STUDY OF DYNAMIC SOMATOSENSORY EVOKED POTENTIALS IN PATIENTS WITH ASYMPTOMATIC CENTRAL CERVICAL SPINAL STENOSIS

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Objective. To perform comparative analysis of the components of dynamic somatosensory evoked potentials (DSSEP) from the upper and lower extremities with varying grades of central cervical spinal stenosis (CSS) in patients with mildly symptomatic and asymptomatic course of the disease.
Material and Methods. The retrospective monocentric study included 56 patients (29 men and 27 women; age 54.8 ± 9.6 years) with CSS examined in 2019–2024. In accordance with the grading system of Kang et al., patients were divided into three groups: Group 1 included 25 patients with grade 1, Group 2 — 23 people with grade 2, and Group 3 — 8 patients with grade 3. All patients underwent DSSEP examination from the upper and lower extremities in the neutral position and in flexion and extension positions of the neck at an angle of 45 Changes in the amplitude of the cortical peak N20, the spinal peak N13 and the interpeak interval N9–N20 were assessed when recording dynamic DSSEPs from the upper extremities. The changes in the amplitude of the cortical peak P38 were assessed when recording DSSEPs from the lower extremities. In addition to assessing the absolute values of the indicators, the index of change in the indicators was calculated.
Results. In the neutral position, statistically significant differences were found between groups 1 and 3 in the amplitude of the N20, N13 and P38 components and the N9–N20 interpeak interval. Statistically significant differences were also found between groups 2 and 3 in N20, N13, P38 peaks and the N9–N20 interval. At the same time, statistically significant differences were not found between Groups 1 and 2. When assessing the dynamic SSEPs, patients in Group 1 showed a statistically significant decrease in the N20 amplitude in the extension position and an increase in the N9–N20 latency in the flexion position. In Group 2, in addition to a statistically significant decrease in the N20 amplitude in the extension position and an increase in N9–N20 latency in the flexion position, a statistically significant decrease in the N13 amplitude was noted both in the flexion position and during extension. In Group 3, a statistically significant decrease in the amplitude of N13 during extension and of P38 during flexion was revealed. When analyzing the index of change in the indicators, no significant differences were found between the groups, however, statistically significant differences were recorded for the N9–N20 interval between Group 1 and Group 3, as well as between Group 2 and Group 3 without statistically significant differences between Group 1 and Group 2.
Conclusion. The use of dynamic SSEPs allows for an objective assessment of the degree of damage to the cervical spinal cord in patients with asymptomatic central stenosis of the cervical spinal canal of varying grades. Further multicenter studies are needed to clarify the reference values of dynamic SSEP parameters and, taking them into account, to develop clear criteria for selecting candidates for surgical treatment.
Key Words: central stenosis of the spinal canal; asymptomatic compression of the cervical spinal cord; dynamic somatosensory evoked potentials.
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Cervical spondylotic myelopathy is a disease associated with the dysfunction of the cervical spinal cord because of its static and dynamic compression, as well as strain as a result of degenerative changes in the intervertebral discs, facet joints, posterior longitudinal and flaval ligaments and spondylosis, with the development of acquired central spinal stenosis at the level of one or more spinal motion segments (SMS) of the cervical spine (CS), which is characterized by various clinical signs [1, 2]. Routine neuroimaging, including MRI and MSCT of the CS, allows identifying spinal stenosis and abnormal signal in case of damage to the cervical spinal cord [1]. Dynamic MRI allows detecting signs of strain and/or anterior compression of the spinal cord by osteophytes and bulging discs during flexion, as well as posterior compression by the vertebral arch and hypertrophied flaval ligament during extension [3]. In several cases, even with severe morphological changes, clinical signs may be rather non-specific or completely absent at the time of examination because of compensatory capabilities, however, over time, they may with particular frequency develop to cervical spondylotic myelopathy with a full-scaled clinical presentation [1]. In such cases, neurophysiological

examinations that are used to evaluate the conduction of nerve impulses through central and peripheral neural structures significantly add to MRI findings and allow solving the following issues:

- detection and quantitative estimation of the cervical spinal cord dysfunction;
- exclusion of other neuromuscular diseases that mimic cervical myelopathy;
- prediction of neurological deficit progression;
- selection of candidates for surgical intervention;
- impartial quantitative evaluation of the outcomes of decompression surgeries.

