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On the issue of modern classification of peripheral nervous system's combat injuries

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ABSTRACT

Combat injuries to the peripheral nervous system are of particular interest because they differ significantly from peacetime nerve injuries and, accordingly, require a different approach to their classification and diagnosis. They are also characterized by a slightly different algorithm of diagnostic measures and treatment tactics. This problem is relevant not only for military surgeons, since gunshot wounds to nerves are not uncommon in peacetime. The leading position in the structure of mine-explosive wounds is traditionally occupied by limb wounds, but cases of damage to cranial nerves are not uncommon. Combat injuries are often characterized by significant damage to soft tissues, main vessels, nerve trunks and bone structures. Among the features of the clinical course of such nerve injuries, a higher frequency of causalgia, as well as a neurological deficit caused by the presence of an intraneural foreign object or due to compression of an intact nerve trunk by a conglomerate of cicatricial tissues, can be highlighted. Traditionally, nerve injuries both in wartime and in peacetime are characterized by a high degree of disability of the victims, which is reflected in a decrease in the quality of life. Available domestic and foreign literature has a significant number of classifications of peacetime injuries to the peripheral nervous system and only isolated mentions of the classification of combat injuries. The lack of a single classification approach to this nosology significantly complicates a multidisciplinary approach in the treatment of such wounded due to the fact that the diagnosis of clinicians of related specialties often differs from the neurosurgical one. In turn, this is reflected in the choice of the wrong treatment tactics and, accordingly, in a decrease in its effectiveness. In this paper, the authors propose an improved modern classification of combat injuries to the peripheral nervous system, based on previously put forward, as well as on the experience of treating nerve injuries in the neurosurgery clinic of the S.M. Kirov Military Medical Academy.

Keywords: peripheral nervous system; combat nerve injuries; classification; surgical treatment tactics; literature review.

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К вопросу о современной классификации боевых повреждений периферической нервной системы

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АННОТАЦИЯ

Боевые повреждения периферической нервной системы представляют особый интерес в связи с тем, что они значительно отличаются от повреждений нервов мирного времени и, соответственно, требуют иного подхода к их классификации и формулировке диагноза. Также для них характерен несколько иной алгоритм диагностических мероприятий и тактики лечения. Данная проблема актуальна не только для военных хирургов, так как огнестрельные ранения нервов не бывают редкостью и в мирное время. Лидирующую позицию в структуре минно-взрывных ранений традиционно занимают ранения конечностей, однако нередки случаи повреждения черепных нервов. Зачастую боевые травмы характеризуются значительным повреждением мягких тканей, магистральных сосудов, нервных стволов и костных структур. Среди особенностей клинического течения таких повреждений нервов можно выделить бóльшую частоту каузалгий, а также неврологический дефицит, вызванный наличием интраневрального инородного тела или вследствие сдавления интактного нервного ствола конгломератом рубцово-изменённых тканей. Традиционно повреждения нервов как в военное, так и в мирное время характеризуются высокой степенью инвалидизации пострадавших, что отражается снижением качества жизни. Доступная отечественная и зарубежная литература располагает значительным количеством классификаций повреждений периферической нервной системы мирного времени и лишь единичными упоминаниями о классификации боевых травм. Отсутствие единого классификационного подхода по данной нозологии значительно затрудняет мультидисциплинарный подход в ходе лечения таких раненых в связи с тем, что диагноз клиницистов смежных специальностей зачастую разнится с нейрохирургическим. В свою очередь, это отражается на выборе неверной тактики лечения и, соответственно, на снижении её результативности. В данной работе авторами предложена усовершенствованная современная классификация боевых повреждений периферической нервной системы, основанная на ранее выдвинутых, а также на опыте лечения травм нервов в клинике нейрохирургии Военно-медицинской академии им. С.М. Кирова.

Ключевые слова: периферическая нервная система; боевые повреждения нервов; классификация; тактика хирургического лечения; обзор литературы.

