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ANALYSIS OF ELECTRONEUROGRAPHY INDICATORS IN PERIPHERAL NERVE INJURIES OF THE UPPER LIMB

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This research is aimed at determining the diagnostic value of electrophysiological examination, compared with ultrasound examination and provocative compression tests, to confirm and establish the degree of severity of peripheral nerve damage, as well as prognosis for further treatment tactics on the example of compression of the median nerve in the carpal tunnel. 130 patients were examined, in whom signs of median nerve damage were detected. All patients underwent provocative tests (Phalen's, Tinel's, Durkan's). During electrophysiological examination, the following indicators were evaluated: amplitude, speed, distal latency of motor and sensory responses. The cross-sectional area of the median nerve at the entrance to the canal during sonography correlates well with the results of electrodiagnosis. Indicators electroneuromyography clearly and reliably determine moderate and severe degree of carpal tunnel syndrome. The problem of diagnosis is that some patients with clinical symptoms of carpal tunnel syndrome have indicators that are not statistically different from indicators in patients of the control group.

Key words: upper limb, injuries, carpal tunnel syndrome, electroneuromyography, sonography, median nerve, regeneration.

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АНАЛІЗ ЕЛЕКТРОНЕЙРОГРАФІЧНИХ ПОКАЗНИКІВ ПРИ УРАЖЕННЯХ ПЕРИФЕРІЙНИХ НЕРВІВ ВЕРХНЬОЇ КІНЦІВКИ

Дослідження направлено на визначення діагностичної цінності електрофізіологічного обстеження, порівнюючи із ультразвуковим дослідженням та провокуючими компресійними тестами, для підтвердження та встановлення ступеня важкості ураження периферичного нерва, а також прогнозу щодо подальшої тактики лікування на прикладі компресії серединного нерва у карпальному каналі. Обстежено 130 пацієнтів, у яких були виявлені ознаки ушкодження серединного нерва. Усім пацієнтам проводили провокуючі тести (Фалена, Тінеля, Дуркана). Під час проведення електрофізіологічного обстеження оцінювалися такі показники: амплітуда, швидкість, дистальна латентність моторної та сенсорної відповіді. Поперечний переріз серединного нерва на вході в канал при сонографії добре корелює з результатами електродіагностики. Показники електронейроміографії чітко та достовірно визначають помірну та важку ступінь синдрому зап'ястного каналу. Проблемою діагностики є те, що частина пацієнтів з клінічними симптомами синдрому зап'ястного каналу має показники, що статистично не відрізняються від показників у пацієнтів контрольної групи.

Ключові слова: верхня кінцівка, травми, синдром зап'ястного каналу, електронейроміографія, сонографія, серединний нерв, регенерація.

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Post-traumatic neuropathies are common conditions that can impair a patient's quality of life and limit their ability to work. Injury resulting from chronic nerve compression is a fairly common occurrence in clinical practice, especially in the upper limb. Median nerve compression in the wrist is the most common compression neuropathy and one of the most frequent reasons for referral for electrophysiological studies. Carpal tunnel syndrome (CTS) accounts for 90 % of all compression neuropathies and is characterized by initial symptoms of paresthesias in the fingers innervated by the median nerve and, in later stages, by thenar muscle atrophy [2].

In the United States, this pathology occurs in 3–12 % of the adult population [11]. When the median nerve is damaged, a range of symptoms and signs can occur, from sensory anomalies, paresthesia, and pain in the initial stages to motor disorders and permanent loss of sensation as the injury progresses, especially in forced positions and at night. Electroneuromyography is the "gold standard" for diagnosing this pathology, enabling accurate determination of the location and extent of nerve damage. According to the literature, the prevalence of carpal tunnel syndrome in the population is about 8.0 % [12] and is often observed in adults aged 40 to 60 years. Females are three times more likely to suffer from this pathology [3]. Provoking factors for compression of the median nerve in the wrist area include heavy physical work with the hands, accompanied by repetitive wrist movements. Risk factors also include diabetes mellitus, hypothyroidism, wrist and forearm injuries, obesity, drug toxicity and exposure to toxins, rheumatoid arthritis, neoplasms, and pregnancy [6].