Among a wide range of techniques used for this purpose and described in detail in the review by Yu et al. [1], somatosensory evoked potentials (SSEP) are the most understood and available technique. As early as 1979, El Negamy et al. [4] first registered a statistically significant increase in the latency of the spinal component of SSEP from the upper extremities in patients with cervical myelopathy compared to healthy subjects. As data accumulated and neuroimaging techniques were implemented into clinical practice, it was revealed that decreased amplitude and/or increased latency of SSEP components from the upper and/or lower extremities in patients with asymptomatic cervical spinal cord compression is a risk factor for the onset or worsening of clinical signs within a year; it helps to predict the development of cervical spondylotic myelopathy with certain probability [5]. The practical use of dynamic SSEP (DSSEP) for impartial evaluation of the conductivity of the cervical spinal cord in different neck positions gives new opportunities for predicting the development of cervical myelopathy and selecting patients with mildly symptomatic disease for surgical treatment [6]. Dynamic change factors for the amplitude of SSEP cortical and spinal components during the flexion and extension of the cervical spine were proposed; their limits were calculated by statistical processing, however, the studies involved a limited number of patients [7]. Moreover, we have found no literature sources on the analysis of DSSEP with cervical central spinal stenosis of various grades.

The objective was to perform comparative analysis of DSSEP components from the upper and lower extremities with varying grades of central cervical spinal stenosis (CSS) in patients with mildly symptomatic and asymptomatic course of the disease.

The type of the publication is original article, with level of evidence IV.

Material and Methods

This retrospective monocentric study involved 56 patients (29 males and 27 females; mean age 54.8 ± 9.6 years) examined in 2019–2024. The main reason for examination was pain syndrome: cervicalgia in 15 (26.8%) patients, cervicobrachialgia in 31 (55.4%), other reasons in 7 (12.5%), and no symptoms at screening in 3 patients (5.4%). Neurological status examination revealed no full-scaled signs of myelopathy in all patients, i.e. pyramidal signs, motor and sensory disorders, vegetative and trophic disorders, pelvic disorders, etc. All patients underwent cervical MRI that revealed central spinal stenosis at the cervical spinal canal. In accordance with the classification by Kang et al. [3], patients were divided into 3 groups according to the stenosis grade: Grade 1 – 25 patients (15 males and 10 females, 52.4 ± 9.9 years), Grade 2 – 23 patients (9 males and 14 females, 56.3 ± 8.6 years), and Grade 3 – 8 patients (5 males and 3 females, 57.8 ± 10.4 years). Patients with multilevel stenosis were assigned to groups in accordance with the SMS with the most significant stenosis. The groups had no statistical differences in age, sex, and the number of SMS involved in the disease process. The clinical status was assessed using the modified Japanese Orthopaedic Association (mJOA) score; the dysfunction grade varied from mild in groups 1 and 2 to moderate in Group 3 with the mean score that was statistically significantly lower than in groups 1 and 2 (Table 1).

Exclusion criteria were the following: clinical presentation of severe cervical spondylotic myelopathy (less than 12 mJOA scores), other diseases of the neuromuscular system that lead to the patient's condition severity and prevailed in the clinical presentation.