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In *The Basics of General Military Field Surgery* [1], Nikolay Pirogov, the founder of the Russian school of military field surgery, defined war as "the trauma epidemic." This statement is indisputable and remains relevant.

According to current data, gunshot wounds to the extremities are most common in the general structure of sanitary losses. This type of combat-related injury accounted for 59%–85% of the total sanitary losses during the Great Patriotic War (1941–1945); 59.1% during the war in Afghanistan (1979–1989); 47.9% and 53.3% during counter-terrorism operations in the North Caucasus (1994–1996, 1999–2002), respectively; and 49.1% in Syria (from 2015 to present) [2, 3].

The overall incidence of peripheral nerve injuries was 1.5%–10% of all cases of combat-related surgical trauma [2], with approximately 50% of all nerve injuries encountered in fractures and 10%–25% in vascular injuries of the extremities [3, 4].

During the military operations in Iraq and Afghanistan (1990–1991) conducted by the U. S. armed forces, 30% of all injuries to extremities were accompanied by nerve trunk injuries [5]. Other studies on the experience of U. S. combat in Yugoslavia and some Middle East countries reported the incidence of peripheral nerve injuries to be 10% and 30% among all injuries and combat-related injuries to the extremities, respectively [6]. Compared with peacetime nerve injuries, combat-sustained injuries were found in most cases, which may be explained by the peculiarities of injury occurrence [5, 7].

The classification of combat-sustained peripheral nerve injuries includes the group of gunshot-related injuries, which are common among the civilian population. For example, in the USA, possession of combat weapon is an integral part of the contemporary culture [8]; making up 5% of the global population, US citizen civilians own approximately 40% of all combat weapon [9]. Considering this, approximately 300,000 Americans are injured in peacetime, and 24,000 of the injured die [10].

Some foreign studies revealed that injuries to the extremities are ranked first among gunshot-related injuries in peacetime, which are accompanied by nerve trunk injuries in 15%–45% of cases [11, 12]. Therefore, the issue of combat-sustained peripheral nerve injuries is relevant for military and civil surgeons.

These injuries are within the area of interest of medical specialists, including neurosurgeons, military surgeons, orthopedic traumatologists, maxillofacial surgeons, ENT specialists, neurologists, and rehabilitation physicians. The present study aimed to develop a relevant classification, including the combat-related injuries. This will promote the integration of the abovementioned specialists in the treatment of nerve injuries [13–15].

Combat-sustained peripheral nerve injuries are difficult to classify as it involves many related fields of medical knowledge. Some of the current classification approaches are based on the anatomical and histological characteristics of the pathological process in the injured nerve, which is characterized by the number of injuries to intraneural structures: axons, myelin sheath, endoneurium, perineurium, and epineurium [16, 17].

In 1942, Herbert Seddon, an English orthopedist, proposed a classification of peripheral nerve injuries based on the histological characteristics of the pathological process, distinguishing three severity degrees [18].

1. Neurapraxia (Greek *apraxia* means no action) refers to minimal anatomical changes in the nerve, which are manifested by myelin sheath disruption (focal or segmental demyelination) and transient conduction block.

2. Axonotmesis (Greek *tmesis* means a cut or separation) refers axonal continuity loss with the development of Wallerian degeneration, but with preserved continuity of the connective tissue elements, namely, the endoneurium, perineurium, and epineurium.

3. Neurotmesis refers to the complete disruption of nerve continuity.

In 1951, Sydney Sunderland, an Australian scientist, expanded the Seddon classification based on the pathological characteristics of injuries [19]. This classification further classified axonotmesis into three degrees of severity. Therefore, he divided the nerve injuries into five degrees:

First degree: neurapraxia;

Second degree: axonotmesis;

Third degree: axonotmesis + disruption of the endoneurium;

Fourth degree: axonotmesis + disruption of the perineurium.

