TREATMENT OF PATIENTS WITH DEGENERATIVE DEFORMITIES OF THE LUMBAR SPINE USING MIS TECHNOLOGIES: ANALYSIS OF 5-YEAR RESULTS

I.I. Vasilenko[1, 2], A.V. Evsyukov[3], S.O. Ryabykh[4], E.V. Amelina[5], Yu.E. Kubetsky[1], I.I. Garipov[3], J.A. Rzaev[1, 5]
[1]Federal Neurosurgical Center, Novosibirsk, Russia;
[2]Research Institute of Clinical and Experimental Lymphology, Novosibirsk, Russia;
[3]National Ilizarov Medical Research Center for Traumatology and Orthopedics, Kurgan, Russia;
[4]National Medical Research Center for Traumatology and Orthopedics n.a. N.N. Priorov, Moscow, Russia;
[5]Novosibirsk State University, Novosibirsk, Russia

Objective. To analyze the results of the use of minimally invasive technologies in the treatment of patients with degenerative deformity of the lumbar spine.

Material and Methods. Design: Single-center, non-randomized continuous retrospective cohort study. The level of evidence is 3b (UK Oxford, version 2009). A total of 57 patients (10 men and 47 women) were operated for degenerative scoliosis of the lumbar spine using minimally invasive techniques. The quality of life indicators using ODI, SF-36, VAS, as well as linear and angulometric parameters of the spine were studied.

Results. The age of patients ranged from 37 to 81 years (62/62 [55; 67], hereinafter the data format is mean/median [1; 3rd quartile]). In the postoperative period, patients operated on with MIS techniques showed a statistically significant decrease in pain by 4.3/4.0 [3; 6] points in the lumbar spine, and by 4.3/4.0 [3; 6] points in the legs. Quality of life indicators according to ODI improved by 24/23 [19; 29], and the level of functional adaptation according to the SF-36 questionnaire – by 18/18 [14; 21] in terms of physical parameters and by 18/20 [16; 23] in terms of mental parameters. The deformity angle in the frontal plane according to Cobb decreased by 12.9°/13.0° [10°; 17°], lumbar lordosis changed by 3.3°/2.0° [-1°; 7°], segmental angle L4–S1 – by 1.0°/0.0° [-5°; 7°], and SVA changed by -7.5/-2.0 [-29; 15] mm. As a result of minimally invasive surgical intervention, a good clinical result was obtained in correcting the scoliotic deformity angle from 17.5°/16.0° [11°; 22°] to 4.6°/4.0° [1°; 7°].

Conclusion. The study showed the effectiveness of minimally invasive surgical treatment of degenerative scoliosis of the lumbar spine with short-segment fixation, which allowed obtaining satisfactory clinical results in 93 % of cases with a minimum number of complications (7 %).

Key Words: degenerative scoliosis, lumbar spine, short-segment fixation, minimally invasive correction, sagittal balance.

Please cite this paper as: *Vasilenko II, Evsyukov AV, Ryabykh SO, Amelina EV, Kubetsky YuE, Garipov II, Rzaev DA. Treatment of patients with degenerative deformities of the lumbar spine using MIS technologies: analysis of 5-year results. Hir. Pozvonoc. 2022;19(4):52–59. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2022.4.52-59.

Adult spinal deformity (ASD) is one of the most relevant manifestations of degenerative disc disease (DDD), which impacts the quality of life of patients in the older age group [1].

There are the two subtypes of ASD: *de novo* scoliosis (dASD) and secondary degenerative scoliosis, which results from the evolution of pediatric idiopathic scoliosis [2]. The term dASD (d-De Novo) is used to refer to patients who have developed deformities in the frontal plane that are linked to bone maturation and degenerative alterations to the spine [3]. In this group of individuals, scoliosis always coexists with spinal canal stenosis and is frequently accompanied by a global sagittal imbalance [1, 4]. Pain and the inability to maintain a vertical posture, which are brought on by spinal deformity and weak back muscles, are the clinical symptoms of sagittal imbalance. The symptoms of compensated imbalance are more frequently caused by spinal canal stenosis [5, 6].

Degenerative scoliosis of the lumbar spine can be surgically treated using a variety of approaches, from isolated local decompression of neural structures to different types of fixation and correction options combined with direct or indirect decompression [7].

Numerous studies with reasonable performance criteria have not offered clear advice on both the length of fixation and the surgical approach for treating patients with dASD, which made our study relevant.

