Introduction. In our previous studies [1,2] we analyzed the principles and tactics of the use of neurophysiological (NPh) diagnostic methods on the basis of the NPh examination of 160 patients with cervical spondylotic myelopathy (CSM) in the course of their surgical and non-surgical treatment. In spite of significant achievements of neurovisualizing technologies in the objective assessment of the functional condition of segmental and conduction structures of the spinal cord, there still remain unclarified questions, including the theoretical and purely methodological ones. The number of published works dedicated to NPh monitoring of the spinal function in patients with compression myelopathy has been steadily increasing lately, which reflects the importance of the problem of diagnosis and treatment of the pathology.

The spinal function disorders, especially that classified as myelopathy, occur in the neurologists’ and neurosurgeons’ clinical practice almost on the daily basis. It is due to high incidence of vertebral column pathology and the patients’ delay in seeking medical advice on the one hand, and imperfection of the pathology diagnosis, insufficient effectiveness of treatment measures, as well as rather high degree of incapacitation of the patients, on the other hand. The cause of spinal cord compression is usually the median protrusion of the intervertebral disc at C2-C3, C4-C5, C5-C6 level.

The spinal cord dysfunction can occur both due to its direct mechanical compression, static or dynamic, at the moment of movement, and to the compression of the vessels supplying the spinal cord (myeloischemia). The factor contributing to the spinal compression at the cervical level of the vertebral column is a congenital or acquired vertebral canal stenosis (i.e.its diameter is less than 11 mm, and the correlation between the anteroposterior diameter of the vertebral canal and the vertebral body is less than 0.8 mm).

In certain cases the changes in the vertebral column revealed with the help of radiography, CT scan or MRI may be clinically asymptomatic. On the other hand, the finding of an intervertebral disc herniation, spondylosis or stenosis of the vertebral canal, does not necessarily mean that only they can cause the patient’s neurological disorders. According to etiology, the most frequent cause of the cervical myelopathy syndrome is the spondylogenic spinal cord compression as a result of: spondylosis, intervertebral disc hernia, acquired stenosis of the vertebral canal, compression by posterior osteophytes, hypertrophied ligament, etc. (according to ICD-10: codes...
M50+, M47.1 (G99.2*); a likely spondylogenic vascular compression of the anterior spinal or vertebral artery with ischemic myelopathy (code M47.0+ (G99.2*). The range of diseases which require differential diagnosis is as follows: consequences of vertebrospinal trauma, tumours of this level (extra- and intramedullar), atypical lateral sclerosis (ALS), syringomyelia, transverse myelitis, hereditary spastic paraplegia, disseminated (multiple) sclerosis, etc [3]. The etiological factor of the compression injury of the spinal cord may be a craniovertebral anomaly, in particular, Chiari 1 malformation (code Q07.0).

In agreement with modern concepts ideas of pathophysiological mechanisms of CSM development, we analyzed a number of typical electrophysiological phenomena which are supposed to accompany the spinal cord compression at the cervical level, including the involvement of the anterior horn motoneurons in the pathologic process.

The objective of the study: to determine the principles and tactics of differentiated application of NPh methods in CSM diagnosis.

Materials and methods. We have been observing 160 patients with CSM since 2007. 96 (60%) out of them were male and 64 (40%) - female. The age range of the patients was from 31 to 76 (52.28±11.83 on the average). We used the following methods of examination: clinico-neurological, neurovisualizing (MRI, CT, functional spondylography). The set of NPh methods included: 1) standard stimulating ENMG with F-wave recording (188 tests); 2) needle electromyography (EMG) (105 tests); 3) motor evoked potentials (MEP) to transcranial magnetic stimulation (TMS) and spinal magnetic stimulation (MS) (188); 4) recording of somatosensory evoked potentials to median nerve stimulation (SSEP) (50).

EMG examination of a single fiber is very important for differentiation of incipient signs of the spinal motoneuron involvement and assessment of denervation-reinnervation changes [4]. It was necessary to use these more subtle (sensitive) methods of examination in 32 (20%) cases to confirm or disprove the involvement of spinal motoneurons in the pathologic process. The needle EMG allows to evaluate the morpho-functional organization of motor units, preservation of innervation, the extent of reinnervation (reorganization), i.e., characterize the condition of peripheral neuromotor system. The single fiber EMG enables us to study the electrical activity of separate muscle fibers, and also determine their density in motor units (MU) and reliability of neuromuscular transmission with the help of jitter-method [4]. Jitter is a deviation of the off period interval of the action potential of two muscle fibers which belong to one MU. The density of muscle fibers reflects the change of MU structure.

