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ORIGINAL PAPER

Contribution of ultrasound in the management of ballistic nerve injury during the 2020 Nagorno-Karabakh war

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Abstract

Purpose To evaluate the contribution of ultrasound in the management of ballistic peripheral nerve injuries (BPNI).

Methods Twenty-five Armenian soldiers who sustained BPNI of 44 different nerves during the Second Nagorno-Karabakh War in 2020 benefited from multidisciplinary team management including ultrasound examination.

Results The injuries affected the upper limb in 17 cases (including 2 bilateral cases), the lower limb in 7 cases and both upper and lower limb in 1 case. The injuries were due to shrapnel in 14 cases and to high-velocity bullets in 10 cases. One median-radial nerve injury occurred after prolonged haemostatic tourniquet. Thirteen patients had at least 2 nerves injuries. Ultrasound showed 16 nerves with neurapraxia, including 2 blast injuries, 8 axonotmesis with a neuroma-in-continuity and 8 neurotmesis. Twelve soldiers got surgery prior to our missions. The preoperative skin marking of nerve lesions under ultrasound control was very useful for the surgeon during the operation. A good correlation with surgery was observed, in 7 cases, and in 10 cases, a correlation with electroneuromyography (ENMG) was found. The ultrasound exploration was not informative in 2 patients.

Conclusion Ultrasound is a useful examination for the assessment of BPNI. It allows exploration of the entire nerve without artefact in the presence of projectiles or external fixator, contrary to MRI. It localizes and characterizes the nerve damage with a good correlation with data from the surgery and ENMG.

Clinical relevance statement Ballistic wounds of peripheral nerves are frequent in war wounded. Ultrasound can localize and characterize nerve injuries with good correlation with surgical and electrophysiological data.

Keywords Nerve · Ballistic injury · Ultrasound

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Key Points

- Ballistic lesions of peripheral nerves are frequent in war wounded patients.
- If the skin condition allows it, ultrasound allows exploring the injured nerve(s).
- Ultrasound is a reliable examination for the localization and characterization of ballistic peripheral nerve injuries.

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Introduction

The Second Nagorno-Karabakh War was a major escalation of the unresolved Nagorno-Karabakh conflict between Azerbaijan and Armenia [1]. Casualties and losses were considerable, with a total of over 11,000 wounded troops from both sides. The use of cluster bombs, armed drones and snipers characterized this conflict. The French Ministry of Foreign Affairs asked the three largest French university hospital centers, Paris, Marseille and Lyon, to organize medical missions to assist in the care of Armenian war wounded. A multidisciplinary team from Lyon was formed including two upper limb surgeons (AG, AT), a hand therapist (PP), an anesthesiologist specializing in pain management (MD), a neurologist (GC), an infectious disease specialist (TF) and a radiologist (OF). Between January 2021 and May 2022, seven missions were carried in Yerevan, the capital of Armenia, which allowed the management of wounded soldiers. Ballistic injuries of the limbs by shrapnel and high-energy bullets were very frequent, leading to multi-tissue injuries including bone and joint injuries, soft tissue injuries, in particular peripheral nerve injuries.

Ultrasound is a good examination for peripheral nerves assessment. It benefits from a spatial resolution superior to magnetic resonance imaging (MRI) and allows the nerve assessment along its entire course from proximal to distal or reverse. It also allows the exploration of most of the course of the nerves of a limb, an essential element in the context of polytrauma, whether by bullets or shrapnel. The palpation using the probe (sono-palpation) is another essential aspect of ultrasound examination. As during the clinical exam, echo-palpation helps to localize the nerve injury or to test the clinical findings when the nerve is suspected to be pathologic on ultrasound images [2]. In the same trend, the dynamic assessment of the nerve is useful to detect pathologic findings. Moreover, ultrasound examination is easily to be repeated and is not artifacted by metal such as projectiles, an external fixator or orthopedic hardware. For optimal assessment, a high-quality ultrasound device with a high-frequency probe is required, of at least 7–10 MHz for deep nerves and 18–24 MHz for superficial nerves.

In this observational study, we report the contribution of ultrasound in the management of ballistic peripheral nerve injuries (BPNI) in 25 war-wounded soldiers and describe the injuries encountered.

Aims

This prospective study was conducted in the routine care setting during 7 missions lasting one week each which were organized between January 2021 and May 2022 at Wigmore Clinic, Yerevan, Armenia. One single radiologist (OF) explored the patients with BPNI using ultrasound (Canon Aplio 500, 18–7 MHz probe) after the clinical examination by the surgeons, allowing the examination to be focused on the affected nerves. The time from injury to ultrasound examination ranged from 45 days to 18 months, with an average delay of 5 months. No early examination was performed. Clinicaly suspected involved nerves was fully explored using transversal scanning from proximal to distal. To prepare the surgery, nerve lesions were tagged using skin marking.

Nerve lesions were described according to Seddon's classification [3]:

- neurapraxia: continuous, normal or thickened nerve, neuropathy;
- axonotmesis: partial section of the nerve, presence of a neuroma-in-continuity;
- neurotmesis: complete section of the nerve, presence of a terminal neuroma.

