injuries. In: Green DP, Hotchkiss RN, Pederson WC (eds) Green's operative hand surgery. Churchill Livingstone, Philadelphia, pp 1631–1650
32. Wilson RH (2003) Gunshots to the hand and upper extremity. Clin Orthop Relat Res 408:133–144
33. Cullis IG (2001) Blast waves and how they interact with structures. J R Army Med Corps 147(1):16–26
34. Dussault MC, Smith M, Hanson I (2016) Evaluation of trauma patterns in blast injuries using multiple correspondence analysis. Forensic Sci Int 267:66–72. https://doi.org/10.1016/j.forsciint.2016.08.004
35. Mathews ZR, Koyfman A (2015) Blast injuries. J Emerg Med 49(4):573–587. https://doi.org/10.1016/j.jemermed.2015.03.013
36. Bartlett CS (2003) Clinical update: gunshot wound ballistics. Clin Orthop Relat Res 408:28–57
37. Phillips P 3rd, Hansraj KK, Cox EE 2nd, Ashley EM (1995) Gunshot wounds to the hand. The Martin Luther King, Jr, General Hospital experience. Orthop Clin North Am 26(1):95–108
38. Stromberg BV (1978) Management of low-velocity gunshot wounds of the hand. South Med J 71(9):1087–1088
39. Hill PF, Watkins PE (2001) The prevention of experimental osteomyelitis in a model of gunshot fracture in the pig. Eur J Orthop

Surg Traumatol Orthop Traumatol 11(4):237–241. https://doi.org/10.1007/BF01686897
40. Acar MA, Gulec A, Aydin BK, Erkocak OF, Elmadag M, Turkmen F (2015) Reconstruction of dorsal hand and finger defects with reverse radial fasciocutaneous forearm flaps. Eur J Orthop Surg Traumatol Orthop Traumatol 25(4):723–729. https://doi.org/10.1007/s00590-014-1544-7
41. Hosseinian MA, Gharibi Loron A, Nemati B, Khandaghy M (2015) Comparison of a distal end-to-side neurorrhaphy with a proximal-distal end-to-side neurorrhaphy: in a rat model. Eur J Orthop Surg Traumatol Orthop Traumatol 25(8):1261–1264. https://doi.org/10.1007/s00590-015-1699-x
42. van Waes OJ, Halm JA, Vermeulen J, Ashford BG (2013) "The Practical Perforator Flap": the sural artery flap for lower extremity soft tissue reconstruction in wounds of war. Eur J Orthop Surg Traumatol Orthop Traumatol 23(Suppl 2):S285–S289. https://doi.org/10.1007/s00590-012-1133-6
43. Kalinterakis G, Koutras A, Syllaios A, Michalakeas N, Lytras D, Tsilikis I (2018) The evolution and impact of the "damage control orthopedics" paradigm in combat surgery: a review. Eur J Orthop Surg Traumatol Orthop Traumatol. https://doi.org/10.1007/s00590-018-2320-x
44. Lerner A, Yaffe B, Soudry M (2010) Functional limb salvage in severe war injuries to limbs. Eur J Orthop Surg Traumatol Orthop Traumatol 20(5):381–388. https://doi.org/10.1007/s00590-009-0571-2
45. Cook A, Osler T, Hosmer D, Glance L, Rogers F, Gross B, Garcia-Filion P, Malhotra A (2017) Gunshot wounds resulting in hospitalization in the United States: 2004–2013. Injury 48(3):621–627. https://doi.org/10.1016/j.injury.2017.01.044
46. Husain ZS, Schmid S, Lombardo N (2016) Functional outcomes after gunshot wounds to the foot and ankle. J Foot Ankle Surg Off Publ Am Coll Foot Ankle Surg 55(6):1234–1240. https://doi.org/10.1053/j.jfas.2015.06.004
47. Manley NR, Fabian TC, Sharpe JP, Magnotti LJ, Croce MA (2018) Good news, bad news: an analysis of 11,294 gunshot wounds (GSWs) over two decades in a single center. J Trauma Acute Care Surg 84(1):58–65. https://doi.org/10.1097/TA.0000000000001635
48. Demiralp B, Ege T, Kose O, Yurttas Y, Basbozkurt M (2014) Amputation versus functional reconstruction in the management of complex hind foot injuries caused by land-mine explosions: a long-term retrospective comparison. Eur J Orthop Surg Traumatol Orthop Traumatol 24(4):621–626. https://doi.org/10.1007/s00590-013-1345-4
49. Beris AE, Soucacos PN, Malizos KN (1995) Microsurgery in children. Clin Orthop Relat Res 314:112–121
50. Beris AE, Soucacos PN, Malizos KN, Mitsionis GJ, Soucacos PK (1994) Major limb replantation in children. Microsurgery 15(7):474–478
51. Pereira C, Boyd JB, Olsavsky A, Gelfand M, Putnam B (2012) Outcomes of complex gunshot wounds to the hand and wrist: a 10-year level I urban trauma center experience. Ann Plast Surg 68(4):374–377. https://doi.org/10.1097/SAP.0b013e31823d2ca1