Currently, in the physician's arsenal for diagnosing median nerve compression, in addition to clinical signs and symptoms, ultrasound and electrophysiological examinations are available. In most cases, the diagnosis can be confirmed by the presence of typical clinical symptoms, along with impaired conduction along the median nerve on electrodiagnostic studies [10]. It is known that the diagnostic value of neurography ranges from 49 % to 84 %, and the specificity exceeds 95 % [14].

Recent advances in ultrasound diagnostics encourage researchers to study its effectiveness in diagnosing carpal tunnel syndrome. This method has several advantages, including painlessness, non-invasiveness, availability, and relatively good diagnostic value [9]. However, the sensitivity and specificity of this technique vary in the literature: sensitivity ranges from 65 % to 97 %, and specificity ranges from 73 % to 98 % [13]. The severity of median nerve damage is crucial for deciding on the appropriate treatment. Practical experience shows that it is not always sufficient to routinely collect anamnesis and perform physical and neurological examinations to accurately establish the localization and extent of peripheral nerve damage, especially in its early stages. Patients with carpal tunnel syndrome may have little connection between the severity of clinical symptoms and abnormalities detected during electrophysiological examination. In addition, assessing the severity of peripheral nerve damage is extremely important for further treatment strategies.

The purpose of the study was to investigate the electroneuromyographic characteristics and the cross-sectional area of the median nerve in carpal tunnel syndrome.

Materials and methods. The study was conducted at the "Neuromed" Medical Center in Vinnytsia from June 2024 to January 2025**.** Clinical and instrumental studies were performed in 130 patients (256 wrists) with suspected CTS, including 81 women (62.3 %) and 49 men (37.7 %) aged 22 to 70 years, mean age 50.7 ± 8.6 years, and 30 practically healthy individuals (60 wrists) aged 25 to 50 years (15 women and 15 men). The diagnosis was based on pain and sensory disturbances using the Symptom Severity Scale (SSS), functional disorders using the Functional Status Scale (FSS) of the Boston Questionnaire.

Patients were included in the study if they met the following criteria: age ≥18 years, presence of clinical symptoms suggestive of CTS (pain, paresthesia, numbness in the median nerve distribution), availability of complete clinical, electrophysiological, and ultrasound examination data, and provision of written informed consent to participate in the study. Exclusion criteria: patients were excluded if they had previous surgical treatment for CTS, traumatic injuries of the wrist or hand, systemic neurological disorders affecting peripheral nerves (e.g., polyneuropathy of another etiology), severe systemic diseases that could influence nerve conduction parameters, or incomplete clinical or instrumental data. No changes in the composition of the study groups occurred after the study began.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision), the Good Clinical Practice (GCP) guidelines, and relevant national regulations governing biomedical research in Ukraine.

Written informed consent was obtained from all participants prior to inclusion in the study. Consent was provided in writing after participants received a detailed explanation of the study objectives and procedures. The study protocol was reviewed and approved by the Local Ethics Committee of National Pirogov Memorial Medical University (protocol No. 7, dated 3.06.2024). The study did not intentionally involve vulnerable populations as defined by the Good Clinical Practice classification (children, prisoners, pregnant women, cognitively impaired individuals, refugees, or economically disadvantaged persons). However, some participants belonged to an older age group, which may be considered a potentially vulnerable population, and this was taken into account during data interpretation.

To ensure confidentiality and prevent patient de-identification, all personal data were anonymized before analysis. Only coded identifiers were used in the dataset, and no personal identifying information was included in the analysis. The control and main study groups included patients from different age categories. Since age-related changes in peripheral nerve conduction may occur, especially in elderly individuals, this factor could potentially influence electrophysiological parameters and introduce selection bias when comparing patient groups with healthy controls. This limitation was taken into account during the interpretation of results and is discussed in the Limitations section.

Patients were divided into 4 groups: a control group and groups with CTS without neurophysiological abnormalities, with mild, moderate, and severe degrees. All patients underwent electrodiagnostic tests using a standard 4-channel electromyograph, "Neurosoft" Neuro-MVP4. The examination included assessment of the median nerve using a standard technique with supramaximal stimulation and surface electrodes, in accordance with the American Association of Neuromuscular and Electrodiagnostic Medicine criteria [1]. During the electrophysiological examination, the following indicators were evaluated: amplitude, velocity, and distal latency of motor and sensory responses. The temperature in the study area was at least 32 degrees Celsius. To assess the M-response, the active electrode was placed on the skin overlying the abductor pollicis brevis muscle, the reference electrode was placed on the metacarpophalangeal joint of the thumb, and the median nerve was stimulated at a distance of 8 cm from the active electrode at the wrist. Sensory nerve action potentials were obtained antidromically using ring electrodes placed over the second finger at a distance of 14 cm from the wrist. For the comparative test, the electrodes were placed over the fourth finger, and the median nerve and ulnar nerve of the wrist were stimulated separately.