The average fiber density was measured in conventional units by means of calculating the average number of single muscle fiber potentials belonging to different MU. This value in healthy patients varies from 1.2 to 1.8, depending on the muscle and on the age. The increase of muscle fiber density in an MU reflects the change of MU structure.

NPh diagnosis was made on the «Neuro-MEP-4» (+Neurosoft, RF) equipment with the use of «Neuro-MS» magnetic stimulator (+Neurosoft, RF).

All the patients gave their informed consent to our conducting NPh examination.

The statistical data processing was carried out with the help of «Statistica 6» application package, the sampling method: sample mean value, mean error; for the definition of the likelihood of the difference between the groups – a nonparametric technique: for binary features - Pearson’s chi-squared test; for two independent groups comparison – Mann-Whitney U-test. The difference was considered feasible when p<0.05. The correlation between the indices was estimated with the help of the Spearman correlation coefficient.

Results and discussion. The main complaints of the patients were as follows: bilateral numbness of the extremities (in 58% of patients), discomfort in walking (56%), weakness in the extremities (68%), the patients usually noted certain clinical manifestations with periods of occasional worsening. Clinically, myelopathy manifested itself in combined or isolated signs of Brown-Sequard syndrome, central spinal syndrome, anterior spinal cord syndrome.

In fact, the necessity of evaluation of degenerative dystrophic changes in the vertebral column in relation to clinical manifestations of myelopathy arises in clinical practice on a daily basis. Such a task, as well as the problem of differential diagnosis, as a rule, dictate the need for use of NPh techniques to diagnose the condition of segmentary and conduction structures of the spinal cord. We have developed and tried out the following scheme of NPh examination of the patients with CSM in our clinical studies (Fig.1).

MU – motor unit; MUP – motor unit potential, SNAP- sensory nerve action potential; CMAP – compound mixed nerve action potential; DRP – denervation-reinnervation process, FP – fibrillation potential; PSHW – positive sharp wave; FscP – fasciculation potential; SF EMG – single fiber EMG; NCV – nerve conduction velocity; M- and F- muscle potential under stimulation ENMG; MEP – motor evoked potential; CMCT –central motor conduction time; SSEP – somatosensory evoked potential.

Following the above scheme of diagnostic examination we managed to pick out of the total number of the examined patients the 19 who had motoneuronal injury; we identified ALS syndrome at the background of cervical myelopathy in 32 (20%) patients; root(s) involvement – in 59 (36.9%) patients, and diagnosed concomitant tunnel syndromes: in 14 (8.8%) patients with carpal tunnel syndrome and 5 (3.1%) - with cubital tunnel syndrome; polyneuropathy – in 18 (11.3%) patients.

MEP is a sensitive technique for detection of subtle (pre-clinical) changes as a result of partial spinal cord compression in cervical spondylosis – the deviation of MEP indices was recorded in 134 (83.8%) cases whereas median SSEP deviation was registered in 29 (58%) out of 50 patients examined.

As is well-known, it is rather difficult to diagnose ALS at the early stages of the disease, especially when...
there exist degenerative-dystrophic changes of the cervical spine and the combination of such changes in the lumbar spine. Controversial cases require NPh reevaluation and other retests. Needle EMG is considered the most important instrument of NPh detection of denervation changes in muscles. If there is a reason to suspect a motoneuron disease on the basis of NPh examination (Fig.1, block III), it is necessary 1) to confirm the peripheral motoneurons involvement in the most damaged muscles; 2) to detect the NPh signs of the peripheral motoneurons injury in the less clinically damaged muscles provided that the nerves are intact.

However, the results obtained are not specific for ALS, as they may be found in cases of spinal cord diseases (for instance, the spinal amyotrophy, poliomyelitis, syringomyelia), motor root diseases (e.g. polyradiculoneuropathy) and peripheral nerve diseases (axonal polyneuropathies) [5].

