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## The choice of method of electroneuromyography in remote consequences of gunshot and mine-blast injuries of limb nerves

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**Objective.** Clarification of the nature of damage and degree of functional disorders in the remote consequences of gunshot and mine-blast injuries of limb nerves using neurophysiological techniques (NP) of functional diagnostics (stimulation and needle electromyography), correlation of these data with the nerve damage characteristics determined during surgical interventions (operative findings).

**Materials and methods.** 480 military personnel and civilians, men aged 18-64 years (average age 33.5 years), with gunshot and mine-blast injuries of limb nerves (LNI) within 1 to 11 months after injury were examined. A total of 1400 EMG studies were conducted. Clinical-neurological methods were used to determine the level, degree, and nature of LNI.

**Results.** Among the examined 480 patients, complete nerve damage was detected in 299, and partial in 181. Causes of nerve damage included: shrapnel, gunshot, mine-blast injuries, nerve rupture due to bone fractures, injuries by sharp objects, iatrogenic damage. In 62.3% of cases of complete LNI surgical interventions were performed using the technique of neurotization using branches of donor nerves. Provided anatomical integrity of nerve structures and presence of conductivity during EMG testing, external or internal neurolysis was performed. Surgical intervention timing: up to 6 months post-injury - 68.1% of cases; up to 3 months - 31.9%. Based on the results of comprehensive clinical-NP research, adapted schemes for assessing NP data corresponding to each pathohistological type of LNI were developed, and NP criteria for classifying consequences of LNI into three degrees of severity of functional deficit - mild, moderate, and severe were proposed.

**Conclusions.** Criteria for choosing the optimal NP diagnostic methodology for the remote consequences of gunshot and mine-blast injuries of limb nerves have been determined. Comprehensive clinical-instrumental diagnostics allows to objectify the level and degree of limb nerve damage, signs of neuromuscular apparatus recovery, provides information for planning of the surgical tactics and subsequent rehabilitation therapy.

**Keywords:** *trauma; gunshot nerve injuries; mine-blast injuries; pain syndrome; diagnosis; electromyography; surgical treatment*

### Introduction

According to contemporary data, peripheral nerve (PN) injuries occur in 9-25% of cases of mine-blast trauma. Damage to brachial plexus structures accounts for 12 to 25% of all combat injuries [1, 2]. The severity of a patient's injury is determined by the caliber and type of projectile, the presence of associated injuries to blood vessels, nerves, limb bones, and soft tissues, which are detected in approximately 80% of cases.

The results of surgical treatment of combat trauma of PN, even with the availability of modern diagnostic equipment and a high level of surgical technique, are often unsatisfactory. This is due to the widespread damage to nerve trunk, the combined action of different

types of energy, its direction, and the complex effects of blast waves on the body, as well as the features of the consequences of combat trauma of PN such as intrastem scars, purulent-inflammatory complications frequently accompanying combat trauma, disruption of microcirculation due to frequent injuries to major vessels, and significant damage to surrounding soft tissues.

Data of S.S. Strafun (2018) [3] indicate that even without disruption of the anatomical integrity of nerves in gunshot and mine-blast injuries, pathological changes occur in the injury zone, potentially causing direct muscle trauma or ischemia in muscles innervated by the damaged nerve. Therefore, there is a need to



determine the nature and severity of nerve damage and, most importantly, to predict future recovery [3,4]. For optimal restoration of lost nerve functions in the limbs, modern neurophysiological (NP) diagnostics is crucial. It allows for the objectification of the level, type of injury, and nature of the pathological process, selection of the surgical treatment option, determination of the features of rehabilitation therapy, as well as monitoring of recovery dynamics.

Thus, the study of the clinical-NP features of the course of remote consequences of combat PN injuries and the use of a complex of modern electroneuromyographic (ENMG) and electromyographic (EMG) diagnostic methods as pathognomonic for objectifying the condition of nerves and muscles after trauma is actual.

**Objective:** to specify the nature of damage and the degree of functional disorders in the remote period of gunshot and mine-blast injuries to the nerves of the limbs using NP diagnostic methods (stimulation and needle EMG), to study the correlation of these data with the features of nerve injuries detected during surgical interventions.

## Materials and methods

### Study participants

During the period from March 2022 to November 2023, ENMG-diagnostics of nerves function and limb muscle was performed in 480 servicemen and civilians aged 18 to 64 years old (mean age - 33.5 years) with gunshot and mine-blast injuries of the PN at the department of Functional Diagnostics of the State Institution of Romodanov Neurosurgery Institute of the National Academy of Medical Sciences of Ukraine. All patients were male. A total of 1400 ENMG and EMG studies were performed. The patients were admitted for specialised treatment within 1 to 11 months after the injury. Upper limb nerve damage was recorded in 53.9% of cases, lower limb nerve damage - in 46.1%.

Informed and voluntary written consent for participation in the study and publication of data was obtained from all patients. The study was approved by the Ethics Committee of the SI "Romodanov Neurosurgery Institute of the National Academy of Sciences of Ukraine" (Minutes No. 2 dated April 14, 2021).