Out of 25 patients included in the study, 12 had surgery by a local surgeon before ultrasound, 7 had surgery after ultrasound and 10 benefited from an electroneuromyographic examination (ENMG) performed by a single operator (GC). The ultrasound results were correlated with surgery and electrophysiology findings.

The study was approved by the Wigmore Clinical Ethics Committee, and all patients signed informed consent.

Results

In total, 25 wounded soldiers with 44 injured nerves had ultrasound examination (Table 1). The BPNI were distributed as follows: 17 in the upper limbs, 7 in the lower limbs, and 1 in both upper and lower limb. Two patients had both upper limbs damaged. Twelve soldiers had a single nerve injury, including one with a bifocal injury. In the remaining 13 soldiers, at least 2 nerves were damaged, including 3 soldiers with lesions to the brachial plexus (Fig. 1). Fourteen injuries were related to bomb fragments (shrapnel), 10 to high-velocity bullets and one to a prolonged hemostatic tourniquet application.

Table 1 Patients and lesion characteristics

#Patient	Damaging agent	Localisation	Nerves	Ultrasound findings	Surgery	ENMG	# Nerves	Limb
1	Shrapnel	R forearm	Ulnar Median	Ulnar: complete section Median: neuroma-in-continuity	N	Y	2	Upper
2	Shrapnel	R leg	Tibial	Complete section with loss of substance	Y	N	1	Lower
3	Bullet	L brachial plexus	Infraclavicular trunks	Hyperechoic dedifferentiation	N	Y	3	Upper
4	Tourniquet	R arm	Median Radial	Neuropathy	N	Y	2	Upper
5	Bullet	R thigh	Sciatic	Normal post-suture appearance	Y	N	1	Lower
6	Bullet	R brachial plexus, elbow	Infraclavicular trunks Posterior branch of radial	Trunks non-visible: skin and bone fragments Posterior branch of radial nerve: neuropathy	N	Y	4	Upper
7	Shrapnel	L elbow, leg	Median Common peroneal	Median: extensive neuropathy (blast) Common peroneal: neuropathy	Y	Y	2	Upper + lower
8	Shrapnel	Both upper limbs	Median (R) Ulnar (L) Radial (L)	Median: impingement by shrapnel	Y	Y	3	Upper + upper
9	Shrapnel	R forearm	Median	Fibrosis and neuropathy	Y	N	1	Upper
10	Bullet	L arm	Radial	Normal post-neurolysis	Y	N	1	Upper
11	Bullet	R arm	Radial	Neuroma-in-continuity	N	Y	1	Upper
12	Bullet	L forearm	Ulnar	Post-suture appearance, fibrosis Ulnar artery occlusion	Y	N	1	Upper
13	Shrapnel	R arm, elbow	Median Ulnar	Median: neuropathy (blast) Ulnar: neuroma-in-continuity	Y	Y	2	Upper
14	Bullet	R forearm	Median Ulnar	Post-suture neuromas and fibrosis	Y	N	2	Upper
15	Bullet	R brachial plexus	Supraclavicular trunks	Hypoechoic dedifferentiation	N	N	3	Upper
16	Shrapnel	R arm L elbow	Median (R) Radial (L)	Median: post-suture neuroma Radial: neurotmesis without neuroma	Y	N	2	Upper + upper
17	Shrapnel	L thigh	Sciatic	Post-suture, very hypoechoic, thickened	Y	N	1	Lower
18	Bullet	L shoulder	Accessory	Fibrosis, non-visible	N	Y	1	Upper
19	Shrapnel	L leg	Common peroneal	Normal post-suture appearance	Y	N	1	Lower

Table 1 (continued)

#Patient	Damaging agent	Localisation	Nerves	Ultrasound findings	Surgery	ENMG	# Nerves	Limb
20	Shrapnel	L lower limb	Sciatic Common peroneal Deep peroneal	Sciatic, common peroneal: neuropathy, fibrosis Deep peroneal: neuroma-in-continuity	Y	N	3	Lower
21	Shrapnel	R leg	Tibial	Neuropathy, fibrosis Tibial artery occlusion	Y	N	1	Lower
22	Shrapnel	L elbow L lower limb	Radial Ulnar	Radial: impingement by orthopaedic hardware Ulnar: neuropathy	Y	Y	2	Upper
23	Shrapnel	L forearm	Median	Post-suture: loss of substance (10 cm)	Y	N	1	Upper
24	Shrapnel	L leg	Tibial	Neuroma-in-continuity	N	N	1	Lower
25	Bullet	L arm	Median Ulnar	Median: complete section with end-bulb neuroma Ulnar: neuroma-in-continuity	Y	N	2	Upper

