INTRAOPERATIVE RESPONSE OF THE PYRAMIDAL SYSTEM TO SURGICAL CORRECTION OF SPINAL DEFORMITIES OF VARIOUS ETIOLOGIES

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Objective. To assess the information value of comparing the results of formalizing intraoperative changes in transcranial motor evoked potentials during surgical correction of spinal deformities of various etiologies.

Material and Methods. Study design: analysis of monocentric retrospective unselected cohort over 5 years, evidence class 2b. Surgical correction of spinal deformity under neurophysiological control was performed in 364 patients (mean age 12.80 ± 0.40 years). The scores of changes in motor evoked potentials were used to compare the pyramidal system response to surgical aggression in patients with congenital spinal deformities, idiopathic scoliosis, and systemic skeletal diseases.

Results. Basic motor responses in patients with systemic diseases of the axial skeleton are to a greater extent depressed and unstable than in those with congenital deformity and idiopathic scoliosis. On surgery completion, these differences are exacerbated. Five identified types of response of the spinal cord conduction pathways to surgical correction of spinal deformity allow comparing intraoperative neuromonitoring results in different groups of patients. The most dangerous types of response are observed more often in patients with congenital and systemic pathologies than in those with idiopathic scoliosis.

Conclusion. The proposed method for the rank assessment of intraoperative changes in motor evoked potentials during surgical correction of spinal deformity allows comparative studies of patients' reactions to surgical intervention in different etiological and age groups. The greatest risk of iatrogenic motor disorders in the postoperative period is observed in patients with systemic skeletal pathology.

Key Words: spine deformity, spinal surgery, intraoperative neuromonitoring, pyramidal system, neurological complications.

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GmbH, Germany) according to a previously described scheme [8]. Indicator muscles to elicit MEPs were selected depending on the level of surgical intervention on the spine and the results of a preoperative EMG examination (test for maximum voluntary contraction) [9]. Registration of basic MEPs was started 40–60 min after a single administration of a muscle relaxant in order to exclude its residual effects [10]. Strength of the test stimulus was adjusted individually, until producing a representative MEP.

Subsequent testing was performed after implantation of support elements of spinal instrumentation and at various stages of corrective maneuvers on the surgeon's command. When comparing an ongoing test with basic MEPs, a decrease in the amplitude by more than 50 % of the baseline level and an increase in the latent period by more than 10 %, if it was accompanied by a reduction in the amplitude [11], were considered as diagnostically significant changes in the response characteristics. The monitoring duration ranged from 45 min to 9 h 52 min (3.50 ± 0.08 h).

Changes (relative to the basic level) in the MEP characteristics and configuration, which were detected during intraoperative neuromonitoring, were assigned a rank, in accordance with a developed scale [8], from zero (Ri = 0 – preservation of the MEP form and amplitude-time parameters close to the baseline ones at the time of an ongoing i-th test) to seven (Ri = 7 – complete disappearance of the MEP without signs of its recovery by the end of surgery). During subsequent testing, the ranking score either remained at the same level or changed upward or downward, depending on the pyramidal system ability to transmit the excitation wave from the motor cortex to the indicator muscle. If the MEP amplitude increased in all leads (Ri = 1), which usually occurred upon a decrease in the depth of anesthesia, the transcranial stimulus intensity was adjusted downward until recovery of the basic MEP characteristics. If MEP values dropped below a critical limit, the transcranial stimulus amplitude was increased. In this case, if the MEP restored to the basic level, the time required for this did not exceed 15 min [12], and an increase in the test stimulus intensity did not exceed a certain critical threshold (in present study, 50 mA); the rank value corresponded to the position Ri = 4a [13]. If one of these conditions was not met, the rank variable was assigned the value 4b. The set of changes in the rank scores of the MEP during surgery characterized the type of pyramidal system response [8].

Upon analysis of the intraoperative neuromonitoring features, patients were divided into 3 comparison groups: group 1 included 216 (87 males, 129 females) patients aged 11.30 ± 0.56 years with congenital spinal deformities; group 2 consisted of 89 (32 males, 57 females) patients aged 16.90 ± 0.63 years with idiopathic scoliosis; group 3 (main) included 59 (22 males, 37 females) patients aged 12.40 ± 0.68 years with spinal deformities associated with systemic genetic skeletal diseases.