The following research methods were used: 1) general clinical - to establish the diagnosis of "combat injuries of PN" (gunshot, mine-blast); 2) clinical and neurological - to assess the degree of traumatic injury of PN using modern generally accepted scales (assessment of the initial neurological status of patients, determination of the topical level of nerve injury, detailed assessment of existing neurological deficit motor (MRC Scale from M0 to M5) and sensory (Seddon від S0 до S5) functions, determination of lost and preserved muscle functions, sensitivity, etc. The degree of expressiveness of the pain syndrome was determined by the visual analogue scale of pain assessment (VAS), neuropathic pain - by the DN4 questionnaire (Bouhassira et al., 2005) [5]). The degree of recovery of movements and sensitivity was assessed using the specified scales and questionnaires;

3) neuroimaging, radiological - as indicated; 4) NP-complex diagnostic methods (preoperative, intraoperative and postoperative electrodiagnostics). The following techniques were used: examination of M-responses to direct nerve stimulation, predominantly innervating this muscle; segmental and step-by-step (short-segmental, as indicated) determination of the excitation conduction velocity (ECV) by motor and sensory fibres of the nerve to identify the site of conduction blockage; intramuscular needle EMG of muscles involved in the pathological process and intact muscles with evaluation of denervation spontaneous activity of muscle fibres and motor units parameters, determination of the severity of damage to structures and signs of recovery. The methods are described in the works [6-10] and are given in national and industry standards.

The studies were performed using the "Neuro-MVP" apparatus ("NeuroSoft", RF). Stimulation was carried out from the cathode with pulses of 0.1, 0.2, 0.5 and 1.0 ms duration, at a of frequency 1-4/s, the stimulation intensity was selected individually, mostly - 20-35 mV (10-30 mA), considering the level at which the maximum amplitude of action potentials (AP) of the nerve and M-response of the muscle was achieved. In some cases, they were recorded simultaneously on two output channels. Skin impedance under the electrodes was 5-10 kOhm. Deployment frequency - 10 ms/division, amplifier sensitivity was 50-100  $\mu$ V for nerve AP, 100-10000  $\mu$ V - for muscle AP. The frequency bandwidth was 10-10000 Hz. The mean value of 4 responses was calculated to determine the AP.

At needle EMG with immersion of a standard electrode in the motor point of the muscle, spontaneous activity of muscle fibres, as well as motor unit potentials (MUPs) during voluntary muscle contraction, interference and pattern of MUPs recruitment were investigated (**Table 1**). Additionally, a modified technique of M-response study during needle electrode withdrawal from the denervated muscle was used.

### Statistical analysis

The research results were analyzed using the EZR package v. 1.35 (R statistical software version 3.4.3, R Foundation for Statistical Computing, Vienna, Austria). For qualitative data presentation, the frequency of occurrence (%), the risk of not achieving high treatment efficiency (%), and their 95% confidence interval (CI) were calculated. For rank variables - indicators of PN, the frequency (%) for each score rating was indicated. When comparing rank variables before and after treatment, the Wilcoxon T-test for paired samples was used, when comparing results between groups - the Kruskal-Wallis test, and for pairwise post hoc comparisons - the Dunn index multiple comparison test. Two-tailed critical regions were used in the analysis, and the critical significance level was set at 0.05.

### Inclusion criteria

Military personnel and civilians aged over 18 with nerve damage due to gunshot and mine blast injuries, confirmed by accompanying medical documentation, referred for ENMG/EMG diagnostics and specialized treatment within 1 to 11 months after injury. All

*This article contains some figures that are displayed in color online but in black and white in the print edition*

participants provided informed consent to participate in the study.

**Group characteristics**

Participants were divided into two groups based on the severity of PN and muscles damage and the decrease/absence of motor function. The study group comprised 299 (62.3%) cases of complete motor dysfunction and severe nerve damage, while the comparator group included 181 (37.7%) cases of partial nerve damage.

The causes of nerve damage (types of trauma mechanisms) were as follows: mine blast shrapnel

wounds - 53.65%, gunshot wounds - 29.87%, nerve damage due to fractures and dislocations of limb bones - 10.36%, nerve injuries during medical evacuation stages (limb damage by tourniquets, iatrogenic injuries during primary surgical treatment) - 6.09%.

Among the examined individuals, 42.5% (204) sustained injuries to the upper limbs, 57.5% (276) to the lower limbs, and 28.0% (134) to both upper and lower limbs. The radial, gluteal, and tibial nerves were most frequently affected (**Fig. 1**).

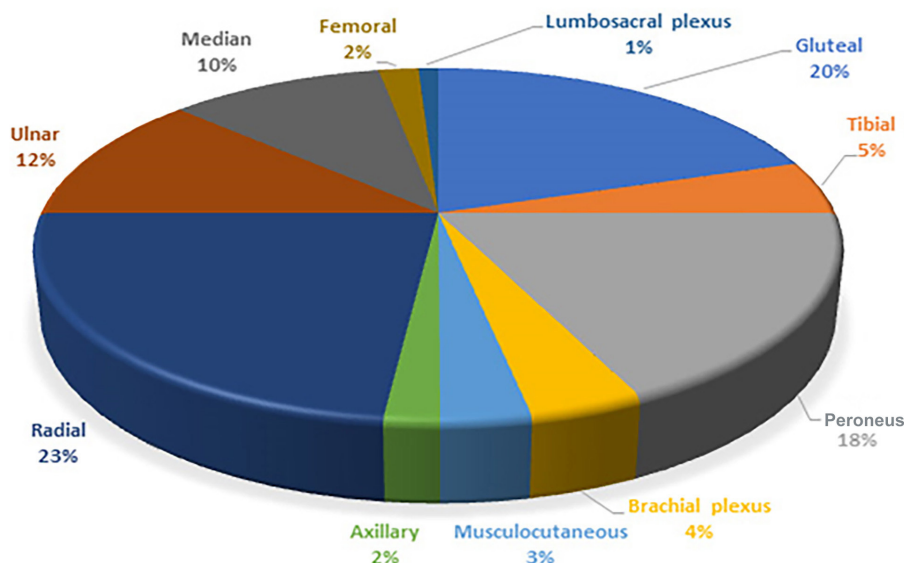
**Study Design**

The study is retrospective cohort (**Fig. 2**).