L left, *N* no, *R* right, *Y* yes

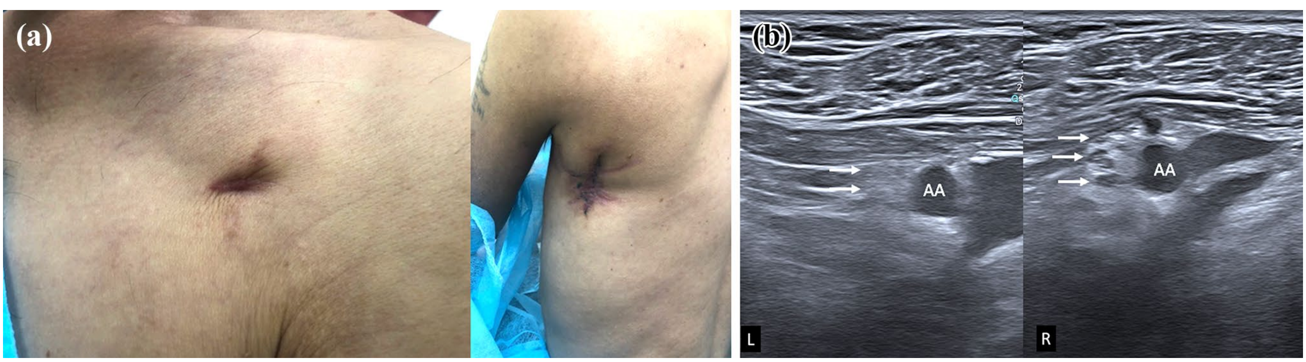

Fig. 1 Gunshot wound of the left infraclavicular brachial plexus (patient #3) **A** Clinical appearance. **B** Comparative sagittal ultrasound sections of the infraclavicular brachial plexus. Tritroncular hyperechoic dedifferentiation on the left pathological side (L). Normal appearance on the right contralateral side (R). *AA* axillary artery

Table 2 Types of nerve damage

Neurapaxia: 16
Axonotmesis: 8 all with neuroma in continuity
Neurotmesis: 8, 2 with end-bulb neuroma

Types of nerve damage (Table 2)

Neurapraxia was found in 36% (16/44 nerves) with a continuous nerve with neuropathy. This included two blast injuries (Fig. 2), one osteosynthesis material conflicting with the radial nerve, one conflict with a shrapnel fragment, one median-radial neuropathy at the arm level related to prolonged hemostatic tourniquet application.

Axonotmesis was found in 18% (8/44 nerves) and in all cases resulted in a neuroma-in-continuity including a variable amount of intact fascicles within the nerve.

Neurotmesis was found in 18% (8/44 nerves), including one ulnar nerve section due to a bone fragment migrated from an ulnar bone fracture (patient #1, Fig. 3). Only two terminal neuromas were identified among these 8 cases.

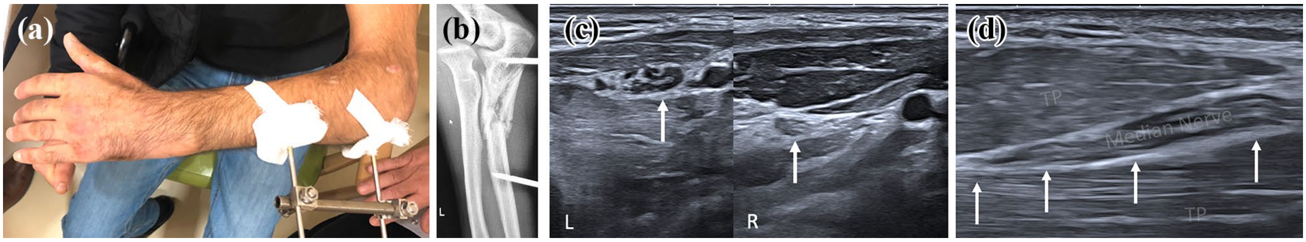

Fig. 2 Shrapnel lesion of the left elbow and forearm (patient #7). Paresis in the territory of the median nerve. Neurapraxia in electroneuromyography. **A** The wounded limb. **B** Ulna fracture treated by external fixator. **C** Comparative axial ultrasound sections showing left thickened pathological nerve (l) compared to normal right median nerve (R). **D** longitudinal sections of the median nerve (arrows) in the arm and elbow showing hypertrophic median nerve neuropathy attributed to blast. *TP* teres pronator

Fig. 3 Shrapnel injury of the right forearm (patient #1). Picture of complete ulnar nerve palsy with neurotmesis in electroneuromyography and axonotmesis of the median nerve. **A** The limb showing skin marking of nerve lesions. **B** Longitudinal ultrasound section showing a complete section of the ulnar nerve at the elbow linked to an intraneural bony fragment. **C** Longitudinal ultrasound section showing a neuroma-in-continuity (large arrow) of the median nerve (small arrows) in the forearm