All patients underwent SSEP examination from the upper and lower extremities in lying neutral position on a flat surface, with cervical flexion and extension at 45°. The angle was adjusted using the couch headrest and a soft headrest used in MSCT examination. SSEP from the upper extremities were registered during rhythmic stimulation of the median nerve using skin electrodes with rectangular pulse, 0.2 ms duration, 4.7–5.1 Hz frequency, and 10–15 mA stimulation strength. The mean responses were registered in the following leads of the international 10–20 system: ipsilateral – contralateral Erb's points, the C2 spinous process – Fz, and C3'/C4' – C4'/C3' leads depending on the stimulation side. When registering DSSEP from the upper extremities, changes in the amplitude of the N20 and N13 components, as well as the central somatosensory conduction time – the N9–N20 interpeak interval (IPI) were assessed.

SSEP from the lower extremities were registered during rhythmic stimulation of the tibial nerve with similar parameters and current strength up to 15–45 mA; average responses were registered in the Pz' – Fz lead of the international 10–20 system. When recording DSSEP from the lower extremities, changes in the P38 component amplitude were assessed. Based on the latency and amplitude of the SSEP components registered in the neutral position, patients were classified according to the grade of myelopathy progression risk within a year (Table 2).

In addition to assessing the absolute values, the parameter change index (PCI) was calculated according to Qi et al. [7] for both the N20, N13, and the P38 amplitude and the differentiated latency of the N9–N20 IPI: (flexion position parameter – extension position parameter) / neutral position parameter × 100. SSEPs were registered using a Neuro-MEP-4 4-channel ENMG system (Neurosoft, Russia) and Viking Quest v11.0 (Nicolet Biomedical, USA).

Statistical processing of the results was performed using online calculators available at https://www.psychol-ok.ru/, http://www.medstatistic.ru/, and https://www.statskingdom.com/, as well as Microsoft Excel. The between-group comparison of quantitative parameters was performed using the Student's t-test for normal distribution, or the Mann–Whitney test for non-normal distribution. The Shapiro–Wilk test was used to determine the normality of data distribution in the groups. The distribution was considered normal at $p \geqslant 0.05$. Groups were compared by qualitative parameters using the χ^2 test. Changes over time were analyzed using the McNemar's test. All differences were considered significant at $p < 0.05$.

Quantitative data with non-normal distribution are provided as Me (Q1–Q3), where Me is the median, Q1 is the first quartile, and Q3 is the third quartile; in case of normal distribution – as M ± σ, where M is the mean value, and σ is the standard deviation. Qualitative parameters are provided as absolute and relative frequencies.

Results

The latency and amplitude of the SSEP components from the upper and lower extremities in the neutral, flexion and extension positions are provided in Table 3. Analysis of the SSEP from the upper and lower extremities demonstrated that the amplitude of the N20 and N13 components in Group 3 was statistically significantly lower than in groups 1 and 2, although the median values of the parameters were within the reference range in all three groups. The N9–N20 IPI indicating the central somatosensory conduction time was statistically significantly higher in Group 3 than in groups 1 and 2, and the median exceeded the reference range (10.8 ms vs normal value of 8.7–9.7 ms). Analysis of the SSEP from the lower extremities in the neutral position revealed that the P38 amplitude in Group 3 was statistically significantly lower than in groups 1 and 2; the median value was also within the reference range in all groups. No significant differences in the above parameters were found between groups 1 and 2. The distribution of SSEP over classes (Fig.) also demonstrated a prevalence of patients with a high risk of myelopathy progression within a year in Group 3, while patients with low and moderate risk predominated in groups 1 and 2. Evaluation of DSSEP showed that the absolute mean values of the N20 and N13 amplitudes in the flexion and extension positions in Group 3 were statistically significantly lower, and the N9–N20 IPI was statistically significantly higher than in groups 1 and 2; however, there were no statistically significant differences between groups 1 and 2. Analysis of changes in parameters over time for Group 1 demonstrated that the N20 amplitude in the extension position statistically significantly decreased and the duration of the N9–N20 IPI in the flexion position increased; Group 2, in addition to the above changes specified for Group 1, also demonstrated a statistically significant decrease in the N13 amplitude in both flexion and extension positions. In Group 3, only a statistically significant decrease in the N13 amplitude in the extension position and in the P38 amplitude in the flexion position was revealed. Analysis of the PCI revealed no significant differences in the amplitude index between the groups; however, PCI for the N9–N20 IPI in Group 3 was statistically significantly higher than in groups 1 and 2, with no statistically significant differences between groups 1 and 2 as well.