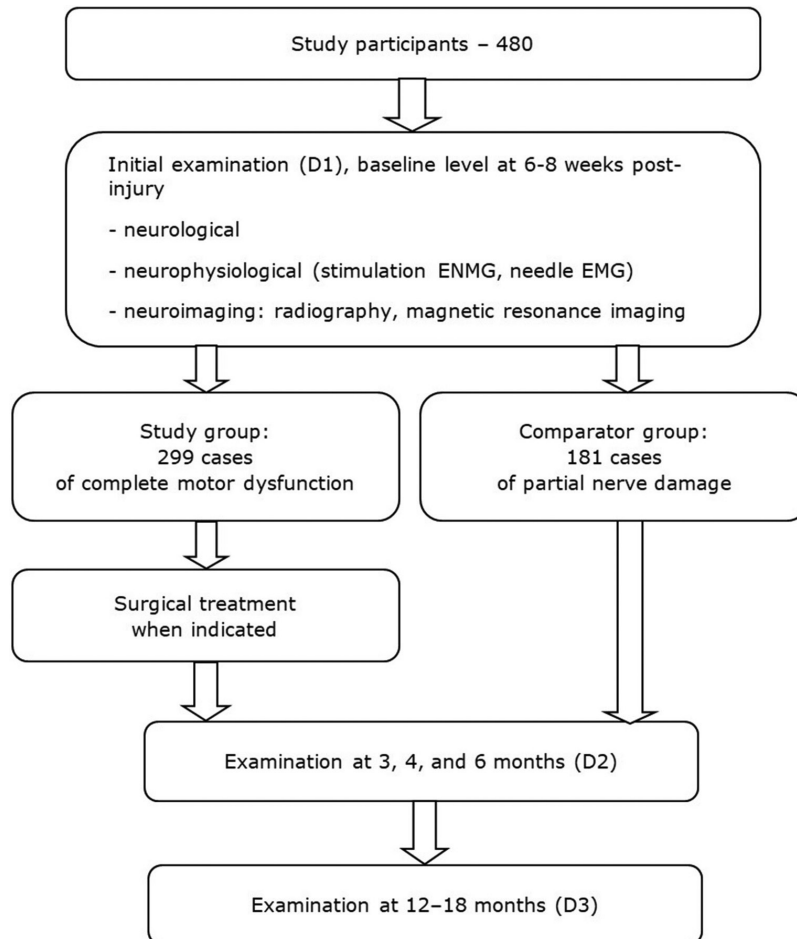
**Table 1.** Investigated nerves and indicators of "key" muscles

Nerves	Muscles
Normative parameters for the nerves of the upper extremity include ECV >50 m/s, terminal (distal) latency for the median nerve <4 ms (with interelectrode distance of 60-70 mm), residual latency not exceeding 2.5 ms, and M-response amplitude not less than 50% compared to the intact side*	
Median	Thenar, radial flexor of the wrist
Ulnar	Hypothenar, ulnar wrist flexor.
Brachial plexus	Shoulder girdle: infraspinous, supraspinatus deltoid, biceps brachii, triceps brachii, wrist extensors, wrist flexors, thenar and hypothenar muscles.
Musculocutaneous	Biceps brachii
Radial	Wrist and finger extensors, triceps brachii
Axillary	Deltoid
Normative parameters for the nerves of the upper extremity include ECV>50 m/s, residual latency <3 ms, M-response amplitude not less than 50% compared to the intact side	
Gluteal	Anterior tibial, gastrocnemius, short extensor of toes, abductor hallucis
Tibial	Gastrocnemius, abductor hallucis muscle
Peroneus	Anterior tibial, short extensor of toes
Femoral	Quadriceps femoris

Note. \* In cases of significantly reduced conduction velocity (CV) and significantly increased distal latency (70% relative to the lower limit of normal), the possibility of tunnel syndrome or polyneuropathy should be excluded.



**Figure 1.** Frequency of combat injuries to limb nerves



**Figure 2.** Study Design

The aim of the ENMG diagnosis was to: 1) determine objective signs of limb nerve damage; 2) assess the degree of nerve function preservation; 3) evaluate the extent of nerve and muscle function loss (compared to the intact limb); 4) identify signs of nerve regeneration and reinnervation. 5) objectively assess changes in nerve and muscle function parameters compared to preoperative ENMG data. The obtained data allowed for the establishment of criteria for selecting ENMG diagnostic methods within specific time frames, i.e., developing a neurophysiological diagnostic algorithm.

The timing scheme was adhered to, as performing baseline electrophysiological studies at the 6th week post-injury is crucial. Subsequent examinations can be conducted at 3-4 months intervals to monitor nerve function recovery or its absence. It should be noted that in the absence of muscle reinnervation within 12 to 18 months, muscle changes become irreversible, hence excessive delay in surgery should be avoided.