The absence of fasciculation potentials (FscP) causes doubts in the motoneuron disease diagnosis,

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### Fig. 1. The scheme of complex NPh examination of a patient with CSM.

| Goal of NPh diagnosis | EMG | SFEMG | MEP | SSEP |
|-----------------------|-----|-------|-----|------|
| I To exclude a more distal lesion (tunnel syndrome, mononeuropathy, brachial mononeuropathy, polyneuropathy) | ENMG | DRP signs in upper and lower extremity muscles, craniobulbar muscles | ⚫ MEP latency under cortical stimulation | ⚫ Latency or absence of spinal (N11, N13) and/or cortical components (N20) |
| | | | ⚫ CMAP amplitude in the corresponding myotome and/or NCV | ⚫ interpeak intervals N11-N13, N9-N13, N9-N20 |
| | | | | ⚫ difference of parameters under symmetrical nerve stimulation |
| | | | | ⚫ amplitude SNAP in corresponding dermatome and/or NCV |
| | | | | ⚫ CMAP amplitude in the corresponding myotome and/or NCV |
| | | | | ⚫ Amplitude of M-response to the proximal stimulation of the nerve – local block of conduction |
| | | | | ⚫ Min latency (or abs) of F-wave (lower sensitivity (motor fibers only)) |
| | | | | Signs of DRP: spontaneous activity FP, PshW, FscP, complex repeated discharges, ⚫ recruitment (acute or chronic) |
| | | | | Changes of MUP: ⚫ amplitude, ⚫ duration, ⚫ polyphasy (when chronic) |
| II To confirm presence of root(s) compression | EMG | ⚫ spontaneous activity and/or MUP changes in muscles innervated by a common root but different nerve+ Paraspinal Muscles |
| III Differential diagnosis of spinal motoneuronal disease (as appropriate) Exclusion of generalized involvement of motoneurons | EMG | DRP signs in upper and lower extremity muscles, craniobulbar muscles | ⚫ spontaneous activity: FP, PShW, FscP, complex repeated discharges, ⚫ recruitment |
| | | | Changes of MUP: ⚫ amplitude, ⚫ duration, ⚫ polyphasy |
| | SFEMG | ⚫ jitter, instability of certain MUP components |
| | | ⚫ density of muscle fibers in MU |
| IV Exclude or confirm spinal structure(s) involvement | MEP | | | |
| | | | | |
but does not exclude it. Jitter-analysis may be helpful for the unstable MUP detection in controversial cases. The considerable increase of jitter and the instability of certain MUP components is explained by the fact that the newly created (as a result of sprouting) terminals and immature synapses do not work with the sufficient degree of reliability. If this occurs, the patients with fast progression of the process demonstrate the most significant jitter and blocking of impulses. The stable form of MUP and the absence of impulse blocking in MUP recording will correspond to a relatively slow progression of the process and the effective reinnervation [6].

We believe the clinical case, which required the use of a number of diagnostic techniques and the consultations of various specialists, to be typical and at the same time totally individualized. The patient I., a 56-year-old female, was referred to the Institute of Neurosurgery with complaints of weakness in her lower and upper extremities, inability to walk unaided, pains in lumbar spine. The anamnesis: she was twice operated on for intervertebral disk herniation excision at L₁-S₁ level, had adhesive epiduritis. The first complaints of weakness in her upper extremities appeared within a year after the last surgery. She arrived for the examination in a wheel-chair; lost 7 kg during the year. The meningeal and non-focal neurological symptoms absent; the cranial nerve function adequate; hypotrophy of upper extremity distal muscles; weakness in upper and lower extremities - tetraparesis in the form of upper spasticato-atrophic paraparesis and lower spastic paraparesis; reduced sensitivity in the L₁-S₁ dermatomes; pelvic organ functions unimpaired.

The ENMG data of upper extremities: excitation conduction velocity indices along the motor and sensory nerve fibers in upper extremities within normal range; significant reduction of distal muscle M-response amplitude (up to 25-35% of the normal). According to needle EMG data in distal and proximal muscles of upper extremities, no signs of acute denervation process were detected. MUP had neuronal (type) changes. As the clinical data dictated the necessity of differentiation with ALS disease, we used the jitter method which is considered to be mainstream in the diagnosis of the fine mechanisms of denervation.

The jitter-analysis data in the deltoid muscle were within the normal range; an increased density of muscle fibers was noted which was the evidence of excessive complete reinnervation (Fig.2).

The needle EMG of the muscles innervated by L₁-S₁ roots (buttocks, lower legs, feet), rare cases of spontaneous activity in the form of PSW and FP in m.tibialis anterior dext were observed; the signs of moderate chronic denervation in the form of increased amplitude and MUP duration, significant polyphasy in mm.gluteus maximus, biceps femoris, tibialis anterior et extensor digitorum brevis were identified.

The ENMG examination allowed us to conclude that no signs of the spinal cord motoneurons generalized involvement were established. There was a maximum likelihood of cervical myelopathy with cervical intumescence motoneuron involvement. The changes in the needle EMG in the muscles of the lower extremities corresponded to the signs of root damage. The patient was recommended to do a cervical spine MRI (Fig.3).