Mathematical processing of the obtained data was carried out using the Microsoft Excel (2010) software and Attestat Excel-integrated data analysis package [14]. The occurrence rate (ν) of various MEP configuration variants and types of pyramidal system response was calculated by formula (1); the error of the occurrence rate (Si) was calculated by formula (2), and its dispersion (D) by formula (3)

$$\nu_i = \frac{(n_i \cdot 100\ \%)}{N}; \qquad (1)$$

$$S_i = \sqrt{\frac{n_i \cdot (1-\nu_i)}{N}}; \qquad (2)$$

$$D_i = \frac{\nu_i \cdot (1-\nu_i)}{N}, \qquad (3)$$

where n_i is the number of observations of the i-th response type; N is the total number of observations in the tested sample.

The significance of differences of a given parameter ($p < 0.05$) in the comparison groups was evaluated using the nonparametric chi-square test and Z-test for difference of proportions.

The absolute and relative values of a change in the test stimulus amplitude during surgery, their arithmetic mean (M), and standard error of the mean (m) were calculated. The statistical significance of differences in this parameter in the comparison groups was evaluated using the non-parametric Mann-Whitney test ($p < 0.05$) due to a pronounced asymmetry of its statistical distribution histogram.

This study was performed in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association (2013) and the Rules of Clinical Practice in the Russian Federation approved by Order of the Ministry of Health of the Russian Federation No. 266 of 06.06.2003. Patients over 18 years of age and parents or legal representatives of children signed an informed voluntary consent for diagnostic tests and publication of data without identification of personality.

Results and Discussion

Parameters of the baseline (basic) MEPs obtained before surgical intervention were characterized by significant variability associated with the features of pyramidal system functional status that was affected by factors such as the age, patient body size, and course of underlying and concomitant diseases. They were not evoked in 12 (3.8 %) cases (0 in Fig. 1). Among a variety of forms obtained during testing of MEPs, two typical configurations may be distinguished: low-amplitude (less than 100 μV) responses unstable in shape and characteristics, with a reduced, to three or less, number of phases (1 in Fig. 1). Similar MEPs are more common in children under three years of age and in patients with a significantly reduced baseline amplitude of spontaneous and evoked bioelectric activity of indicator muscles – 53 (17.0%) cases. Polyphase (four or more phases) high-amplitude responses (2 in Fig. 1) with a stable form reproduced in successive repetitions of test stimuli were obtained in the vast majority of cases – 79.2 %.

The differences in occurrence rates of the selected variants of basic MEPs are presented in Table 1. Despite the fact that the number of observations and the percentage of cases without basic responses or cases of low-amplitude unstable MEPs in idiopathic scoliosis were significantly lower than in the other groups due to a small *n* value and different values of *N* in the comparison groups, these differences were statistically insignificant ($p > 0.05$). At the same time, the percentage of cases with stable, well-defined, and high-amplitude responses in the group of patients with idiopathic scoliosis was statistically significantly higher ($p < 0.05$) than that in the group with systemic diseases.

Therefore, the main group is characterized by the maximum percentage of cases, relative to the comparison groups, with full absence of basic MEPs at the minimum occurrence rate of stable, well-defined responses. This tendency is partially confirmed statistically. In particular, the variance of this parameter in the main group significantly differs from appropriate values in the comparison groups, i.e. the differences cannot be caused only by random fluctuations in the functional state of the pyramidal system due to fluctuations in anesthesia and hemodynamics factors.

During surgery, various changes in the MEP characteristics and configurations were recorded, which were assessed using a previously developed rank scale [8]. If the shape and amplitude-time parameters of MEPs during testing were close to the basic ones, they assigned a zero rank. If degradation of motor responses increased, the rank value was elevated up to 7.

Generalization of the accumulated data for the entire tested sample enabled identification of 5 stable combinations of MEP ranks (Fig. 2) reflecting typical variants of intraoperative dynamics of the functional state of the pyramidal system in patients. In our opinion, they represent 5 types of response of the spinal cord pathways to surgical correction of spinal deformity [8].