The first assessment of the outcomes of reconstructive interventions was conducted at least 2 months earlier than the predicted regeneration period. The timing of the next (second) follow-up examination was within the predicted regeneration period. Subsequent evaluations were performed at the patient's repeat visits (on

demand) and until there was no significant progress in the recovery of lost neurological functions.

For interpreting the data from the first neurophysiological diagnosis, the following factors were important: 1) the cause of injury and the time elapsed since it (and primary surgical treatment); nerve function recovery.

When choosing the type of surgical intervention for gunshot injuries to the peripheral nerves, the level of nerve damage, the number of damaged structures, the nature of the injury, the extent of diastasis, and the type of intraneural nerve structure were taken into account. Surgical interventions for the consequences of gunshot injuries to the peripheral nerves and brachial plexus included neurolysis, autoneuroplasty, selective neurotization, chronic electrical stimulation, tendon and muscle transposition.

#### *External and internal neurolysis*

Neurolysis of peripheral nerve structures was considered the release of anatomically preserved nerve structures from surrounding scar tissue both circumferentially and in the distal/proximal direction relative to the level of injury (external neurolysis). Internal neurolysis involved performing longitudinal epineurotomy above the most affected segment of

the nerve structure until a typical fibrous structure appeared.

#### *Nerve suturing*

In cases of gunshot injuries, nerve suturing most commonly involved techniques of epineurial and perineurial sutures. In some cases, fascicular nerve suturing was performed. Whenever possible, attempts were made to perform direct suturing of the damaged nerve ends. For this purpose, such methods of overcoming the diastasis between nerve ends included mobilization within acceptable limits, transposition of the nerve to a new bed to provide a shorter pathway, optimizing limb position, etc. In cases of direct nerve suturing, a differentiated microsurgical nerve suturing was applied depending on the nerve's structural type [11].

#### *Autologous nerve grafting*

The technique of autologous nerve grafting, involving the placement of segments of appropriate length between the proximal and distal segments of the injured nerve, predominantly sensory nerves, has been described in numerous literature sources [12] and did not differ significantly when performed in the patients involved in the study. Cutaneous nerves (most commonly sural nerve, superficial branch of the radial nerve, medial cutaneous nerves of the upper arm and forearm) were usually used as donor nerves. In cases of significant nerve defects, ulnar, median, or peroneal nerves were used in 14 cases.

#### *Selective reinnervation - neurotization, anatomical, physiological, and technical principles*

Nerve transfer (or neurotization) is a reconstructive surgical method aimed at restoring the functional capacity of only the distal part of the damaged peripheral nerve by involving the proximal part of another peripheral nerve with preserved functional capacity, i.e., neurons and their axonal processes serve as donors for reinnervation of the distal effector organ, for example, muscle or muscle groups [13]. The concept of this reconstructive surgical method involves sacrificing the function of less important donor nerves and donor muscles to restore more functionally significant recipient nerves and recipient muscles [14].

The anatomical and physiological principles underlying neurotization are quite simple: a) for restoring sensory function, a sensory donor nerve is used; for restoring effective motor function, a donor nerve with an appropriate number of motor fibers is used; b) loss of function of the donor nerve or donor muscle due to denervation (donor harvesting) should not result in the loss of important or critical function.

Technical principles aimed at achieving maximum functional outcome (effective function): a) harvesting the donor nerve as close as possible to the terminal effector organ; b) performing a direct anastomosis between the donor and recipient nerve without using an autologous graft between them, c) using donor nerves whose primary function closely resembles the desired function of the recipient nerve (agonistic functions) to facilitate cortical re-adaptation, d) performing neurotization at earlier stages for maximal effective recovery.

ENMG diagnostics was used for an objective assessment of nerve function recovery, corresponding

muscle functions, and movements of the injured limb to obtain potential criteria for justifying further patient management tactics.

## **Results and Discussion**

Analyzing the peculiarities of clinical manifestations and ENMG diagnostics data of the consequences of gunshot and mine blast injuries to the nerves of the upper and lower extremities at different levels, we proceeded from existing concepts of two possible mechanisms of restoring neuromuscular function: reinnervation of muscle fibers by collateral sprouting of axons of motor fibers or axon regeneration. If "foreign" axons "pick up" denervated muscle fibers (collateral sprouting), this manifests as high-amplitude polyphasic motor unit action potentials (MUAPs). Low-amplitude and polyphasic potentials are manifestations of axon regeneration.

In assessing the ENMG diagnostics data functions of traumatized peripheral nerves were relied on the AAEM EFNS/PNS criteria (Criterion of American Association of Electrodiagnostic Medicine and European Federation of Neurological Societies/Peripheral Nervous System). Surviving Schwann cells are capable of remyelination within 6–12 weeks. Axonal regeneration within the Schwann cell sheath occurs at a rate of approximately 1 mm/day in cases of axonal injury. However, its sprouting may occur in the wrong direction, leading to improper innervation, such as fibers of another muscle, tactile receptors in the wrong location, or temperature receptors instead of tactile ones. Regeneration becomes impossible if the cell body dies, and it is unlikely if the axon dies completely.

### **ENMG criteria for determining the pathohistological type of limb nerve injury**

**Neurotmesis** (complete anatomical transection of the nerve and its sheaths) at 4-6 weeks after injury was characterized electroneuromyographically by the absence of the M-response with distal and proximal nerve stimulation (**Fig. 3, A**). Taking into account the innervation characteristics of the muscle, the M-response amplitude of <100  $\mu$ V to supramaximal stimulation can be considered as the absence of the M-response. At needle ENMG of the corresponding key muscle (muscles), there is absence of motor unit potentials (MUPs) on voluntary contraction, with vigorous spontaneous activity manifesting as fibrillation potentials (FPs) and positive sharp waves (PSWs) (**Fig. 3, B, Table 2**). According to L.F. Kasatkina (1980), in cases of neurotmesis of long nerves, such an ENMG pattern is typical for 11-16 days after injury [8].