Based on the analysis of electroneuromyographic characteristics, mild CTS was identified: a decrease in sensory response velocity and/or prolongation of distal sensory response latency, moderate CTS: impaired sensory conduction, prolongation of distal motor response latency with normal motor response amplitude; severe CTS: decreased motor response amplitude and/or absence of sensory response.

Ultrasound examinations were performed using a high-frequency linear array transducer with optimized musculoskeletal settings (TOSHIBA Aplio 400 14 MHz). A standard technique was used for ultrasound examination of the median nerve: the upper limb is flexed at the elbow, the forearm is positioned horizontally with the palmar surface facing up, the hand rests on a special roller, and the fingers are relaxed.

Statistical analysis was performed using Excel and Statistica 8 software. The correctness of the distribution of features for each of the obtained variational series, the mean values of each feature studied, and the standard quadratic deviation (STD) were evaluated. The reliability of the difference between independent quantitative values was assessed using the Mann-Whitney U test. The difference was considered significant at $p<0.05$.

Results of the study and their discussion. Electroneuromyographic parameters were analyzed in both the control group and patients with varying degrees of carpal tunnel syndrome to identify characteristic diagnostic patterns. Particular attention was paid to changes in motor and sensory conduction parameters as a function of disease severity.

The results of the electroneuromyography stimulation conducted under normal conditions and in the clinical pathology of carpal tunnel syndrome had their own peculiarities. In the examined patients in the control group, the amplitude of the M-response (Amp-M-response) of the studied abductor pollicis brevis muscle showed a high, clear peak and similar electroneuromyograms (Fig. 1), with a mean of 10.7±2.5 mV.

The motor amplitude of the M-response of the abductor pollicis brevis muscle in 78 examined patients did not show statistically significant differences in the presence of clinical symptoms. In the mild degree of CTS severity, the indicator slightly decreased by 1.3 times ($p>0.05$), and in the moderate and severe degree of carpal tunnel syndrome, it was significantly lower by 2.2 and 6.2 times ($p\leq0.05$), respectively, compared with the control group (Fig. 2, Table 1).

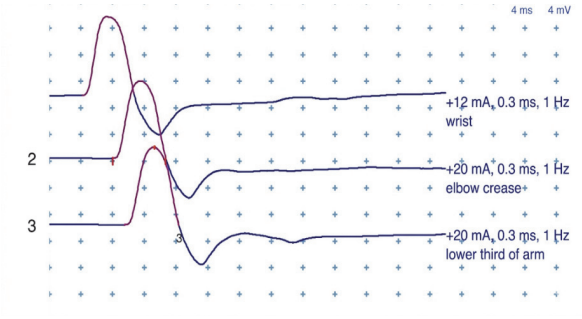

Fig. 1. Electroneuromyogram of patient B. The amplitude of the M-response of the right abductor pollicis brevis muscle is normal.

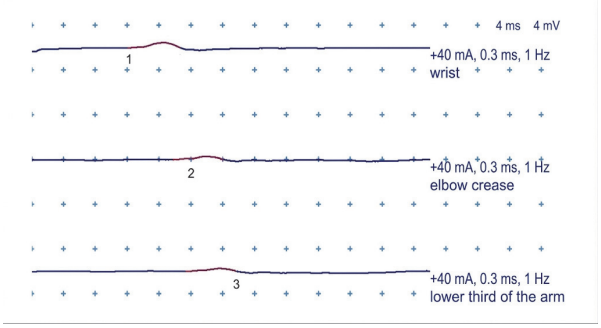

Fig. 2. Electroneuromyogram of patient K. The amplitude of the M-response of the right abductor pollicis brevis muscle in severe carpal tunnel syndrome.

The distal latency of the M-response (DL-M-response) increased significantly ($p<0.05$) in patients with mild (1.5 times), moderate (2.3 times), and severe (2.8 times) severity.