Fifth degree: neurotmesis

Fig. 1 shows the structural changes in nerve injuries and corresponding degrees according to the Seddon and Sunderland classifications. Currently, these classifications are most popular among foreign colleagues, including surgeons, neurologists, and diagnosticians [20, 21]. Subsequent attempts to classify peripheral nerve injuries involved the modernization of the Seddon and Sunderland classifications.

In 1988, Mackinnon and Dellon expanded the Sunderland classification by introducing the sixth degree of peripheral nerve injury, combining different degrees of injury [22]. However, this was not widely used in clinical practice [23].

In the same year, Lundborg developed another variant of the classification of peripheral nerve injuries, which was similar to the Sunderland classification with a slight expansion [24]. Lundborg classified neurapraxia into two processes, namely, the *physiological conduction block* and *prolonged conduction block*.

The physiological conduction block was further divided into type A and type B blocks. Type A is characterized by intraneural circulatory arrest within the nerve, leading to a metabolic block without structural damage and process reversibility within several minutes to several hours. Type B is demonstrated by intraneural nerve damage with an increase in intraneural pressure and process reversibility within days or weeks.

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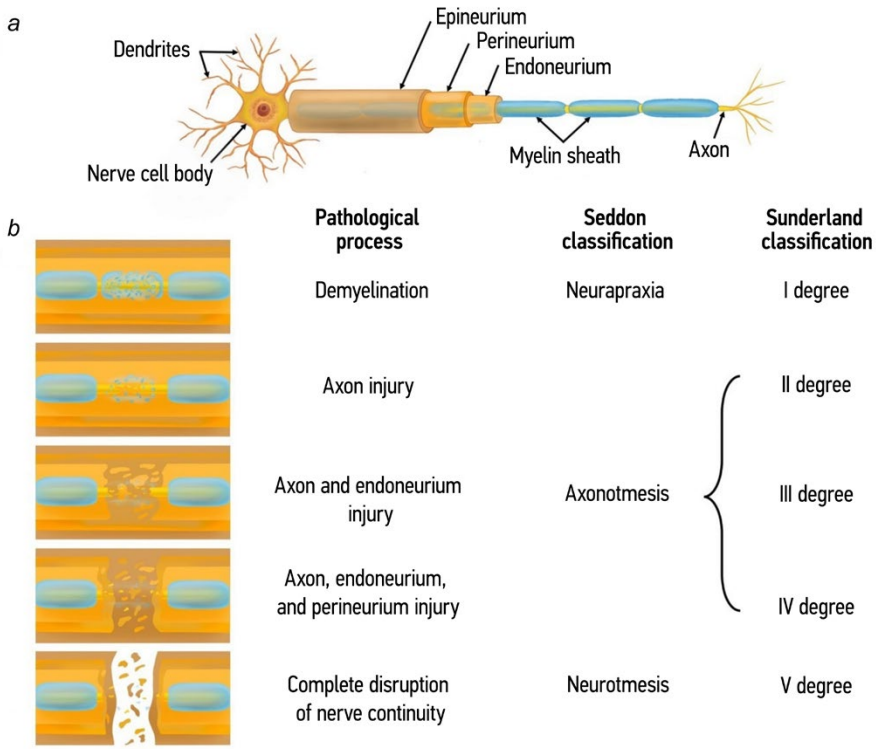

Fig. 1. Structural changes in nerve injury and degrees according to the Seddon and Sunderland classifications: *a*, normal structure of the peripheral nerve; *b*, schematic view of morphological changes in nerve injuries according to the Seddon and Sunderland classifications

A longer physiological conduction block is associated with a more severe nerve fiber damage, still classified as neurapraxia and first degree according to the Seddon and Sunderland classifications, respectively. Such pathological process manifests as local demyelination; minor motor, proprioceptive, and autonomic impairment; and absence of axon injury and Wallerian degeneration. Full functional recovery from an injury may be spontaneous, but usually occurs within several weeks or months. Other nerve injury degrees according to the Lundborg classification correspond to axonotmesis and neurotmesis [25].