Therefore, the ENMG+EMG diagnostic method proved to be sufficiently sensitive in detecting neurotmesis (87%) and specific (89%). The method is informative regarding the presence of ENMG+EMG signs of neurotmesis and their absence (81–92%) in the subacute period of traumatic nerve injury, which is important in the preoperative period.

The study on the use of ENMG+EMG methods in patients with traumatic nerve injuries of the extremities allows determining the presence and severity of the



injury. The advantages of the method lie in its high sensitivity, specificity, and informativeness (prognostic value), reproducibility in repeated examinations, quantitative assessment of changes, which is important in dynamic monitoring.

**Axonotmesis** – complete axonal intrastem nerve interruption – due to complete disruption of axonal transport leads to axon death and the development of Wallerian degeneration, therefore, the ENMG picture is similar to that described for neurotmesis. Fibrillation potentials (FPs) appear on days 4–16, positive sharp waves (PSW) – approximately 7 days after FP.

If **axonotmesis is partial**, there is Wallerian degeneration of only a part of axons within the nerve and partial muscle denervation. Unlike cases of neurotmesis, within 2 weeks, along with denervation, reinnervation processes are activated, characterized by ENMG signs:

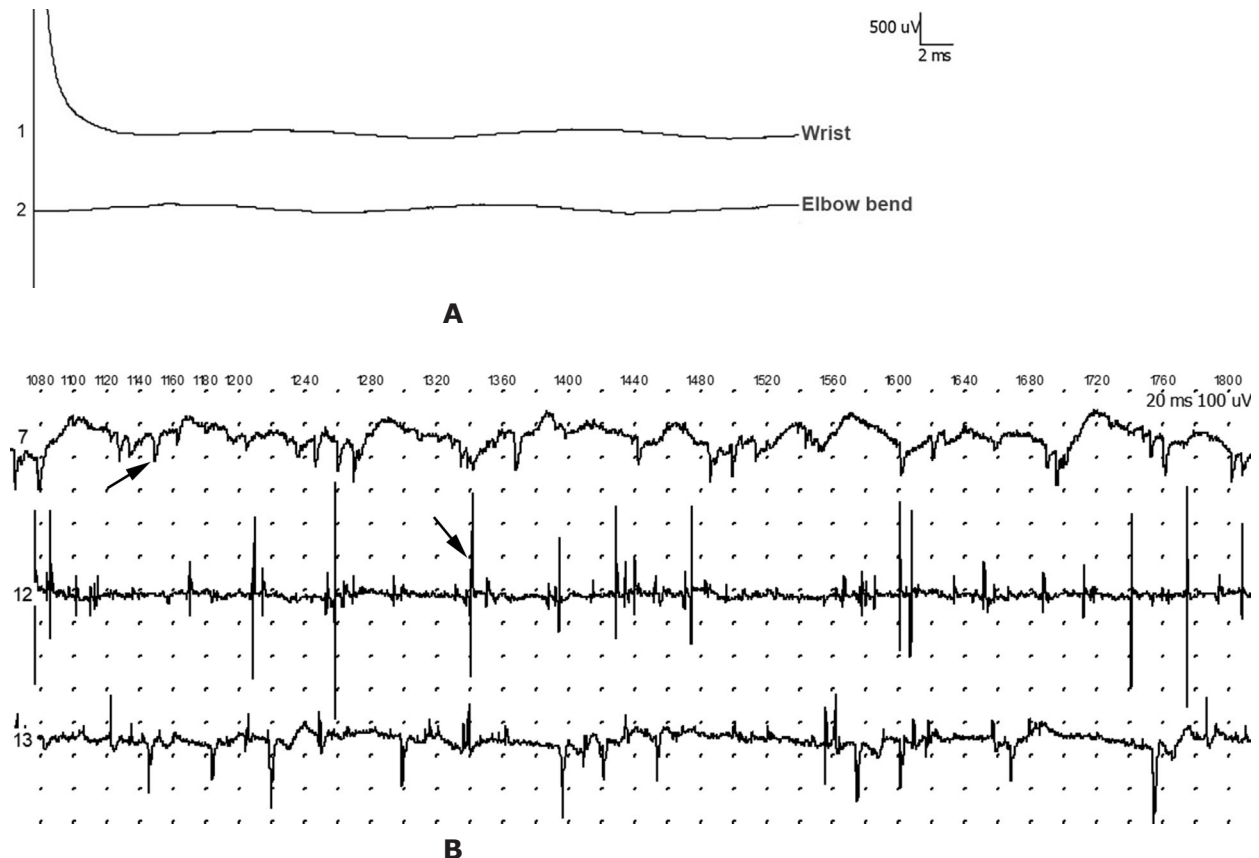
- significant decrease in M-response amplitude (by  $\geq 50\%$ );
- significant decrease in ECV (from  $-50\%$  to  $0$  m/s);
- conduction block (CB) in the affected segment (due to damage to the myelin sheath) may be so pronounced that there is no M-response to nerve stimulation proximal to the lesion zone;
- loss of nerve sensory response.