The M-response velocity of the m. abductor pollicis brevis (MCV-M-response) during stimulation of the abductor pollicis brevis muscle in 78 examined patients did not show statistically significant differences in the presence of clinical symptoms, whereas in the group of patients with mild, moderate, and severe degrees of severity, it decreased statistically significantly by 1.3, 1.6, and 2.1 times, respectively (Table 1).

Distal latency of the sensory response (DL-S-response) in patients with CTS increased compared to patients in the control group in the mild degree of severity by 1.6 times ($p>0.05$), in the moderate degree by 2.2 times ($p<0.05$), in the severe degree by 2.6 times ($p<0.05$).

The amplitude of the sensory response (Amp-S-response) in 78 examined patients did not show statistically significant differences in the presence of clinical symptoms, and in patients with CTS with a mild degree of severity, it decreased by 1.3 times ($p>0.05$), with a moderate degree by 1.9 times ($p<0.05$), with a severe degree by 3.9 times ($p<0.05$) compared with patients in the control group. The sensory response velocity (MCV-S-response) was also examined in 78 patients, who did not show statistically significant differences in the presence of clinical symptoms, while in the group of patients with mild, moderate severity, it significantly decreased by 1.3; 2.2 times ($p<0.05$), respectively, and in the severe degree, the absence of a sensory response was observed.

According to the results of our study, the average cross-sectional area of the median nerve in the wrist area in mild, moderate, and severe degrees of CTS was: (11.5±1.1) mm²; (14.7±2.9) mm²; and (18.3±2.4) mm², respectively. The indicators were statistically significantly different from those of the control group and from one another ($p<0.05$).

Phalen's (17.9 %), Tinel's (20.5 %), and Durkan's (26.9 %) tests yield positive results even when there are no neurophysiological deviations from the norm in CTS. Phalen's test was positive in 44.4 %, 79.1 %, 86.2 % and Tinel's test was positive in 33.3 %, 74.7 %, 82.3 in mild, moderate, and severe degrees of CTS cases, respectively, while Durkan's test was positive in 50.0 %, 80.2 %, 90.2 %, respectively.

Table 1

Indicators of electroneuromyography, cross-sectional area of the median nerve, and provocative tests in patients with CTS of varying severity

Indicator	Control Group	CTS without neurophysiological deviations n=78 (M±STD)	CTS Severity Level		
	n=60 (M±STD)		Mild severity, n=36 (M±STD)	Moderate severity, n=91 (M±STD)	Severe degree of severity, n=51 (M±STD)
DL-M-response (ms)	3.52±0.6	3.2±0.3	3.9±0.8*#	5.2±1.5*#	7.31±3.4*
Amp-M-response (mV)	8.3±4.1	10.7±2.5	10.1±3.3	7.7±2.9*#	4.3±3.5*#
MCV-M-response (m/s)	52.2±7.5	57.5±4.5	53.7±5.9*#	54.4±7.9*#	46.6±12.3*#
DL-S-response (ms)	3.7±0.9	2.4±0.3	3.0±0.7	3.94±1.5*#	4.4±1.6*
Amp-S-response (mV)	15.6±12.1	30.6±12.7	21.1±9.7	13.2±7.3*	6.0±9.6*
MCV-S-response (m/s)	53.3±9.0	57.6±5.8	42.6±12.9*#	39.3±11.3*#	15.7±20.3
CSA (mm^2)	10.9±3.8	10.04±1.1	11.5±1.1*#	14.7±2.9*#	18.3±2.4*#
Tinel's Test n (%)	-	14 (17.9)	12 (33.3)	68 (74.7)	42 (82.3)
Phalen's Test n (%)	-	16 (20.5)	16 (44.4)	72 (79.1)	44 (86.2)
Durkan's Test n (%)	-	21 (26.9)	18 (50.0)	73 (80.2)	46 (90.2)

Notes: * – statistically significant differences ($p<0.05$) according to the Mann-Whitney U test between the corresponding indicators of patients with CTS compared to the indicators of the control group. # – statistically significant differences ($p<0.05$) according to the Mann-Whitney U test between the corresponding indicators of patients with CTS compared to the indicators of the previous severity group.