In 1993, Thomas and Holdroff attempted to simplify the classification of peripheral nerve injuries [26]. They classified neurapraxia as a nondegenerative injury and axonotmesis and neurotmesis as degenerative injuries. Although this classification approach is simple and clear, it does not reflect the pathological process occurring in neural structures, thus hindering the determination of the optimal treatment method. Hence, this classification was not widely used in clinical practice [27].

Table 1 presents the evolution of classification approaches to peripheral nerve injuries.

The above classifications are based on the morphofunctional characteristics of the pathological process in peripheral nerve injuries; however, we believe that they do not reflect many peculiarities of combat-sustained nerve injuries. Nonetheless, Oberlin and Rantissi considered the Sunderland classification relevant in determining the suitable surgical treatment regardless of the injury origin [10]. They emphasized the urgency of fourth-degree injuries, as the nerve may be considered intact on visual examination and thus the wait-and-see treatment tactic may be erroneously chosen with unfavorable outcomes [10].

Moreover, Dunn et al. found no association between the Sunderland classification and time to evaluation, mechanism of injury, or degree of nerve trunk injury. The only factor that the classification was correlated with was the neurological deficit level [26].

Some studies used concepts such as the level of nerve injury, time after injury, time between injury and surgery, the nature of wounding projectile, intraoperative findings (e.g., nerve disruption, intrastem neuroma, etc.), and others. However, these terms are used in forming patient cohorts for research rather than classifying combat-sustained peripheral nerve injuries [8, 27, 28].

The current national classifications of peripheral nerve injuries are more cumulative and reflect more aspects characterizing the pathological process. The national typology is based on the nerve injury classification developed by Solomin in 1975 and in 1981 by Professor Grigorovich, a prominent Soviet neurosurgeon and anatomist. In a short form, they may be presented as follows [29, 30].

I. By character of nerve injury

1. Closed (concussion, contusion, compression, dislocation, destruction).

2. Open:

a) Gunshot (bullet, missile, etc.)

b) Non-gunshot (stab, slash, contusion, etc.)

Table 1. Classification approaches to peripheral nerve injuries developed by foreign authors

H. Seddon, 1942	S. Sunderland, 1951	D. Lundborg, 1988		P.K. Thomas, B. Holdroff, 1993
Neurapraxia	I	Physiological conduction block	Type A	Nondegenerative nerve injury
			Type B	
		Prolonged conduction block		
Axonotmesis	II	Axon injury		Degenerative nerve injury
	III	Axon and endoneurium injury		
	IV	Axon, endoneurium, and perineurium injury		
Neurotmesis	V	Complete nerve continuity disruption		
	VI (S. Mackinnon, A. Dellon, 1988)	—	—	—

II. By injury location

1. Cranial nerves
2. Cervical plexus
3. Brachial plexus
4. Nerves of the upper extremities
5. Lumbar plexus
6. Nerves of the lower extremities

III. By type and degree of nerve injury

1. Concussion
2. Contusion
3. Compression
4. Traction
5. Partial nerve disruption
6. Full nerve disruption

IV. Mixed and combined injuries

1. Nerve injuries mixed with vascular, skeletal, and tendon injuries and massive muscle crush injury

2. Nerve injuries combined with burns, frostbites, chemical injuries, etc.

V. Iatrogenic injuries caused by wrongful actions during surgeries and various medical procedures

VI. Periods during nerve injuries

1. Acute (first 3 weeks after injury): the true functional impairment is unclear.

2. Early (from 3 weeks to 2–3 months): the true nature of nerve injury is identified; full functional recovery after concussion.

3. Intermediate (subacute) (2–3 to 6 months): clear signs of functional recovery of the nerve are identified (in irreversible changes).