Discussion

Analysis of the SSEP in the neutral position in a group of patients with grade 3 central cervical spinal stenosis with MRI-confirmed morphological changes in the cervical spinal cord revealed a statistically significant decrease in the amplitude of both the spinal and cortical components of SSEP, as well as a statistically significant increase in the central somatosensory conduction time, which, in turn, is a risk factor for

Table 1
Features of patient groups

Parameters	Group 1	Group 2	Group 3	*p*
Number of patients, *n*	25	23	8	–
Age, years	52.4 ± 9.9	56.3 ± 8.6	57.8 ± 10.4	>0.05
Sex, *n* (%)				0.284
male	15 (60.0)	9 (39.1)	5 (62.5)	
female	10 (40.0)	14 (60.9)	3 (37.5)	
Number of SMS, *n* (%)				0.554
single-level stenosis	14 (56.0)	10 (43.5)	5 (62.5)	
multi-level stenosis	11 (44.0)	13 (56.5)	3 (37.5)	
mJOA	17 (17–18)**	17 (16–18)*	16 (14.8–17)	<0.05

** Statistically significant differences between groups 1 and 3 at $p < 0.05$; * statistically significant differences between groups 2 and 3 at $p < 0.05$;
SMS – spinal motion segment; mJOA – modified Japan Orthopaedic Association score.

Table 2
Classification of changes in the cortical components of somatosensory evoked potentials according to the degree of clinical deterioration risk within a year in patients with central cervical spinal stenosis [5]

Incidence of myelopathy symptom progression	SSEP UE	SSEP LE	SSEP UE+ LE
Class 1: normal lat. and amp. of SSEP from the UE and LE	2.6 %	18.8 %	0.0 %
Class 2: normal lat., decreased amp. from the UE or LE	27.7 %	39.4 %	13.7 %
Class 3: normal amp., increased lat. from the UE or LE	23.8 %	42.3 %	24.3 %
Class 4: normal amp., increased lat. from the UE and LE	86.7 %	83.3 %	91.1 %
Class 5: increased lat., decreased amp. from the UE and/or LE	100.0 %	100.0 %	100.0 %

SSEP — somatosensory evoked potentials; UE — upper extremities; LE — lower extremities; lat. — latency, amp. — amplitude.

the progression of symptoms within a year. None of the patients in Group 3 demonstrated normal SSEP in the neutral position. Despite different compression grades according to MRI findings, patients with grade 1 and 2 spinal stenosis and without morphological changes in the cervical spinal cord had no statistically significant differences in SSEP in the neutral position. For DSSEP in patients with grade 1 spinal stenosis, the amplitude of the N20 cortical component decreases in response to extension; it can be biomechanically explained by compression of the posterior columns of the cervical spinal cord by the hypertrophied flaval ligament; the N9–N20 IPI increases in the flexion position as well, and it is probably associated with stretching of the spinal cord. Scheuren et al. [9] in their recent study demonstrated that patients with multi-level abnormalities have a higher grade of craniocaudal displacement of the spinal cord during registering dermatomal contact heat evoked potentials according to phase contrast MRI findings compared to the control group, and this fact confirms our ideas [8]. When recording DSSEP in patients with grade 2 spinal stenosis, the above changes persist, however, they are accompanied by a statistically significant decrease in the N13 spinal component amplitude both during flexion and extension. Experiments on rodents revealed that during flexion in the cervical spine, according to MRI findings, the intensity of the intramedullary signal in T2WI mode increases and, according to laser Doppler photometry, blood flow in the cervical spinal cord decreases resulting in its ischemia [9]. Since ischemia of neural structures leads firstly to the decreased amplitude of SSEP components, we assumed that the decreased amplitude of N13 spinal component is associated with the overlay of a vascular factor in Group 2 patients. When recording DSSEP in patients with grade 3 spinal stenosis, a statistically significant decrease in amplitude was observed only for the N13 spinal component during extension and for the P38 cortical component during flexion. This is probably associated with the relatively small number of findings,