In needle EMG:

- during the first week, electrical "silence" is possible;
- on days 7–16, vigorous spontaneous activity in the form of FP can be recorded;
- on days 14–30, vigorous PSWs;
- on the 3-4th week, against the background of pronounced denervation activity of FP and PSW during voluntary muscle contraction (tension), MUPs are recorded (**Fig. 4**).

In the first six months after injury, signs of contraction were noted only in large proximally located muscles of the limb, and later (6 months–1 year) motor function was restored in muscles located more distally. Already 90 days after the injury, some of the affected individuals exhibited the appearance of substitute movements, allowing compensation for motor impairments through gross undifferentiated locomotion.

**Demyelinating lesions** are considered as nerve contusion due to accompanying compression of the nerve by bony, fibrotic, or other volumetric formations (hematoma, foreign body). In stimulation ENMG of motor conduction along nerve segments and inching (stepwise examination) in the demyelination site, ECV significantly decreases, and the ENMG phenomenon of CB is revealed. Schwann cells, surviving after trauma, are capable of restoring the affected myelin sheath within 6-12 weeks.

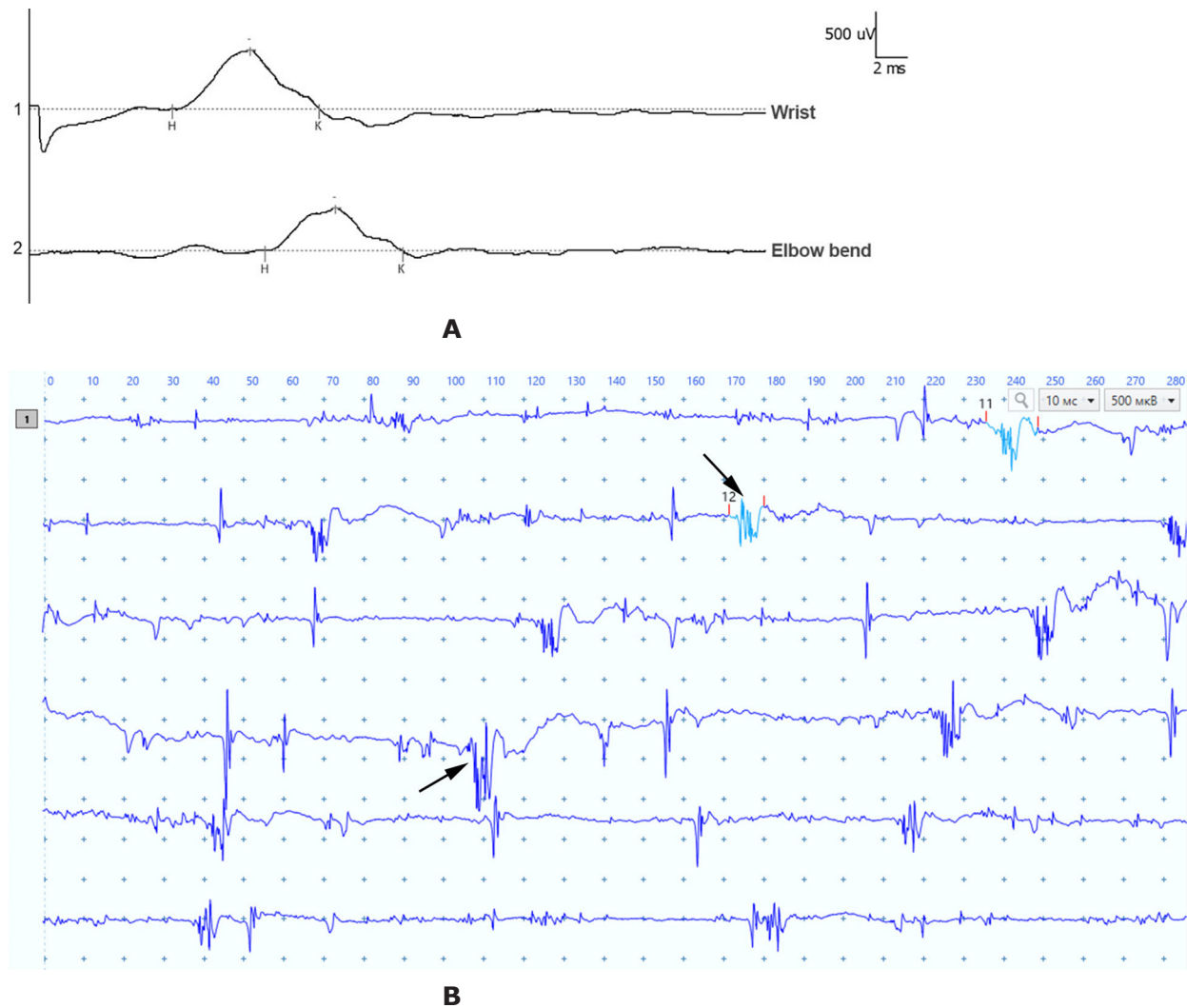


**Figure 3.** Complete axonal transection of the median nerve, absence of the M-response (A), vigorous spontaneous activity in the form of fibrillation potentials and positive sharp waves (B)

**Table 2.** Sensitivity, specificity, and informativeness of ENMG+EMG parameters for intraoperative diagnosis of neurotmesis

Indicator	Based on changes in M-response and motor ECV	Based on changes in M-response, motor ECV, and intramuscular registration of denervation potentials
Sensitivity = $\frac{TP}{TP+FN} \cdot 100\%$	72	87
Specificity = $\frac{TN}{TN+FP} \cdot 100\%$	80	89