The objective is to analyze the results of the use of minimally invasive technology (MIS LLIF TPF) in the treatment of patients with degenerative deformities of the lumbar spine.

Design: Single-center, non-randomized continuous retrospective cohort study. The level of evidence is 3b (UK Oxford, version 2009).

Material and Methods

Inclusion criteria:

– degenerative scoliosis of the lumbar spine with the deformity angle ⩾ 10° and ⩽ 40° according to Cobb in the frontal plane;

– no clinical signs of global sagittal balance disorder, confirmed by the age-adjusted SVA indicator;

– no grade C and D central spinal canal stenosis , according to Schizas;

– clinical signs such as spinal pain syndrome, radiculopathy, and/or a combination of the two;

– availability of full imaging studies;

– no good results from non-surgical comprehensive treatment for at least two months.

The deformity angle degree in the frontal plane according to Cobb of ⩾ 10° and ⩽ 40° was defined on the basis of the study by Chen et al. [8–10]. This is because more severe deformities imply a malfunction of the global sagittal and frontal balance, necessitating the application of more aggressive techniques (osteotomy, open transpedicular fixation, etc.) to treat them.

The study did not include patients with idiopathic and congenital scoliosis, spinal deformities associated with general and neuromuscular diseases, coxarthrosis, symptomatic stage II–III gonarthrosis, or patients with previousr spinal surgery.

Patients

A total of 86 individuals who had undergone surgery were initially included in the study; however, 29 patients had to be dropped because there were no control studies and they did not participate in the survey or questionnaire. The final sample consisted of 57 patients, 10 (18 %) men and 47 (82 %) women, who had degenerative lumbar spine scoliosis without disorders of the global sagittal balance and who underwent surgery by MIS LLIF technique (Lateral Lumbar Interbody Fusion) followed by short-segment percutaneous transpedicular fixation. The age of the subjects (Mean/Median presentation format) was 62/62 [55; 67] years (from 39 to 81). The period of data collection was from 2014 to 2019.

Techniques

The pre- and postoperative examination routines comprise taking a patient's history, general clinical examination, clinical and neurological examination with an assessment of the primary syndrome, neurophysiological monitoring and completing questionnaires. The observation period was from 7 to 62 months and the value was 31/32 [14; 45].

Among the imaging modalities used were full-length radiography of the spine with the capture of the femoral heads in the patient's standing position in two projections, and SCT and MRI of the lumbar spine. VAS was used to evaluate the severity of the pain syndrome in the back and lower extremities. The degree of functional adaptation was evaluated using the Oswestry questionnaire [11]. The Short Form-36 (SF-36) was applied to evaluate the quality of life [12].

Patients' surgical treatment protocol

All patients underwent minimally invasive surgery (MIS) of degenerative scoliosis of the lumbar spine and restoration of impaired spinopelvic relationships according to the LLIF technique with indirect decompression of neural structures and subsequent percutaneous transpedicular fixation of spinal motion segments. During the procedure, neurophysiological monitoring of spontaneous electromyographic activity with the *m. rectus femoris vastus lateralis* (L2–L4), *m. tibialis anterior* and *m. gastrocnemius* (L5–S1) was performed from the side of surgical approach. Direct electrical stimulation of the lumbar plexus branches that pass through the psoas major muscle was conducted in order to visualize the nerves of the lumbar plexus at the surgical site and avoid damaging them.

Evaluation criteria

The deformity magnitude according to Cobb in the frontal plane was determined using X-ray data [13]. The type of spinal deformity was classified according to SRS-Schwab using modifiers for evaluating the parameters of the sagittal and frontal balance [14]: the type of curve in the frontal plane (T, TL, L, N); sagittal modifiers: PI (Pelvic incidence), SS (Sacral slope), PT (Pelvic tilt), and LL (Lumbar lordosis).

The target values of the integrated indicators such as SVA (Sagittal vertical axis), SSA (spino-sacral angle), and PI-LL (PI minus LL) were assessed with an adjustment for age [14]. In order to identify the LL target values, the following formula was used: LL = PI × 0.54 + 27.6° [15].

The position of the vertebrae, the development of osteophytes and the existence of a bone block on the facet joints or the margins of the vertebral bodies were identified before the surgery according to the SCT data. The position of the implants and the rigidity of the vertebral end plates were evaluated in the postoperative period [16]. The screw malpositions were evaluated according to the classification of Rao et al. [17]. A control SCT was conducted in early postoperatively and during control examinations to assess the position and potential dislocation of implants and screws.