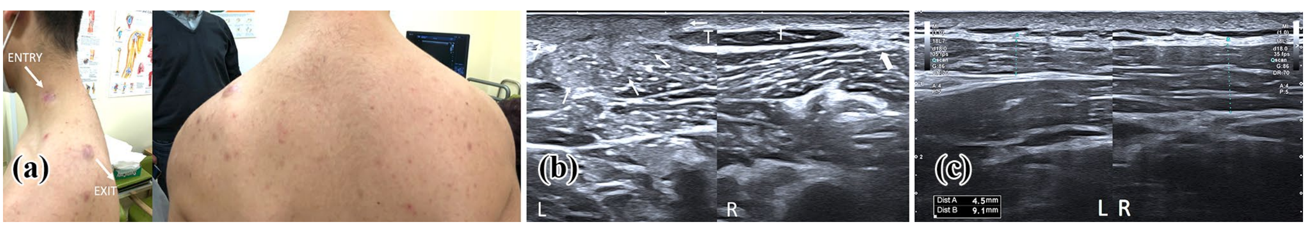

Fig. 4 Gunshot wound of the left shoulder (patient #18). **A** Entry and exit points (white arrows), amyotrophy of the left trapezius. Axonotmesis of the accessory nerve in electroneuromyography. **B** Comparative axial ultrasound sections showing extensive fibrosis (small white arrows) on the left side (L) which does not allow identification of the accessory nerve (large white arrow) which is visualized on the right side (R). **C** Comparative axial ultrasound sections showing trapezius amyotrophy on the left side

Ultrasound limitations

In one injured patient [#18], the left accessory nerve continuity could not be identified because of extensive fibrosis (Fig. 4). The ENMG examination showed complete denervation of the middle trapezius with recovery on a later ENMG. In another patient [#6] with infraclavicular brachial plexus involvement, ultrasound exploration was impossible because of a botriomycoma and bone interposition due to a multi-fragmented fracture of the coracoid process.

Role of ultrasound guided regional analgesia

In 4 patients, the ultrasound exploration of peripheral nerves was challenging due to the presence of allodynia and hyperalgesia. In these patients, we realized an ultrasound guided block (3 blocks for fore-arm exploration and 1 block for the leg) with Lidocaine 0.5 mg/ml (injected volume from 2 to 5 ml). All blocks were realized by the trained anesthesiologist-pain specialist (MD), successful and uneventful. Motor function was preserved in all patients, and further ultrasound diagnostic was enabled.