4. Late (6 months to 3–5 years): slow nerve regeneration, after a surgery.

5. Long-term (residual) (3–5 years after injury): further functional recovery is impossible.

In 1989, this classification was supplemented by a group of neurologists from the Kirov Military Medical Academy to include various functional disorders [31]. The latest modifications and supplements were introduced by Goven'ko in 2010. They were presented as a working clinical classification of nerve injuries (Table 2), which is widely used by neurosurgeons [32].

Table 2. Working clinical classification of nerve injuries (Goven'ko, 2010)

1. Open (injuries) • Isolated (cut, incised, contused, bite, avulsion, crushed, gunshot, and burn) • Mixed with: – tendon injuries – skeletal injuries – articular injuries – vascular injuries – massive soft tissue defect
2. Closed • Isolated (concussion, contusion, compression, and strain/traction) • Mixed with: – skeletal injuries – articular injuries – vascular injuries – soft tissue injuries
3. Nerve injuries mixed with injuries to other body parts (head, chest, abdomen, and pelvis)
4. Nerve injuries combined with: – toxic exposure – ionizing radiation exposure
5. Ischemic and ischemic compression injuries
6. Iatrogenic injuries

An example of the national classifications of combat-sustained peripheral nerve injuries is the *Classification of Gunshot-Related Peripheral Nerve Injuries* by Egorova (1952) [33]. In this classification, three major types of peripheral nerve injuries were distinguished, namely:

1. complete anatomical disruption,
2. partial anatomical disruption, and
3. intrastem changes in gunshot-related injuries without epineurium injury.

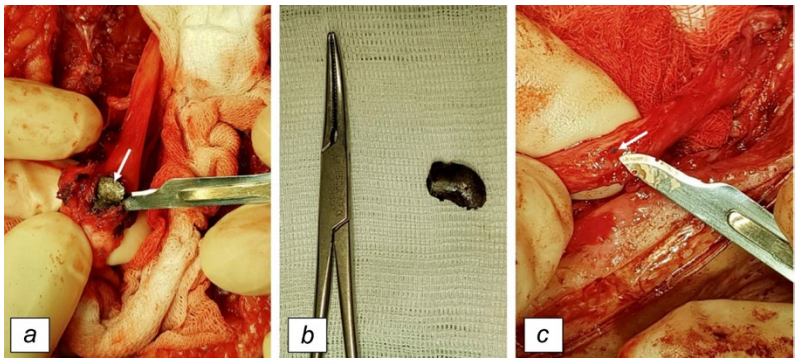

Fig. 3. Foreign intraneural bodies (from the authors' archive). The arrow indicates the intraoperative findings: metal fragments in the nerve trunk

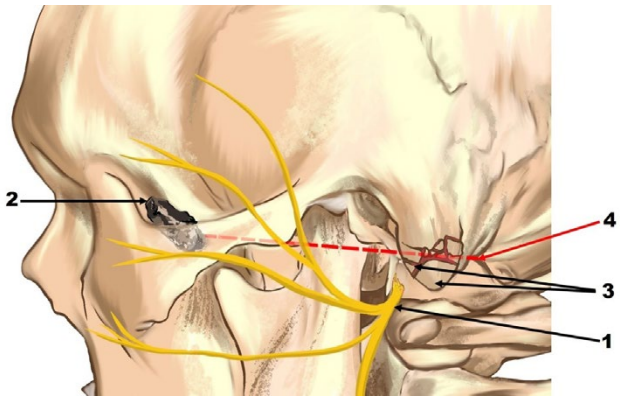

Fig. 2. Schematic view of combat-sustained facial nerve injury: 1, facial nerve trunk; 2, metal fragment; 3, fractured fragments of the mastoid process; and 4, wounding projectile trajectory

Each form of combat-sustained nerve injury was classified into three: anatomical (structural-morphological), clinical, and physiological (functional and dynamic) [33].

In the opinion of the authors, the current national classification of peripheral nerve injuries contradicts the basic terminology used in traumatology and military field surgery. According to the national guidelines and instructions on military field surgery, mixed injuries result in injuries (by one or several wounding projectiles) in several anatomical regions such as the head, neck, chest, abdomen, pelvis, spine, and extremities.