The surgery duration, the volume of blood loss, and the length of hospital stay were considered. The complications requiring surgical intervention were classified according to the Dindo – Clavien criteria [18].

The formation of the bone block according to Tan [19] was assessed 12 months after the treatment: the formation was observed at values of Grade 1, 2, and absence – at Grade 3, 4 [19].

Statistical analysis

The numerical data in the article reflecting the research results are shown in the form of the mean/median [lower; upper quartiles]. This is due to the negative results of tests to check the normality of the distribution for most parameters (Shapiro – Wilk test and histogram analysis). The Wilcoxon Signed Rank Test was used to compare dependent samples (data before and after the surgery).

The data were estimated using the density function of the basic functionality of the R software, Density graphs were used for visualization, where histograms display the distribution of the study's indicators.

R software version 4.0.5 was used to make the calculations [20].

Results

The age of patients ranged from 37 to 81 years old (62/62 [55; 67] years). Each patient in the study group suffered from vertebral pain syndrome scored 6.3/6.0 [5; 8] points on the VAS. The majority of clinical cases also included radicular pain in one or both legs (89 % of patients had a leg/legs VAS of 5.5/5.0 [4; 7] points). According to neuroimaging data, the radicular pain syndrome was associated with nerve root compression in the foramen on the concave side of the deformity. According to the ODI, all patients had a decrease of 49/46 [42; 54]. According to the assessment of the functional adaptation of the SF-36 scale, the level of the physical component of the scale (PH) was 23/23 [20; 25], and the mental component (MH) was 23/22 [20; 24].

When assessing the deformity type according to the SRS-Schwab classification, the frontal modifier corresponded to type N in all cases (less than 30°).

The deformity angle in the frontal plane was 17.5°/16.0° [11°; 22°]. All patients had a local segmental imbalance of the spinopelvic relationships with a deficiency of L4-S1, LL, and SSA. SVA values was not exceeded the global imbalance indicator's determining value in any of the patients.

The blood loss volume was 271/200 [150; 350] ml; the surgery duration was 297/270 [225; 355] min; and length of hospital stay was 12.7/12.0 [9; 15] days.

Changes in pain syndrome parameters, quality of life and spinopelvic relationships. Good clinical outcomes were achieved in all patients as a result of the treatment, as shown by a statistically significant reduction of pain syndrome in the lumbar spine and radicular pain.

There were a statistically significant reduction in vertebral pain syndrome and radicular pain in the legs according to VAS, improvement in the ODI's markers of life quality and the level of functional adaptability measured by the SF-36 in the postoperative period. Deformity angle in the frontal plane according to Cobb was decreased by 12.9°/13.0° [10°; 17°], the lumbar lordosis was increased by 3.3°/2.0° [-1°; 7°], the segmental angle L4–S1 – by 1.0°/0.0° [-5°; 7°], and the SVA was changed by -7.5/-2.0 [-29; 15] mm. The formula "the indicator after the surgery" minus "the indicator before the surgery" was used to calculate the change in value. Table 1 displays the outcomes of the patients' treatment.

During the entire follow-up period, a number of patients had complications, which were classified according to the Dindo – Clavien criteria (Table 2).

Discussion

Variations in techniques, the decision about the length of fixation and the possibility of indirect decompression of neural structures are the surgical trends for treating degenerative scoliosis that are most frequently discussed in modern vertebrology.

Minimally invasive procedures result in fewer postoperative complications [21]. In most studies, the spinal fusion was subdivided into short-segment (up to three levels inclusively) and extended (more than three levels) with an effort to mitigate the deformity [7, 22–24].

Short-segment fixation was described by Wang et al. [5] as local decompression followed by stabilization of the targeted segments, whereas extended deformity stabilization was described as correction of the entire curve. In the study by Cho et al. [25], short-segment fusion was described as stabilization inside the deformity without stabilization of the transitional vertebrae of the arch; and extended fusion was described as any stabilization that ends over the cranial transitional vertebra.

Clinical outcomes of the correction of degenerative scoliosis are ambiguous. Hosogane et al. [26] state that short-segment fixation can result in a rapid progression of deformity. It is partially supported by Tsutsui et al. [27]. They maintain that postoperative vertebrogenic pain syndrome in the lumbar spine in patients with dASD is related to the severity of the residual deformity angle in the frontal plane and to the imbalance in the sagittal plane. At the same time Lee et al. [28] say that the total Cobb angle advancement following short-segment stabilization of degenerative scoliosis in patients with dASD is comparable to the natural progression of the curve.