The cervical spine MRI (Fig.3) showed: complicated osteochondrosis (antespondylolisthesis) of C₁V vertebra, uncovertebral spondylarthrosis deformans, spondylosis) of cervical spine, secondary myelopathy with myelomalacia or ischemic type spinal circulatory disturbance?

Thus, comparing the results of Nph and MRI tests, we received a confirmation of pathologic process with peripheral motoneuron degeneration at the cervical intumescence level (most likely, of ischemic origin). The absence of generalized motoneuron involvement according to needle EMG data and normal jitter indices, as well as the absence of impulse blocking, were indicative of neuromuscular contact stability, though the clinical presentations lasted for about 12 months. It conforms to the statements that in cases of neurogenic chronicity [5, 6], normal jitter indices and absence of impulse blocking is evidence of neuromuscular contact stability and completion of reinnervation processes in MU. According to the published research

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**Fig.2.** The single fiber EMG in the deltoid muscle (muscle strength 3 points). The jitter indices are within the normal range – 32.4 µs (normal up to 50 µs); impulse blocking was not observed. The muscle density in the given MU (the spike number) was increased in the 1st case (A) to 8 SI units, in the 2nd (B) – to 4 SI units.

**Fig.3.** The cervical spine MRI of the 56-year-old female patient. A - sagittal; B - axial section.
data, single fiber EMG may be very important for confirmation or exclusion of the deviations in mild manifestations of or doubts about neuronal diseases [7,8]. As a result of due to the verification of the sufficient number of muscles with the help of this technique, the presence of deviations may be established even in subclinical cases. A combination of jitter measurements and muscle fiber density allows us to identify the stage and completeness of reinnervation, as the increase of muscle fiber density and MU component stability reflect the reinnervation completeness.

Our research enabled us to systematize the approaches to clinical interpretation of NPh diagnosis results in patients with SCM. The use of a complex of modern NPh methods considerably improves the diagnostics of this pathology.

Conclusion
A scheme of the use of the optimal sequence of NPh methods for SCM diagnosis has been suggested.

The use of MEP and SSEP techniques makes it possible to improve the diagnosis of SCM, spinal cord conduction structures compression, and assess the degree of their function impairment.

The use of jitter-analysis is highly informative for the differential diagnosis of motoneuron disease, especially at the early stages of the pathologic process. In order to identify the involvement of the peripheral and central motoneurons in patients with SCM it is appropriate to use a complex of NPh techniques taking into account the predominant clinical presentations, the stage of the disease and its treatment, the dynamics of NPh sign changes.

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Інформативність нейрофізіологічних методів діагностики в диференціації ураження мотонейронів спинного мозку

Цель исследований — определить принципы и тактику дифференцированного применения комплекса нейрофизиологических (НФ) методов в диагностике спондилогенной шейной миелопатии (СШМ).

Материалы и методы исследований. Проанализированы результаты клинико-нейрофизиологического исследования у 160 пациентов в возрасте от 31 до 76 лет с СШМ. Использованы методы: клинико-неврологические; нейровизуализирующие (МРТ, КТ, функциональная спондилография); комплекс НФ методов — стимуляционная электронейромиография (ЭНМГ) с регистрацией F-волны; гольчатая ЭМГ; моторные волокнистые потенциалы (МВП); соматосенсорные вызванные потенциалы (ССВП); ЭМГ поодиночного мышечного волокна с определением средней плотности мышечных волокон в двигательных единицах и надежности нервно-мышечной передачи.

Результаты. Разработана и применена в исследовании схема оптимальной последовательности использования методов НФ диагностики у пациентов с СШМ. У 19 (11,9%) пациентов выявлено поражение мотонейронов, у 33 (20%) — синдром БАС на фоне СШМ, у 39 (24,3%) — сопутствующая радикулопатия. Доказана чувствительность метода МВП для выявления частичной компрессии спинного мозга при шейном спондилезе — у 134 (83,8%) больных, ССВП — у 29 (58%). На клиническом примере определена роль джиттер-анализа при необходимости тонкой дифференциации болезни мотонейронов, ишемического компрессионного поражения спинного мозга.

Выводы. Предложена схема оптимальной последовательности использования методов НФ диагностики у пациентов с СШМ. Благодаря применению методов МВП и ССВП усовершенствована диагностика компрессии проводящих структур спинного мозга и тяжести нарушения их функции. Использование джиттер-анализа позволяет повысить информативность НФ диагностики поражения мотонейронов спинного мозга, особенно на ранних стадиях патологического процесса.

Ключевые слова: спондилогенная шейная миелопатия, диагностика, ЭМГ, джиттер-анализ.