Most of the surgical interventions (Fig. 2) proceeded normally (type I and II response) or with moderate anxiety (type III). Totally, they amounted to 62.7 % of all observations. In 14.0 % (IV), there were significant changes in the MEP characteristics and configurations, which were assessed as neurophysiological signs of danger to the spinal motor pathways. In the case of their appearance, appropriate measures (administration of glucocorticoids, regulation of blood pressure and heart rate, and correction of surgeon's manipulations) were taken. In these cases, surgery was completed with MEPs decreased relative to the baseline level. In the postoperative period, these patients had no clinical signs of impaired motor function. Control EMG examinations in them revealed a reversible decrease (by 10–25 %, on average) in the amplitude of spontaneous EMG activity of the indicator muscles [15]. In 3 (5.3 % of patients with type IV response) cases, there were sensory disorders in the form of transient paresthesias.

In 6.4 % of cases, there was a complete disappearance of MEPs (type V) at the end of surgery upon completing correction of spinal deformity. However, only 7 (26.9 %) of 26 patients had motor disorders after recovering from anesthesia, which were transient and eliminated by conservative treatment. Differences in the occurrence rate of types of pyramidal system response to correction of spinal deformity in the comparison groups (Table 2) are not statistically significant ($p > 0.05$). However, it should be noted the highest occurrence rates of full MEP absence cases during the entire operation and V, the most dangerous type of response, in the group with systemic pathology. The occurrence rate of type I and type II responses in the group of congenital and systemic scoliosis is close to that in the group of idiopathic scoliosis where this parameter is higher ($p > 0.05$). The variability of these characteristics, which is reflected in variance values, also differs in the comparison groups. It is more pronounced in the main group.

During surgery, spontaneous EMG activity developed in 30 (7.4 %) cases; it had the form of either frequently repeated action potentials from individual motor units, or intense interference EMG (evidence of surgical activity in a dangerous proximity to the spinal cord roots), or rhythmic action potentials (pathological automatisms) indicating reactive changes in the functional state of the pyramidal system. Spontaneous EMG activity in the 3rd group occurred more often (Table 2) than in the comparison groups ($p > 0.05$). In patients with idiopathic scoliosis, spontaneous EMG activity was minimal.

After completing spinal deformity correction, a high (close to preoperative) percentage of well-defined, high-amplitude, stable MEPs still remained (Fig. 1C). Due to the appearance of type V response, the number of observations of full MEP absence (0) at the end of surgery increased statistically significantly ($p < 0.05$). However, the number of observations of unstable low-amplitude (1) responses significantly decreased ($p < 0.05$).

In the comparison groups (Table 1), the common pattern of changes, similar to that shown in Fig. 1C, retained, i.e. the percentage of observations with full absence of MEPs at the end of surgery increased in all groups. This increase in the 1st group was statistically significant ($p < 0.05$). The occurrence rate of low-amplitude unstable responses decreased. In the 3rd group, this decrease was statistically significant ($p < 0.05$). Statistically significant differences in the occurrence rates of high-amplitude responses between the 2nd and 3rd groups disappeared. At the same time, the difference in the percentage of cases of full MEP absence between the same groups became significant ($p < 0.05$) due to a larger increase in these cases in surgery for systemic scoliosis than for idiopathic scoliosis. As before surgery, there was a significant difference in the variance of this parameter between the main group and the comparison groups (Table 1), i.e. the features of its variability were not associated with the effects of anesthesia.

In 56.8 % of surgical interventions, the test signal intensity during intraoperative neuromonitoring was usually adjusted upward relative to the baseline level. Over the sample, it was changed