Among current warlike conflicts, the incidence of mixed injuries accounts for 22%, multiple injuries (several injuries within the same anatomical region) for 13%, and isolated injuries for 65%. Extremity injuries occur in the structure of sanitary losses, accounting for 53% of all combat-related surgical traumas [3]. In the available classifications of peripheral nerve injuries, concomitant nerve and skeletal, articular, vascular, and other injuries are called mixed. In the latter case, it is advisable that the word "mixed" be replaced with a synonym, for example, "cooperative," to eliminate contradiction with the generally accepted terminology.

Including ischemic compression neuropathy, which is often caused by chronic degeneration of the surrounding tissues and represents a separate disease area, into the classification of nerve injuries remains debatable. We believe that the classification should include only ischemic compression neuropathy caused by acute nerve compression or its compression with scar tissue and relatively acute nerve injury symptoms.

In addition to the current classifications, we propose to introduce the term *multilevel injury* to one nerve trunk at several sites, which is common in missile and mine-blast injuries to extremities and in improper placement of external fixation devices during delivery of medical assistance.

The injury location category should be supplemented with a subcategory of injury level. For example, complete anatomical interruption of the ulnar nerve in the upper third of the shoulder and at the level of the wrist joint are two types of injury, which are significantly different by functional deficit.

Furthermore, the inclusion of *cranial nerve injury* is a crucial part of this classification section with regard to combat-related injuries. The statistical data in *Experience of Soviet Medicine during the Great Patriotic War 1941–1945* indicated that cranial nerve injuries accounted for 0.15% of cases [33].

During Operation Enduring Freedom and Operation Iraqi Freedom, cranial nerve injuries were detected in 244 medical evacuees, which accounted for 6% of all craniofacial injuries. Facial (34%), auditory vestibular (30%), and optic (15%) nerve injuries were the most common [34].

The authors reported that facial nerve injuries (50%) prevail in the structure of combat-sustained cranial nerve injuries. However, to obtain more accurate statistics, these patients should be treated in one in-patient department, which may be difficult owing to frequent injuries to the maxillofacial, temporal, and mastoid regions.

Facial nerve injuries are often accompanied by gunshot-related multi-fragmentary fractures of the mastoid process (Fig. 2). This neural structure is particularly interesting because surgical interventions for this injury are characterized by favorable long-term recovery results. In accordance with the contemporary classification of combat-sustained nerve injuries, the diagnosis should indicate the injury level, which is challenging for cranial nerves. Thus, the skull bone markers may be used for indicating injury level.

The introduction of "intrastem nerve injury with a foreign body" into the *Pathomorphology* section is a new category in the contemporary classification. Foreign intraneural bodies include metal fragments, bullets, fractured fragments, etc. (Fig. 3). Notably, regardless of their size, foreign bodies (Fig. 3*c*)

may cause marked neurological deficits, manifested as motor or sensory impairment and severe pain syndrome—causalgia.

Considering the above and based on the classifications by Solomin (1975), Grigorovich (1981), and Goven'ko (2010), the authors attempted to overcome the contradictions with the terminology of military field surgery and propose the following variant of the contemporary classification of combat-sustained peripheral nerve injuries [29, 30, 32, 35].

CLASSIFICATION OF COMBAT-SUSTAINED PERIPHERAL NERVE INJURIES

I. By injury etiology: combat-related injury and iatrogenic injuries caused by wrongful actions during surgeries and medical procedures, for example, in cases of improper application of tourniquet, car accident injury, fall from height, etc.

II. By risk of infection

1. Open:

– gunshot (bullet, missile, mine-blast wounds, and blast injuries)

– non-gunshot (cut, incised, avulsion/contused, bite, cut, burn, etc.)