Notes: TP - true positive (correct wear); FP - false positive (false wear); FN - false negative (false non-response); TN - true negative (correct non-response)



**Figure 4.** ENMG in partial axonal injury of the median nerve – significant decrease in M-response amplitude (A) at 4 weeks after injury, motor unit potentials are registered (B)

Modern views on the phenomenon of conduction block (CB) as evidence of demyelinating processes have undergone changes. Conduction block is an electrophysiological phenomenon of decreased amplitude and area of motor response upon stimulation at the

proximal point compared to the distal response. There is active discussion on the significance of CB in the differential diagnosis of demyelinating and axonal neuropathies, as well as criteria for diagnosing conditions in which this phenomenon is recorded. It has been established that the

detection of CB in electrophysiological studies, as well as the value of its parameters, is not strictly associated with morphological changes. Regardless of the presence of proven myelinopathy or axonopathy, CB with NP positions does not differ. The general and specific pathophysiological mechanisms of CB formation in compression neuropathies should be considered within each nosological form [15].

In our opinion, it is expedient to distinguish three degrees of CB severity: 1st – decrease in M-response amplitude <50% relative to the contralateral nerve index of the intact limb, 2nd – decrease in amplitude by 50–75%, 3rd – decrease in amplitude by >75% [9].

During the period up to 8 months after gunshot nerve injuries both in neurotmesis and axonotmesis, among sensory disturbances, symptoms of loss (hypoesthesia, anesthesia) predominated, with manifestations of paresthesia in the denervation zone. Motor disorders were manifested by weakness, and in cases of neurotmesis, often (in >35% of cases) also by the absence of movement in the corresponding muscle groups; almost all cases involved muscle atrophy, and in some affected individuals (about 9%), contractures were present.

Performing distal neurotization was effective, reducing the distance to the target (muscle, muscles). It is important to know the internal anatomy of the nerves, especially the branches. This operation is more useful, especially in the case of the 3rd degree, when it is unclear whether anything will change for the better; the operation allows obtaining a more satisfactory result [14]. Decompression can be performed in the 1st degree. The third degree is highly variable: there are no FP and PSW, and the registration of MUPs becomes crucial. It should be remembered that the optimal intervention times are 3-6 months after the injury. If the operation is performed later, the recovery will be much worse.

#### **ENMG signs of axon regeneration and muscle reinnervation in patients with remote consequences of combat trauma of limb nerves**

Results were interpreted using the classification of peripheral nerve injuries [16], which is convenient and detailed (**Table 3**). During electrodiagnostic examination of nerve conduction (ENMG) and with the help of a needle electrode (EMG) in acute lesions, when FP and PSW are present, the axonal type of injury is determined; in the absence of FP and with paresis present, neuropraxia with a favorable prognosis for recovery, i.e., demyelinating lesion.

If motor unit potentials (MUPs) are registered in the affected muscles located proximal to the site of injury after approximately 3 months, the prognosis for recovery is favorable. Such a neurophysiological pattern may be characteristic of grade II axonotmesis. In the absence of MUPs after ≥4 months or the appearance of initial MUPs, it is difficult to determine the prognosis (recovery may be partial or incomplete). If there are no MUPs during this period, the prognosis is unfavorable, and

consideration should be given to surgical intervention. The developed classification of the consequences of PN injuries helps determine the severity of functional deficit (mild, moderate, and severe).

#### **Analysis of factors influencing the clinical and neurophysiological features of the course of remote consequences of gunshot injuries to the nerves of the extremities**

Analysis of ENMG data and the results of neurosurgical treatment of patients allowed the development of schemes that help predict the rate and possibility of recovery based on ENMG indicators for a specific type of extremity nerve injury (**Fig. 5**).

The proposed schemes also provide a rationale for decision-making in the treatment of patients with remote consequences of combat-related nerve injuries of the extremity. Conducted ENMG studies allow comparing the identified features of the remote period of combat trauma of the nerves of the limbs and adopting as axiomatic recommendations of modern neurophysiology. The most informative ENMG study, conducted within 2-3 weeks after nerve injury, taking into account the distance of the injury to the muscle. Detection of denervation changes in the muscle depends on the development of Wallerian degeneration of the damaged axons. A decrease in the number of motor units recruited during muscle contraction (recruitment pattern analysis) is an adequate criterion for determining the topical level of nerve injury in the early stages after trauma. Needle EMG allows identifying two types of recovery processes in nerve injury - reinnervation of muscle fibers through collateral sprouting and the formation of new MUPs due to axon regeneration.

Thus, motor and sensory nerve conduction studies and needle EMG provide objective data useful for determining the localization of peripheral nerve injuries, identifying and quantifying the degree of axonal loss, predicting recovery, and making decisions about further treatment. The goal of surgical intervention is often to improve function rather than normalize it. Achieving optimal treatment outcomes requires comprehensive diagnostics with a multidisciplinary approach to the problem and differentiated use of new surgical treatment methods for patients with combat-related nerve injuries of the extremities.