Table 3
Values of dynamic somatosensory evoked potentials (DSSEP)

SSEP components	Group 1	Group 2	Group 3
Amp. N20 neutral, mkV	2.8 (2.0–3.5)$^{++}$	2.4 (1.8–3.7)$^{+}$	1.5 (0.9–2.9)
Amp. N20 flexion, mkV	2.8 (2.0–3.6)**	2.4 (1.8–3.5)*	1.7 (0.8–2.8)
Amp. N20 extension, mkV	2.6 (1.8–3.4)$^{\downarrow **}$	2.3 (1.7–3.7)$^{\downarrow *}$	1.7 (1.1–2.6)
PCI, %	8.4 (4.0–14.2)	11.3 (5.0–17.6)	9.0 (4.6–21.7)
Amp. N13 neutral, mkV	2.5 (1.8–3.1)$^{++}$	2.5 (1.9–3.0)$^{+}$	1.8 (1.5–2.1)
Amp. N13 flexion, mkV	2.5 (2.0–2.9)$^{++}$	2.4 (2.0–3.1)$^{\downarrow +}$	1.8 (1.3–2.0)
Amp. N13 extension, mkV	2.5 (1.9–3.4)$^{++}$	2.4 (1.7–2.9)$^{\downarrow +}$	1.5 (1.2–2.1)$^{\downarrow\downarrow}$
PCI, %	14.4 (5.5–39.2)	14.2 (6.2–33.0)	19.0 (7.2–26.0)
Amp. N9–N20 neutral, mkV	9.2 (8.9–9.7)$^{++}$	9.3 (8.9–9.7)$^{+}$	10.8 (10–11.5)
Amp. N9–N20 flexion, mkV	9.4 (9.0–10.0)$^{\downarrow\downarrow ++}$	9.4 (9.0–10.0)$^{\downarrow\downarrow +}$	10.5 (9.9–11.3)
Amp. N9–N20 extension, mkV	9.3 (8.8–9.8)**	9.3 (8.8–9.9)$^{+}$	10.6 (9.2–11.6)
PCI, %	3.0 (1.4–6.5)$^{++}$	2.2 (1.2–4.3)$^{+}$	5.9 (4.5–12.0)
Amp. P38 neutral, mkV	0.83 (0.65–1.27)$^{++}$	1.1 (0.5–1.7)$^{+}$	0.58 (0.42–0.73)
Amp. P38 flexion, mkV	0.85 (0.57–1.18)$^{++}$	0.91 (0.47–1.86)$^{+}$	0.52 (0.23–0.57)$^{\downarrow}$
Amp. P38 extension, mkV	0.84 (0.66–1.17)$^{++}$	0.90 (0.47–1.7)*	0.57 (0.38–0.76)
PCI, %	16.9 (7.1–35.2)	11.8 (6.9–27.5)	15.8 (6.6–36.5)

Neutral — registration of SSEP in the neutral position of the neck; flexion — registration of SSEP in the flexion position; extension — registration of SSEP in the extension position; PCI — parameter change index; Amp. — amplitude; * statistically significant differences between groups 2 and 3, $p < 0.05$; ** statistically significant differences between Groups 1 and 3, $p < 0.05$; $^{+}$ statistically significant differences between groups 2 and 3, $p < 0.01$; $^{++}$ statistically significant differences between groups 1 and 3, $p < 0.01$; $^{\downarrow}$ statistically significant differences in SSEP values in the flexion/extension position compared to the neutral position of the neck, $p < 0.05$; $^{\downarrow\downarrow}$ statistically significant differences in SSEP values in the flexion/extension position compared to the neutral position of the neck, $p < 0.01$.