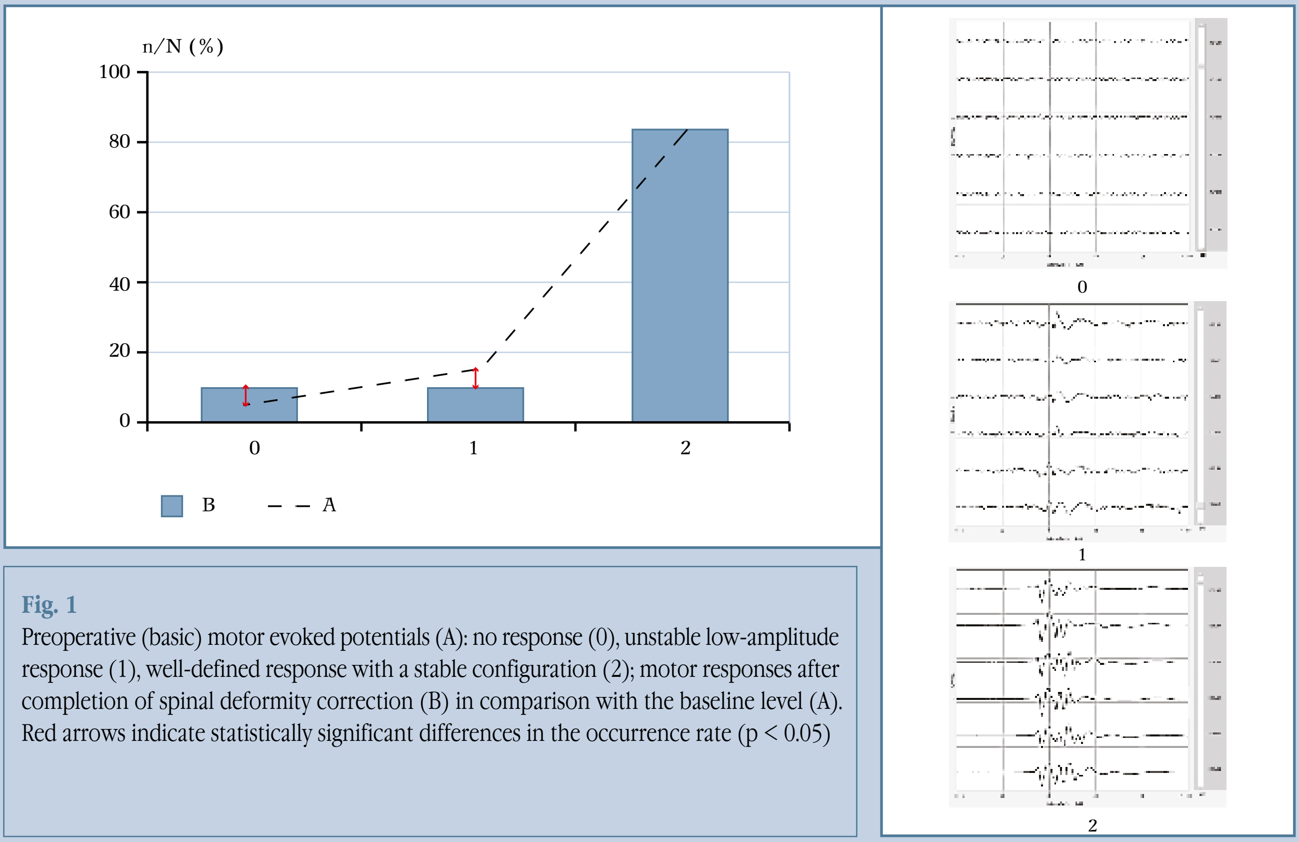

Fig. 1
Preoperative (basic) motor evoked potentials (A): no response (0), unstable low-amplitude response (1), well-defined response with a stable configuration (2); motor responses after completion of spinal deformity correction (B) in comparison with the baseline level (A). Red arrows indicate statistically significant differences in the occurrence rate ($p < 0.05$)

by 18.1 ± 1.53 mA, on average. The increase in this parameter in the comparison groups was close to the mean sample increment. It amounted to 15.6 % in the 1st group, 13.6 % in the 2nd group, and 14.3 % in the 3rd group relative to a baseline level of (18.80 ± 1.99 mA), (16.50 ± 3.28 mA), and (17.7 ± 3.67 mA), respectively.

Summarizing the obtained results, it should be noted that the differences in the selected comparison groups are mainly not statistically confirmed tendencies. In the 2nd group, the absolute and relative numbers of cases of full MEP absence and cases of MEPs with an unstable, low-amplitude configuration are smaller. The group with congenital

Table 1

Occurrence rate of different variants of basic motor evoked potentials (MEPs) in comparison groups