In the study of the relationship between sonographic parameters (cross-sectional area) and the results of electrodiagnosis, which include distal sensory latency, amplitude of the sensory response, distal motor latency and amplitude of the motor response, correlations were established between the average value of the cross-sectional area of the median nerve at the wrist and the following parameters: distal sensory latency ($r=0.50$; $p<0.001$), amplitude of the sensory response ($r=-0.33$; $p<0.001$), distal motor latency ($r=0.48$; $p<0.001$) and amplitude of the motor response (r:-0.25; $P<0.001$). It is also important that with increasing disease severity, sonographic parameters also increase statistically significantly.

In various studies, there is a divergence of opinions regarding the need for additional tests, such as ultrasound and electroneuromyography, for the diagnosis of carpal tunnel syndrome. Thus, in their study, Paiva Filho et al. (2022) [7] found that clinical examination data, ultrasound, and electroneuromyography were not statistically associated with the severity of CTS. The authors believe that the Tinel, Phalen, and Durkan tests are insufficient for diagnosing CTS, and that patients with clinical symptoms of CTS and normal electroneuromyography results are also common.

Our study showed that as disease severity increases, sonographic parameters also increase significantly.

Seyed Mansoor Rayegani (2024) [9] and his colleagues showed in their study that the cross-sectional area of the median nerve at the entrance to the carpal canal on sonography correlates with electrodiagnostic results. Yadong Gu et al. (2022) [4] believe that a combined neuroelectrophysiological and ultrasound examination can improve the rate of diagnosis of compression diseases of peripheral nerves and clarify the location, nature, and extent of compression lesions, which deserves clinical application.

Löppönen P. et al. (2022) [5] consider clinical examination together with neuroelectrophysiological and ultrasound examination to be particularly valuable in the differential diagnosis between pronator syndrome, anterior interosseous nerve syndrome, and compression of the proximal median nerve.

A recent expert consensus suggests that combining sonography with neuroelectrophysiological examination and other clinical measures can increase diagnostic accuracy, differentiate CTS severity, and be more informative than using each method separately [8].

Thus, we have shown that electroneuromyography indicators clearly and reliably distinguish moderate and severe CTS. At the same time, 60 % of patients with clinical symptoms of CTS have indicators that are not statistically different from those in patients in the control group. Using ultrasound, the cross-sectional area of the median nerve was measured in patients with varying severity, and the results were statistically significantly different.

Our study showed that as disease severity increases, the cross-sectional area of the median nerve increases. We have established positive

correlations between the indicators of the cross-sectional area of the median nerve at the wrist and the indicators of electroneuromyography: with the indicators of distal sensory latency (positive correlation of moderate strength), amplitude of the sensory response (negative correlation of moderate strength), distal motor latency (positive correlation of moderate strength) and amplitude of the motor response (negative correlation of weak strength). Positive Phalen, Tinel, and Durkan tests were also detected, even when there are no neurophysiological deviations from the norm in CTS. The Durkan test was the most informative. Based on the study results, it is appropriate to perform the diagnosis of CTS using electroneuromyography and ultrasound in addition to the clinical diagnosis.

Limitations. The study has several limitations that should be considered when interpreting the findings. Differences in age distribution between the control and patient groups may have influenced electrophysiological parameters, particularly in older participants. Furthermore, the single-center design may somewhat limit the generalizability of the results.

Conclusions

1. Electroneuromyography indicators clearly and reliably identify moderate and severe degrees of CTS. The diagnostic challenge is that some patients with clinical symptoms of CTS have indicators that are not statistically different from those in the control group.

2. The cross-sectional area of the median nerve at the wrist increases with increasing disease severity and has positive correlations with distal sensory latency and distal motor latency, and negative correlations with sensory response amplitude and motor response amplitude.

3. To improve the diagnosis of CTS, along with neurological examination, the Boston questionnaire, it is rational to use electroneuromyography, ultrasound, and Phalen's, Tinel's, and Durkan's tests.

Prospects for further research. Future studies involving larger and more diverse patient populations are warranted to improve early diagnostic approaches for carpal tunnel syndrome. Particular attention should be given to the development of integrated diagnostic models combining clinical assessment, electroneuromyography, and ultrasound findings. In addition, further research is needed to evaluate the effectiveness of pharmacotherapy and its role in the comprehensive management of patients with carpal tunnel syndrome.

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Conflict of interest. The authors have no conflicts of interest to declare.

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