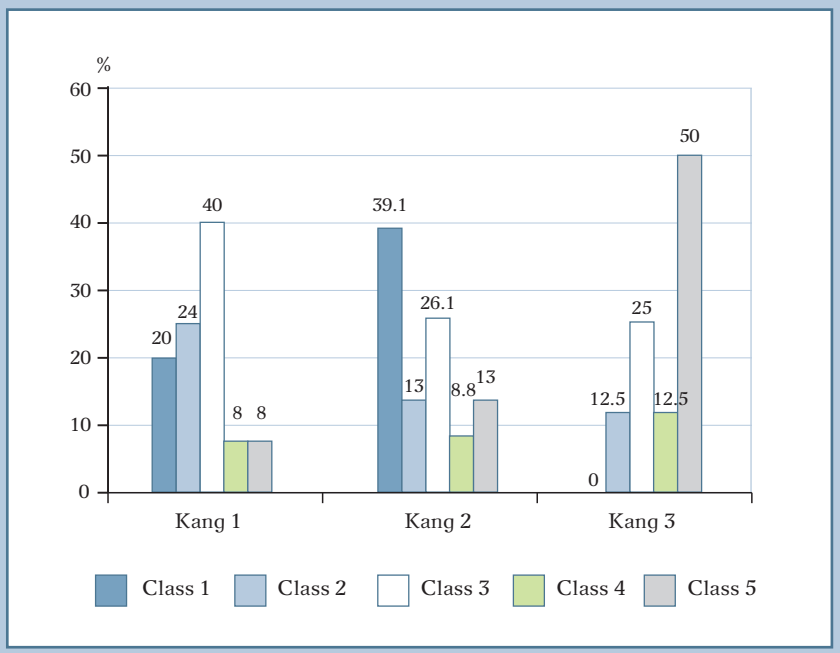

Fig.
Risk of myelopathy progression within a year according to Feng et al. [5] in patients with varying grades of central cervical spinal stenosis: Class 1–5 – degrees of myelopathy progression risk within a year; Kang 1, 2, 3 – degrees of spinal stenosis at the cervical spine according to Kang et al. [3]

since the patients selected had an asymptomatic or mildly symptomatic course of the disease, and, as a rule, there was already a detailed clinical presentation of cervical spondylotic myelopathy in patients with grade 3 central cervical spinal stenosis. It is interesting that the amplitude change index proposed by Qi et al. [7] had no statistically significant differences in all groups for all components of the SSEP from the upper and lower extremities, however, the PCI for the N9–N20 IPI was statistically significantly higher in patients with grade 3 spinal stenosis than in patients with grade 1 and 2 stenosis; for this reason, it can be assumed that, during dynamic tests, spinal cord strain predominates among the other damaging factors in patients with grade 3 spinal stenosis and already developed morphological changes in the cervical spinal cord because of chronic compression and ischemia. On the other hand, it can be assumed that the duration change index of more than 6% for the N9-N20 IPI when registering DSSEP is the most significant marker of damage to the cervical spinal cord because of its strain; it is typical for patients with grade 3 spinal stenosis and should be most particularly considered when assessing the risk of symptom progression and selecting candidates for surgical intervention.

Conclusion

The use of DSSEP allows for an impartial evaluation of the grade of the cervical spinal cord damage in patients with mildly symptomatic central cervical spinal stenosis of different grades. When selecting candidates for surgical treatment, a decrease in the amplitude of both the cortical and spinal components below the reference range, or by 50% of the baseline is critical, as well as the index of change in the central somatosensory conduction time. Further multicenter studies are required to clarify the reference values of DSSEP parameters and, with that knowledge, to develop definite criteria for selecting candidates for surgical treatment.

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The study was approved by the local ethics committees of the institutions.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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