Group	MEP	Surgery start			Surgery end		
		n	v ± s	D	n	v ± s	D
1st	0	7	2.90 ± 1.15	0.01	22	9.20 ± 1.81*	0.03
	1	39	16.30 ± 2.37	0.06	28	11.70 ± 2.07	0.04
	2	193	80.40 ± 2.55	0.07	190	79.20 ± 2.56	0.07
2nd	0	1	1.10 ± 1.050	0.01	4	4.20 ± 2.06†	0.04
	1	8	8.40 ± 2.85	0.08	5	5.30 ± 2.29	0.05
	2	86	90.50 ± 3.00†	0.09	86	90.50 ± 3.15	0.00
3rd	0	4	5.60 ± 2.70	0.07	12	16.70 ± 4.39†	0.19
	1	14	19.40 ± 4.66	0.22	4	5.60 ± 2.70*	0.07
		54	75.00 ± 5.10†	0.26	56	77.80 ± 4.90	0.24

n is the number of observations of the parameter in the comparison group; v is the occurrence rate; *s* is an error; D is the variance of the occurrence rate; † indicates cases of statistically significant ($p < 0.05$) intergroup differences; *indicates cases of statistically significant changes in the occurrence rate of different MEP variants at the end of surgery relative to their basic state.

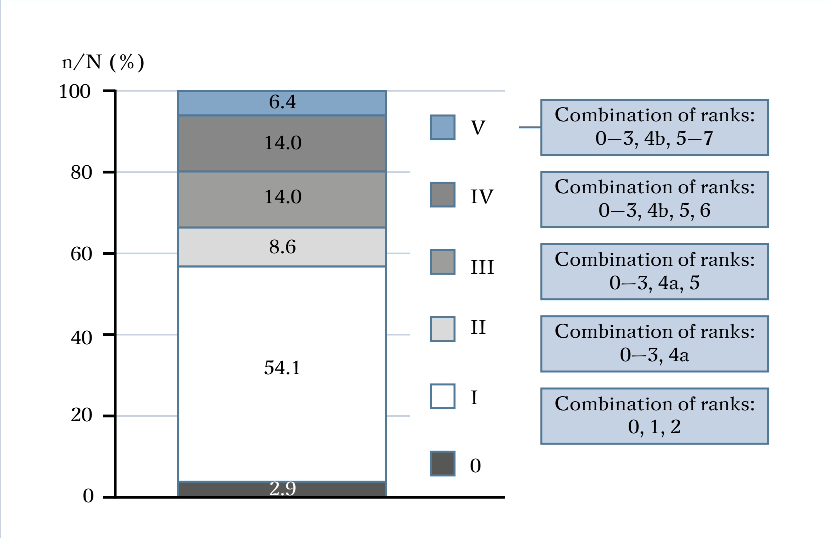

Fig. 2
Occurrence rate of types (I–V) of pyramidal system response to surgical correction of spinal deformity in the analyzed sample

scoliosis is more numerous than that with systemic diseases, but the latter is characterized by relatively more often cases of baseline absence of MEPs or the appearance of unstable low-amplitude potentials. However, a high variability of the physiological characteristics within the comparison groups makes the differences between them statistically insignificant because other factors, in addition to the etiology (e.g., the patient's age underlying the degree of central nervous system maturation), significantly affect the functional state of the pyramidal system, which is reflected during intraoperative neuromonitoring [8, 16].

The occurrence rate of the identified types in the comparison groups was close, but the total of types V and VI was characterized by a minimum percentage in the sample with idiopathic scoliosis and a maximum percentage in the case of systemic diseases. Of course, this reflects an increased risk of motor disorders associated with correction of spinal deformity in patients with systemic skeleton diseases. However, this risk assessment can be considered extremely qualitative.

By the end of surgery, the number of cases with full MEP absence was significantly increased in all groups due to type V response of the pyramidal system. However, this increase was statistically significant ($p < 0.05$) only in the 1st group due to its large size. The relative increase in these cases was maximal in the case of systemic diseases.

Conclusion

The proposed method for ranking assessment of intraoperative changes in MEPs during surgical correction of spinal deformity enables comparative studies of the patient response to surgical intervention in different etiological and age groups [8]. The greatest risk of iatrogenic motor disorders in the postoperative period occurs in patients with systemic skeleton diseases.