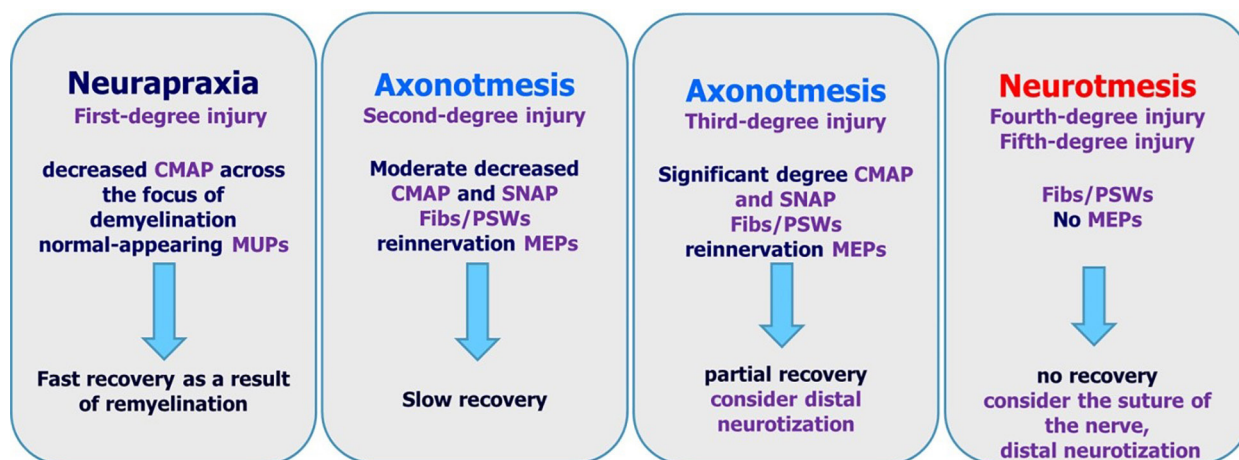
ENMG and needle EMG with the detection of MUPs and denervation phenomena objectively determine the localization of PN damage, the degree of axonal loss and recovery prognosis, facilitate decision-making about further treatment, and the specifics of rehabilitation therapy. Neurophysiological diagnostics not only help determine the level and type of nerve injury but also are an important factor in determining the prognosis for recovery, the need for surgical intervention, and the optimal timing for its implementation.



**Table 3.** Neurosurgical aspect of classification of peripheral nerve injuries with ENMG parameters at different time points after trauma depending on the severity of nerve damage, registration in the distal part of the limb

Degree of injury	Recovery prognosis	Recovery period	Recovery	Electrodiagnostic examination					
				Acute PN injury			Chronic PN injury		
				FP/PSW	MUP	Surgical intervention	FP/PSW	MUP	Surgical intervention
I	Favorable	Fast (<12 weeks)	Complete	-	Normal	+/-	-	Normal	-
II	Favorable	Slow (1 mm/day)	Complete	Present	+ (≤3 months)	+/-	-	++	-
	Variable	Slow (1 mm/day)	Partial	Present		+/-	-	++	-
III	Unfavourable	Absent	Absent	Present	+ (≥4 months)	+	-	-	-
IV	Unfavourable	Absent	Absent	Present		+	-	-	-
V	Unfavourable	Absent	Absent	Present		+	-	-	-
VI	Mixed			Recovery and the type of surgical intervention depend on the injury and combination of nerve injury grades					

Notes: (-) – absent; (+) – collateral sprouting or emerging potentials; (++) – stable motor unit potentials or emerging low-amplitude polyphasic potentials. (Adapted from Interpreting Electrodiagnostic Studies for the Management of Nerve Injury // Stahs Pripotnev, Robert C Bucelli, J Megan M Patterso, Andrew Yee, Mitchell A Pet, Susan Mackinnon // Hand Surg Am. 2022 Sep;47(9):881-889. doi: 10.1016/j.jhnsa.2022.04.008 [16])



**Figure 5.** Prediction of neuromuscular apparatus recovery based on a set of ENMG data

Note: sensory nerve action potential (SNAP), compound muscle action potential (CMAP), fibrillations (Fibs), and positive sharp waves (PSWs)

### Conclusions

1. According to the results of a complex clinical and electroneuromyographic study of the state of the neuromuscular apparatus of the extremities and its functional capabilities in individuals with combat-related nerve injury, it has been established that the peculiarities of the course of the recovery period within 4-6 (8) months after gunshot and mine blast injuries to limb nerves depend on the level and severity of axonal damage. The pathohistological variant of the nerve injury has the greatest impact on recovery outcomes (69.2%), while the localisation of the injury affects to a lesser extent (29.8%).

2. The recovery of lost limb functions in the specified terms due to regenerative sprouting exhibited a slow course and was most effective in the proximal parts of the limb. ENMG correlates of this pattern in the majority of patients (69.5%) were two-stage restoration of electrical excitability and conductivity of the damaged nerve trunk and functionally related muscle groups.

3. Without the use of needle EMG, a current objective assessment of axonal and demyelinating processes in the injured nerve and the effectiveness of motor unit recovery is not possible.

4. According to the results of the complex clinical and neurophysiological study of individuals with the consequences of combat-related injuries of the PN, the classification of the consequences of PN injuries was developed, distinguishing three degrees of functional deficit severity – mild, moderate, and severe.

5. Prediction schemes for the recovery of neuromuscular apparatus function on the basis of a set of ENMG-study data have been created.

### Disclosure

#### Conflict of interest

The authors declare no conflict of interest.

#### Ethical approval

All procedures performed on patients comply with the ethical standards of institutional and national ethics committees, the 1964 Declaration of Helsinki and its amendments or similar ethical standards.

#### Informed consent

Informed consent was obtained from each of the patients.

#### Funding

The study was conducted without sponsorship.

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