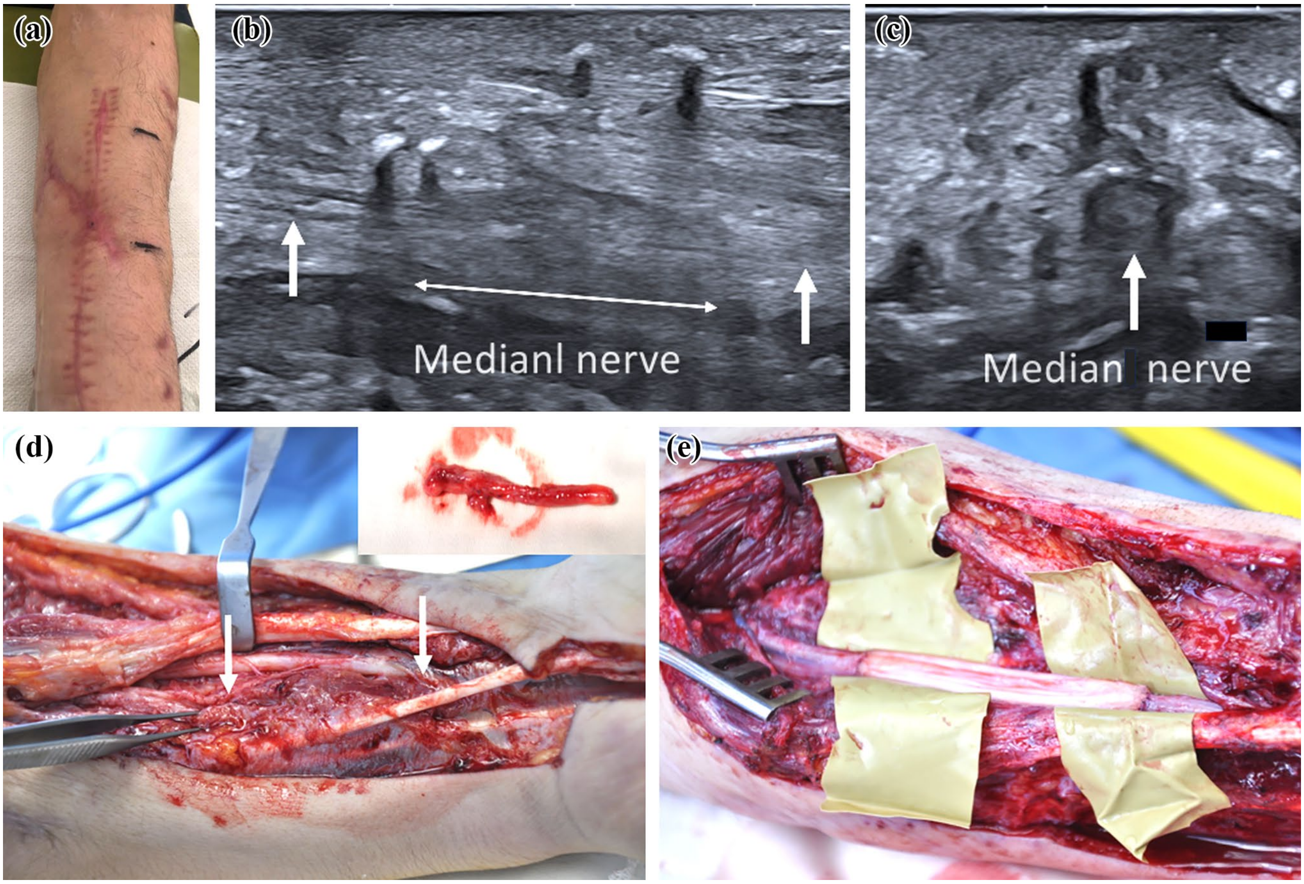

Fig. 5 Shrapnel injury of the left forearm (patient #23). Median nerve injury already sutured. No recovery. **A** Postoperative scars and skin marking of nerve lesions. **B** and **C** Ultrasound, longitudinal (**B**) and axial (**C**) sections showing a destructured, hypoechoic and dedifferentiated nerve over 5 cm (double-head arrow). **D** and **E** Intraoperative views showing the extent of the nerve damage (white arrows) and the appearance after the sural nerve grafting

Previously operated patients

Twelve patients had already undergone nerve surgery at the time of the ultrasound examination. Nine had nerve sutures and 3 had neurolysis. In 7 cases of suture, the ultrasound appearance of the suture was unfavorable: neuroma, extensive intraneural fibrosis with loss of the fascicular appearance of the nerve, extensive loss of substance, suture in tension with a thickened and hypoechoic nerve. It should be noted that the abovementioned sutures were mostly performed in emergency situations without the proper application of microsurgical techniques. One patient [#23] had undergone median nerve suture to the forearm without recovery (Fig. 5). Ultrasound showed extensive nerve loss over 5 cm (Fig. 5B and C). This patient benefited from a sural nerve graft performed by a surgeon of the team (AG) (Fig. 5D and E). One patient [#17] had a sciatic nerve suture distal to the pyramidalis muscle without any sign of recovery at 5 months. The nerve was continuous on ultrasound at the level of the suture but very thickened and hypoechoic, suggesting a tension suture. Five patients [##9, 12, 14, 20 and 21] had significant intra-neural fibrosis in the area of the suture with complete loss of the fascicular aspect of the nerve and a neuromatous aspect. Only two patients [##5 and 19] presented a favorable aspect of the suture on ultrasound with continuous nerves and respected fascicular aspect.

Table 3 surgery findings

Patients	
2	Lost of substance, 5 cm
7	Extensive neuropathy
8	Impingment with schrapnel
9	Neuropathy and scare with fibrosis
22	Impingment with orthopedic hardware
23	Lost of substance, 5 cm
25	End bulb neuroma