2. Closed:

– concussion;

– contusion;

– compression (ischemic compression injuries);

– strain/traction

III. By type

– solitary (solitary nerve trunk injury) / multiple (multiple nerve trunk injuries of one extremity);

– mixed (with injuries to other body parts);

– combined (with exposure to several affecting factors—ionizing radiation, thermal action, toxic agents, etc.)

– co-operated (to injuries to tendons, bones, joints, vessels, and massive soft tissue defect of the affected extremity)

– single-level/multilevel (injuries to one nerve trunk at several sites)

IV. By location and level

– cranial nerves

– plexus: cervical, brachial, and lumbar

– nerves of the extremities: upper (radial, median, ulnar, etc.)/lower (sciatic, tibial, peroneal, etc.)

– at the level of the lower third of the shoulder, knee joint, upper third of the forearm, etc.

V. By pathomorphology and functional disorders

– with complete anatomical disruption of the nerve

– with partial anatomical disruption (rupture)

– intrastem nerve injuries (hematoma, foreign bodies, and subepineural trunk disruption with formation of intrastem neuroma)

The injuries should be classified by functional disorders:

– with complete conduction block (not indicated in the diagnosis in case of complete anatomical disruption);

– with partial preservation of conduction;

– with neuropathic pain syndrome

VI. Nerve injury periods: acute, early, intermediate, late, and long-term.

EXAMPLES OF CLINICAL DIAGNOSES, WORDED USING THE PROPOSED CLASSIFICATION

1. Gunshot wound of the right lower extremity. Traumatic neuropathy of the right sciatic nerve with complete anatomical disruption at the level of the mid-third of the hip caused by penetrating gunshot injury co-operated with deep femoral vessel injury. Early period. Condition after primary surgical debridement of penetrating gunshot injury to the right hip, deep femoral vessel ligation (date).

2. Combat-related injury. Closed multi-fragmentary fracture of the mid-third of the left shoulder bone. Iatrogenic postoperative left radial nerve neuropathy, nerve compression with the metal osteosynthesis plate in the mid-third of the shoulder with complete conduction block. Acute period. Condition after surgery: reposition, plate metal osteosynthesis of closed displaced fracture of the left shoulder bone (date).

3. Penetrating gunshot radiary temporal mastoid parabasal injury to the skull and brain on the left (date). Traumatic neuropathy of the facial nerve, with complete anatomical disruption at the level of the stylomastoid foramen. Acute period.

CONCLUSION

Contemporary studies have described several classifications of peripheral nerve injuries, which are distinguished by descriptions of the level of nerve injury, separation of respective zones, and classification by injury etiology (e.g., iatrogenesis) [36–41]. Accumulation of such typologies into the unified systematic classification of nerve injuries will result in excessive information, complicating clinical diagnosis. However, the proposed classification is not stringent nor invariable.

Some of the items in this classification provoked debates between the authors and required a compromise approach. Moreover, the described classification of combat-sustained peripheral nerve injuries is not exhaustive. Notably, there cannot be a final and irrevocable solution to this complex and multifaceted issue of systematizing nerve injuries. Thus, we would like to invite all concerned specialists to a discussion and collaboration.

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ADDITIONAL INFORMATION

Authors' contribution. A.I.G.—conceptualization, methodology, writing—original draft, investigation, writing—review & editing, validation, data curation; B.V.K.-S.—conceptualization, formal analysis, investigation, visualization, writing—review & editing; D.V.S.—conceptualization, methodology, validation, supervision; D.M.I.—formal analysis, investigation, resources, methodology; L.I.Ch.—formal analysis, investigation, resources.

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Competing interests. The authors declare that there is no conflict of interest in the presented article.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. А.И.Г. — концептуализация, методология, создание черновика, исследование, редактирование рукописи, проверка, обработка и управление результатами; Б.В.К.-С. — концептуализация, анализ, исследование, визуализация, редактирование рукописи; Д.В.С. — концептуализация, методология, проверка, общее руководство; Д.М.И — анализ, исследование, ресурсы, методология; Л.И.Ч. — анализ, исследование, ресурсы.

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