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References

1. **Riabykh SO.** The choice of surgical approach for congenital spinal deformity caused by multiple vertebral malformations. Hir. Pozvonoc. 2014;(2):21–28. In Russian. DOI: 10.14531/ss2014.2.21-28.
2. **Riabykh SO, Savin DM.** Possibilities of Type III kyphoses surgical treatment using «Pedicle subtraction osteotomy» technique. Genij Ortopedii. 2013;(1):120–123. In Russian.
3. **Riabykh SO, Shusharina VL, Ochirova PV, Tret'iakova AN, Riabykh TV.** Perioperative risk reduction for vertebrologic surgeries in patients with hereditary diseases of the connective tissue. Genij Orthopedii. 2015;(4):48–52. In Russian. DOI: 10.18019/1028-4427-2015-4-48-52.
4. **Schwab F, Blondel B, Chay E, Demakakos J, Lenke L, Tropiano P, Ames C, Smith JS, Shaffrey CI, Glassman S, Farcy JP, Lafage V.** The comprehensive anatomical spinal osteotomy classification. Neurosurgery. 2014;74:112–120. DOI: 10.1227/NEU.0000000000000182o.
5. **Gibson PR.** Anaesthesia for correction of scoliosis in children. Anaesth Intensive Care. 2004;32:548–559. DOI: 10.1177/0310057X0403200413.
6. **Koruk S, Mizrak A, Kaya Ug**ur B, Ilhan O, Baspinar O, Oner U. Propofol/dexmedetomidine and propofol/ketamine combinations for anesthesia in pediatric patients undergoing transcatheter atrial septal defect closure: a prospective randomized study. Clin Ther. 2010;32:701–709. DOI: 10.1016/j.clinthera.2010.04.010.
7. **Lieberman JA, Lyon R, Feiner J, Diab M, Gregory GA.** The effect of age on motor evoked potentials in children under propofol/isoflurane anesthesia. Anesth Analg. 2006;103:316–321. DOI: 10.1213/01.ane.0000226142.15746.b2.
8. **Saifutdinov MS, Ryabykh SO, Savin DM, Tretyakova AN.** Formalizing the results of intraoperative neurophysiological monitoring of the motor pathways into the spinal cord during the surgical correction of spinal deformities. Vestnik khirurgii im. I.I. Grekova. 2018;177(1):49–53. In Russian. DOI:10.24884/0042-4625-2018-177-1-49-53.
9. **Shein AP, Krivoruchko GA, Ryabykh SO.** Reactivity and resistance of the spinal structures when performing instrumental correction of spinal deformities. Rossiiskii fiziologicheskii zhurnal im. I.M. Sechenova. 2016;102(12):1495–1506. In Russian.
10. **Levshankov AI.** Monitoring and Management of Neuromuscular Conduction During Surgical Operations. St. Petersburg, 2014. In Russian.
11. **Jameson LC.** Transcranial motor evoked potentials. In: Monitoring the Nervous System for Anesthesiologists and Other Health Care Professional, ed. by A. Koht, T.B. Sloan, J.R. Toleikis. New York; London, 2012;27–45. DOI: 10.1007/978-1-4614-0308-1_2.
12. **Khit MA, Kolesov SV, Kolbovskiy DA, Morozova NS.** The role of the neurophysiological intraoperative monitoring to prevention of postoperative neurological complication in the surgical treatment of scoliosis. Nervno-mysecnye bolezni. 2014;(2):36–41. In Russian. DOI: 10.17650/2222-8721-2014-0-2-36-41.
13. **Belova AN, Baldova SN, Kazmin AV.** Use of intraoperative neurophysiological monitoring in the case of surgical intervention in spinal column and spinal cord. Voprosy Travmatologii i Ortopedii. 2014;(2):21–25. In Russian.
14. **Gaidyshev IP.** Data Analysis and Processing: A Special Reference Book. St. Petersburg, 2001. In Russian.
15. **Shein AP, Sayphutdinov MS, Skripnikov AA, Krivoruchko GA, Ryabykh SO.** Correlation of the intra-operative neuromonitoring data and emg-characteristics of post-operative motor deficit in patients with spinal deformities. Khirurgiya. Zhurnal im. N.I. Pirogova. 2017;(4):19–23. In Russian. DOI:10.17116/hirurgia2017419-23.
16. **Kuzmina VA, Syundyukov AR, Nikolaev NS, Mikhailova IV, Nikolaeva AV.** Effectiveness of intraoperative neurophysiological monitoring during spinal surgery. Pediatric Traumatology, Orthopaedics and Reconstructive Surgery. 2016;4(4)33–40. In Russian. DOI: 10.17816/PTORS4433-40.

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