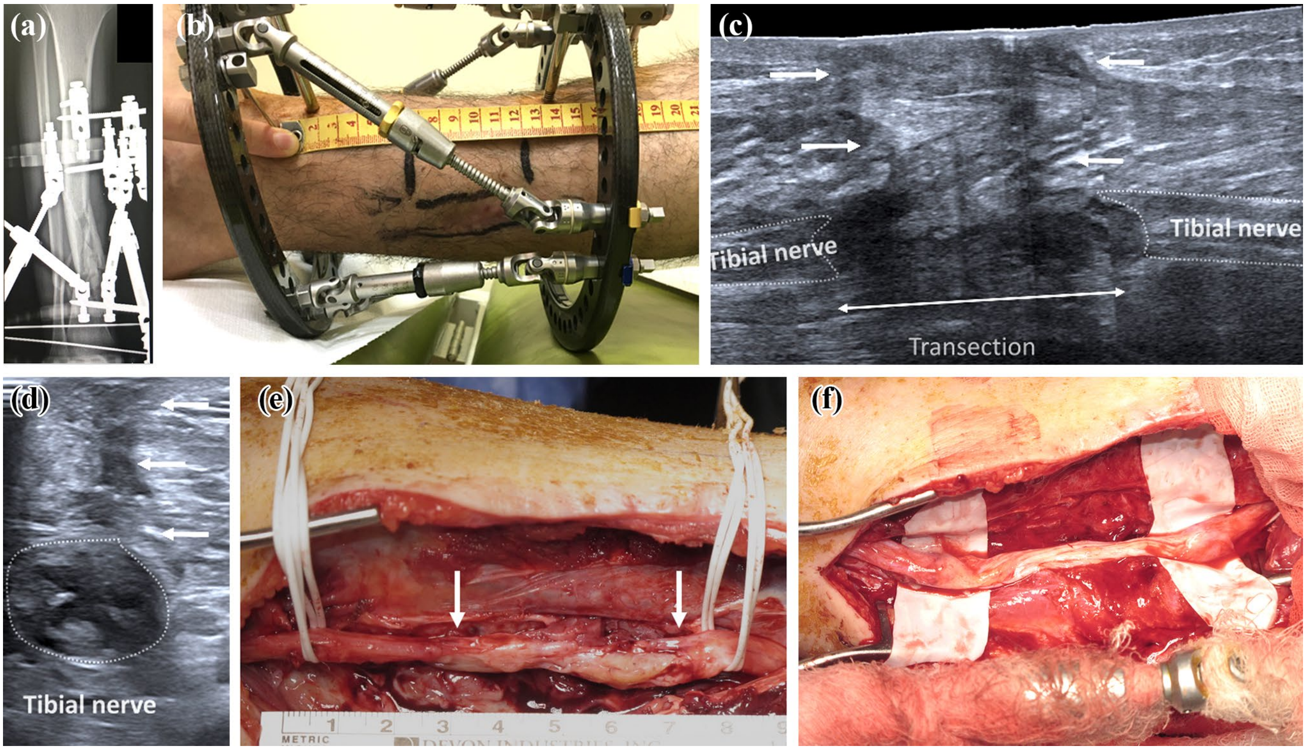

Fig. 6 Shrapnel injury of the left leg (patient #24). Paralysis of the tibial nerve. **A** Anteroposterior radiographic view of the leg showing tibial and fibular bone fractures treated by external fixator. **B** Skin marking of the nerve injury. Longitudinal (**C**) and axial (**D**) ultrasound sections showing the path of the projectile (white arrows) and the tibial nerve transection with extensive loss of substance (double-head arrow). Intraoperative views of the tibial nerve injury (**E**) and sural nerve graft (**F**)

Echosurgical correlations (Table 3)

We have echosurgical correlations for 7 injured patients. We did not note any discrepancy between the surgery and the ultrasound data. In two patients, extensive loss of substance of the median [patient #23] and tibial [patient #2] nerves (Fig. 6) described on ultrasound were found intraoperatively. A conflict between a humerus osteosynthesis and the radial nerve was confirmed in patient #22. Patient #8 had a conflict between a shrapnel and the median nerve in the forearm, resulting in disabling neuropathic pain requiring opiates. Ultrasound examination provoked ultrasonographic Tinel sign (compression of the affected nerve by transducer-induced paraesthesia). The ultrasound diagnosis was confirmed by a local anaesthetic test with lidocaine. The patient improved after removal of the shrapnel. Patient #13 had extensive median nerve neuropathy in the arm up to the level of the pronator teres muscle, attributed to the blast with ulna fracture. This neuropathy benefited from neurolysis.

Interest of the skin preoperative marking

During the preoperative ultrasound assessment, we systematically marked the skin using an indelible felt-tip pen. We tagged the nerve lesion extent, in the event of loss of substance, particularly. We also tagged the vessels to limit the vascular harm during surgery access. A picture was taken with the patient's smartphone in case the surgical management was delayed.

Table 4 ENMG findings

Patients	
1	Median: axonal lesion, ulnar: conduction bloc
3	Median: full axonal lesion, ulnar: partial axonal lesion
4	Median and radial: axonal lesion and conduction bloc
7	Median: neurapraxia
11	Radial: axonotmesis 95%
13	Median and ulnar: partial axonotmesis,
16	R median: important axonotmesis
18	Accessory: partial axonotmesis
22	Radial: complete denervattion
25	Median: neurotmesis, ulnar: axonotmesis

Table 5 Proposed structural ultrasound report for ballistic peripheral nerve lesions

Parameters	Ultrasonographic description
Nerve transection	Complete Partial Percentage of injured fascicles Substance loss extent Distance between the stamps
Neuroma	Terminal In continuity
Neuropathy	Axial surface measurements Oedematous phase Thickened Hypoechoic Dedifferentiated Doppler hyperaemia Chronic phase related to axonal loss Atrophic Hyperechoic Loss of fasciculation
Compressive element	Projectile Bone fragment Other
Fibrosis	Intraneural Perineural
Muscle status	Early hyperechogenicity Atrophy Fatty infiltration
Vascular status	Vessel patency

Correlations of ultrasound with ENMG (Table 4)

The ultrasound findings in 10 injured patients were in accordance with the ENMG data. In all cases of neuroma-in-continuity observed on ultrasound, axonotmesis of varying severity was detected on ENMG. In case of blast neuropathies observed on ultrasound, ENMG showed axonal damage and prolonged conduction block. In case of atrophy and dedifferentiation of the nerves found on ultrasound, ENMG showed a pronounced axonal loss.

Proposed structural report (Table 5)

Precise condition of the nerve must be described for acute management of BPNI. Table 5 shows the different findings to report including: nerve transection details, presence of terminal/in continuity neuroma, descriptive findings of neuropathy orienting on oedematous or chronic phase, the presence of projectile, bone fragment or other specific compressive element, and the presence of intra/peri-neural fibrosis. Vascular status was added because of frequent associated wounds, and muscular consequences showing denervation findings.

Discussion

In war wounds, priority is given to life-threatening injuries and surgical exploration of limb injuries for the purpose of haemostasis, vascular and bone repair. The lesion topography in wartime has been well studied [4, 5]. Because of the wearing of personal protective equipment, the limbs are most often affected [6]. The main characteristic of ballistic injuries is that they are most often multi-tissue, from skin to bone, including vessels and nerves. Thus, even if rapid lethal wounds are mainly axial, limbs injuries can alter the vital prognosis if the blood loss is not rapidly stopped. The functional prognosis is then burdened with complications, infection mainly [7, 8], then the more long term disability consequences because of nerve and musculoskeletal system lesions.