Scoliosis with short-segment fixation can progress, which is a major issue, particularly in patients who have edge level of fixation at the deformity curve apex. Houten et al. [29] and Cho et al. [25] noticed that the prevalence of degeneration of adjacent segments was less common in patients who underwent extended spinal fusion. According to a number of authors, patients with dASD can experience scoliosis progression of up to 3° a year after short-segment stabilization of degenerative scoliosis, which is comparable to the curve natural progression [25, 28, 30–32]. Moreover, the authors found that groups with extended and short-segment fixations in control studies did not experience degenerative scoliosis progression [25, 29]. Similar findings were obtained by Chen et al. [8], who came to the conclusion that patients with dASD ⩾ 30° according to Cobb should have extended spinal fusion with deformity correction. Other authors with similar viewpoint claims that decompression and short segment fixation are necessary when non-surgical treatment for vertebral pain syndrome fails and the patient has deformities less than 40° according to Cobb [31]. Have analyzed data of 382 patients with scoliotic deformities of the lumbar spine, I.V. Basankin et al. [33] found that the most significant risk factors for proximal transitional kyphosis and instability of the surgical hardware are osteoporosis, correction of lumbar lordosis more than 30°, a proximal transitional angle equal to or greater than 10°, and displacement of the sagittal vertical axis anteriorly by more than 50 mm.

Extended fixation with correction of degenerative scoliotic deformity is recommended for patients with risk factors for the progression of scoliosis, the presence of laterolisthesis, pronounced rotational deformity, loss of lumbar lordosis, the magnitude of the scoliotic component of deformity with a Cobb angle more than 40°, the presence of osteophytes on the concave side of the deformity, asymmetric degeneration of the disc, and osteoporosis [26, 29, 32, 34]. In addition, using short-segment MIS-procedures is beneficial in the absence of these severe disorders [5].

Simmons [31] states that aggressive surgical treatment is not recommended if the patient has a pronounced concomitant somatic disorder. This is confirmed by Transfeldt et al. [7] when analyzing the data of patients who underwent short-segment fixation of deformity in comparison with extended fixation and correction of deformity, and who had a similar improvement in the quality of life according to ODI, while the volume of intraoperative blood loss was less, the length of hospital stay was shorter, and the number of complications was also less. In a study of 54 patients with degenerative spinal pathology associated with scoliotic deformity, S.G. Mlyavykh et al. [37] found that after surgery, patients who underwent minimally invasive procedures experienced a more pronounced regression of radicular pain syndrome, and patients who underwent open surgery experienced a more pronounced regression of axial pain syndrome. The authors point out that patients who underwent open procedures showed signs of major clinical regression of back pain more frequently, while those who underwent minimally invasive procedures showed signs of significant clinical regression of leg pain syndrome.

Our study found that the use of minimally invasive techniques led to a smaller intraoperative injury, which encouraged obtaining comparable values of key indicators of quality of life and the degree of deformity correction, as well as acknowledging minimal blood loss, which amounted to 271/200 [150; 350] ml. One patient required a revision surgery to reinstall the pedicle screw due to its medial malposition. Another patient was diagnosed with adjacent segment disease 34 months after initial surgery with the development of a herniated intervertebral disc above the fixation segment at the L1–L2 level after the correction of the frontal balance by 20° (25° before surgery, 5° after surgery). In terms of clinical manifestation, the pathology, in accordance with the relevant dermatome, was a radicular pain syndrome. In eight weeks, the patient underwent another surgery after receiving unsatisfactory non-surgical treatment. A herniated disc was removed since the patient did not have any back pain. After LLIF intervention in 2015, the local sagittal balance at the L2–L3–L4 levels didn't change. The changes were not noticed neither before nor after the herniated disc was removed. However, an increase in deformity in the frontal plane of up to 18° was seen. When looking back at the circumstances, a great length of fixation at the L2–L5 vertebral levels can be seen as a sign of pathology at the level below [36].

Short-segment scoliotic deformity correction with minimally invasive techniques results in decrease of surgical injury and significantly reduce intraoperative blood loss with equivalent radiological and clinical outcomes. Our analysis revealed that MIS-correction and fixation in the treatment of patients with dASD serve as substitutes in terms of reducing pain syndrome in the lumbar spine and legs, enhancing quality of life values, and increasing the degree of functional adaptation, as well as correcting the severity of deformity in two planes and regularizing the parameters of the sagittal profile.