Nerve injuries can be direct, projectile-related or indirect. Direct nerve injuries may result in partial or complete section of the nerve. Indirect nerve injuries may be bone fragment related: when a bullet penetrates a bone, bone fragments accompany the projectile. The projected bone fragments can themselves become nerve-damaging [9]. They can also be caused by the shock wave (blast) resulting in neuropathy, as the nerves are very sensitive to the energy transmitted to them. Thus, considering the variety of injuries encountered, and given the difficulties encountered in establishing the precise cause of nerve damage in a soldier who has suffered multiple impacts, imaging of BPNI is essential to evaluate patients after hemodynamic conditions stabilization and bone injury and infection management.

Ultrasound is an effective tool, correlated with clinical, surgical and electrophysiological data, to localize the nerve injury and to determine its severity using the Seddon classification [3]. Ultrasound allows precise preoperative spotting with skin marking. The correlations of the ultrasound with the ENMG are interesting and the two examinations are complementary, especially in case of insufficiency of one of the two techniques. During the first three weeks, the ENMG is usually uninformative. It is necessary to wait for the Wallerian degeneration for the denervation due to the axonal damage to occur. When no response is obtained on ENMG, it is not possible to differentiate axonotmesis from neurotmesis [10] and ultrasound is useful in showing and characterizing nerve damage. Ultrasound is also essential when the ENMG is not able to localize the lesion precisely. Conversely, ENMG is of great interest when ultrasound is not informative, such as in case of extensive fibrosis or when the skin condition makes it impossible. These two techniques are complementary for nerve assessment and must be included in a multidisciplinary approach, as we proposed during our missions in Armenia. It helps the surgeon to make a more accurate diagnosis, to determine the indication and to prepare the nerve repair optimally, adequately guided by skin marking when necessary.

However, it is important to remember that MRI is more effective than ultrasound for the objective assessment of muscle denervation edema.

In our series, we noted a clear predominance of BPNI in the upper limbs (17 of 25 patients). About half of the patients (13/25) had at least two injured nerves. Most BPNI were non-transection injuries or so-called lesions-in-continuity, including neurapraxia (36%) and axonotmesis with neuroma-in-continuity (18%). Similar epidemiological data are also reported in the military surgery literature [11, 12]. Neurotmesis was present in 18% with only two terminal neuromas. In one case, the neurotmesis was due to an intraneural bone fragment.

Twelve patients had already undergone surgery, 10 of whom had a nerve sutured. However, most of these nerve repairs had been performed in emergency situations or without the proper use of microsurgical techniques leading to an unfavourable ultrasound appearance with neuroma, extensive intraneural fibrosis, loss of substance or suture tension.

Our first mission took place in January 2021, 45 days after the end of the conflict. Considering that primary nerve repair is usually contraindicated in war wounds [11], and extensive evaluation can be delayed. However, this has to be balanced between difficulties faced because of skin and soft-tissue injuries, and the substantial help provided by ultrasound in characterizing nerve damage prior to treatment, as observed during our missions and already related in previous publication [13, 14]. There are few articles in the literature concerning the contribution of ultrasound to peripheral nerve lesions in times of war. Smith and al [13] described 4 cases of military personnel wounded by gunshot or blast with metal fragment injuries. Clinical and electrodiagnostic exam provided inadequate localization and severity data of the nerve injuries. High-resolution peripheral nerve ultrasound disclosed nerve abnormalities like focal enlargement, nerve discontinuity and neuroma, confirmed intra-operatively.

In addition to ultrasonography, other imaging technologies (if available) can be used to better visualise BPNI. A radiographic assessment with 2 perpendicular incidences allows the localization of the projectile(s) and the visualization of bone and joint injuries. The contrast-enhanced CT scan is the gold standard [15] to identify thoraco-abdominal, vascular and bone lesions and to localize the projectiles [16]. The MRI is useful for exploring the medulla, the brain, and the brachial plexus [15].

Utrasound of nerves requires a high-end device and quality probes whose frequency is adapted to the explored nerve: at least 14 or 18 MHz for deep nerves, 22 or 24 MHz for superficial nerves. The operator must be trained and have a perfect knowledge of the anatomy and semiology. In the acute stage, priority is given to life-threatening lesions, treatment of fractures and vascular lesions. The skin condition is an important limitation to ultrasound exploration of nerves, especially in case of decaying wounds or extensive scarring. However, only two 2/25 patients could not be successfully explored by ultrasound: one because of extensive fibrosis preventing visualization of the accessory nerve, the other because of the skin condition associated with multiple bony fragments of the coracoid process preventing exploration of the infraclavicular brachial plexus.

The ultrasound report must describe the affected nerve(s) and the location of the lesions. Based on our experience, we elaborated a comprehensive ultrasound report, based on Seddon classification [3]. Elshewi and al. [17] similarly offer a structured analysis of nerve damage with a similar approach. They use the Sunderland classification in 5 stages [18]. In this classification, the ultrasound distinction between stages 1 and 2 where the nerve can be thickened in both stages and between stages 3 and 4 where there is a loss of the fascicular aspect of the nerve which is thickened is difficult and makes us prefer the Seddon classification into three stage easier to use in ultrasound.

Conclusion

Ballistic nerve injuries are often multifocal, due to the use of cluster bombs, automatic weapons and sniper fire. The after-effects of this type of injury are severe, and the management is complex, hence the need for a multidisciplinary team including surgeons, anesthesiologists specializing in pain management, infectious diseases specialists, neurologists, physiotherapists and radiologists. Ultrasound is the key imaging test to explore ballistic nerve injuries, once the acute phase is over, provided that suitable equipment is available and that there is a good knowledge of anatomy and semiology. Ultrasound allows localizing the nerve injury(ies) which can be multifocal and affect several nerves. In our experience, it also allows a good characterization of the nerve lesion with a good correlation with the electrophysiology and surgical data.

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Declarations

Conflict of interest O Fantino,, G Chauplannaz, T Ferry, A Tchurukdichian, P Pernot, A Gazarian, M Dziadzko, M Nersisyan and JB Pialat have no conflict of interest who could influence the content of this article.

Ethical approval The current study had been approved By Wigmore Clinic Erevan ethical committee.

Consent to participate Informed consent was obtained from all individual participants included in the study. Written informed consent was waived by the Institutional Review board.

Consent for publication Consent for publication was obtained from all individual participants included in the study.

References

1. Cigolotti O, Carlotti MA (2003) Sénat [cited 10 July 2024]. Haut-Karabagh: dix enseignements d'un conflit qui nous concerne. https://www.senat.fr/rap/r20-754/r20-754.html
2. Chipman JN, Mott RT, Stanton CA, Cartwright MS (2009) Ultrasonographic Tinel sign. Muscle Nerve déc 40(6):1033–1035
3. Seddon HJ (1942) A classification of nerve injuries. Br Med J 2(4260):237–239
4. Pinto A, Russo A, Reginelli A, Iacobellis F, Di Serafino M, Giovine S et al (2019) Gunshot wounds: ballistics and imaging findings. Semin Ultrasound CT MR févr 40(1):25–35
5. Bellamy RF (1992) The medical effects of conventional weapons. World J Surg 16(5):888–892
6. Montgomery SP, Swiecki CW, Shriver CD (2005) The evaluation of casualties from Operation Iraqi Freedom on return to the continental United States from March to June 2003. J Am Coll Surg 201(1):7–12 (**discussion 12-13**)
7. Russell R, Clasper J, Jenner B, Hodgetts TJ, Mahoney PF (2014) Ballistic injury. BMJ 348:g1143
8. Bruner D, Gustafson CG, Visintainer C (2011) Ballistic injuries in the emergency department. Emerg Med Pract 13(12):1–30 (**quiz 31**)
9. Straszewski AJ, Schultz K, Dickherber JL, Dahm JS, Wolf JM, Strelzow JA (2022) Gunshot-related upper extremity nerve injuries at a level 1 trauma center. J Hand Surg 47(1):88.e1-88.e6
10. Wijntjes J, Borchert A, van Alfen N (2020) Nerve ultrasound in traumatic and iatrogenic peripheral nerve injury. Diagn Basel Switz. 11(1):30
11. Giannou C, Baldan M, Molde Å (2024) War surgery: working with limited resources in armed conflict and other situations of violence, vol 2 [cited 10 July 2024]. https://shop.icrc.org/war-surgery-working-with-limited-resources-in-armed-conflict-and-other-situations-of-violence-volume-2.html
12. Dunn JC, Eckhoff MD, Nicholson TC, Campbell W, Kenney K, Smith J et al (2021) Combat-sustained peripheral nerve injuries in the United States Military. J Hand Surg 46(2):148.e1-148.e8
13. Smith JK, Miller ME, Carroll CG, Faillace WJ, Nesti LJ, Cawley CM et al (2016) High-resolution ultrasound in combat-related peripheral nerve injuries. Muscle Nerve 54(6):1139–1144
14. Howard IM, Sedarsky K, Gallagher M, Miller M, Puffer RC (2024) Combat-related peripheral nerve injuries. Muscle Nerve. https://doi.org/10.1002/mus.28168
15. Ditkofsky NG, Maresky H, Mathur S (2020) Imaging ballistic injuries. Can Assoc Radiol J J Assoc Can Radiol 71(3):335–343
16. Mathieu L, Goncalves M, Murison JC, Pfister G, Oberlin C, Belkheyar Z (2022) Ballistic peripheral nerve injuries: basic concepts, controversies, and proposal for a management strategy. Eur J Trauma Emerg Surg Off Publ Eur Trauma Soc 48(5):3529–3539
17. Elshewi IE, Fatouh MM, Mohamed RNES, Basheer MA, El Liethy NE, Abbas HM (2023) Value of ultrasound assessment for traumatic nerve injury of the upper limb. J Ultrasound 26(2):409–421
18. Sunderland S (1990) The anatomy and physiology of nerve injury. Muscle Nerve 13(9):771–784