The efficiency of a staged short-segment correction with minimally invasive treatment of degenerative scoliosis of lumbar spine is confirmed by positive postoperative clinical outcomes effective. The lumbar spine and leg pain syndrome statistically significantly decreased, the ODI and SF-36 quality of life indicators improved, the degree of scoliotic deformity and lumbar lordosis were corrected, sagittal profile parameters were normalized and there was significantly less blood loss.

Conclusion

Correction of the frontal and local sagittal balance disorders using minimally invasive technologies in patients with degenerative scoliosis of the lumbar spine with an angle in the frontal plane of ⩾ 10° and ⩽ 40° and without global

Table 1

Results of treatment of patients with degenerative scoliosis of the lumbar spine

Indicators	Before surgery	After surgery	p
VAS (back), points	6.3/6.0 [5; 8]	2.0/2.0 [1; 3]	<0.001
VAS (legs), points	5.5/5.0 [4; 7]	1.2/1.0 [0; 2]	<0.001
ODI	49/46 [42; 54]	25/22 [18; 32]	<0.001
SF-36 (physical)	23/23 [20; 25]	41/40 [37; 44]	<0.001
SF-36 (mental)	23/22 [20; 24]	41/41 [39; 44]	<0.001
SS, degree	30.5/30.0 [25; 37]	32.5/33.0 [26; 39]	0.042
PT, degree	20.3/21.0 [15; 25]	18.8/20.0 [13; 24]	0.090
LL, degree	45.4/46.0 [40; 52]	48.7/48.0 [43; 54]	0.003
L4–S1, degree	31.9/30.0 [24; 40]	32.9/32.0 [28; 38]	0.404
SVA, mm	18.5/18.0 [0; 31]	11.0/16.0 [-1; 26]	0.210
SSA, degree	123.9/123.0 [118; 128]	126.2/125.0 [122; 130]	0.073
Cobb, degree	17.5/16.0 [11; 22]	4.6/4.0 [1; 7]	<0.001
TK, degree	31.0/32.0 [23; 39]	32.7/32.0 [27; 39]	0.143

Table 2
Complications in patients according to the Dindo — Clavien classification

Grade	Type of complication	Number
IIIA	Pharmacoresistant neuropathic pain syndrome	1
IIIB	Intracanal malposition of the pedicle screw of grade III according to Rao (reoperation)	1
	Acute embologenic thrombosis of the popliteal vein (ligation of the superficial femoral vein on the left)	1

sagittal imbalance enables to achieve excellent and good outcomes with the minimal number of complications, which is highly essential in the presence of concomitant somatic pathology.

Limitations of the integrity

A small patient population, a retrospective, non-randomized study design, and a short period of follow-up. This issue requires more in-depth investigation, including randomized trials and longer follow-up periods.

The authors declare that they have no conflict of interest. The study received state budget funding.
The study was approved by the institutions' local ethics committee.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

References

1. **Taneichi H.** Update on pathology and surgical treatment for adult spinal deformity. J Orthop Sci. 2016;21:116–123. DOI: 10.1016/j.jos.2015.12.013.
2. **Youssef JA, Orndorff DO, Patty CA, Scott MA, Price HL, Hamlin LF, Williams TL, Uribe JS, Deviren V.** Current status of adult spinal deformity. Global Spine J. 2013;3:51–62. DOI: 10.1055/s-0032-1326950.
3. **Kebaish KM.** Degenerative (*de novo*) adult scoliosis. Semin Spine Surg. 2009;21:7–15. DOI: 10.1053/j.semss.2008.11.002.
4. **Klimov VS, Vasilenko II, Evsyukov AV, Khalepa RV, Amelina EV, Ryabykh SO, Rzaev DA.** The use of LLIF technology in adult patients with degenerative scoliosis: retrospective cohort analysis and literature review. Genij Ortopedii. 2018;24(3):393–403. DOI 10.18019/1028-4427-2018-24-3-393-403.
5. **Wang G, Cui X, Jiang Z, Li T, Liu X, Sun J.** Evaluation and surgical management of adult degenerative scoliosis associated with lumbar stenosis. Medicine (Baltimore). 2016;95:e3394. DOI: 10.1097/MD.0000000000003394.
6. **Burtsev AV, Ryabykh SO, Kotelnikov AO, Gubin AV.** Clinical issues of the sagittal balance in adults. Genij Ortopedii. 2017;23(2):228–235. DOI:10.18019/1028-4427-2017-23-2-228-235.
7. **Transfeldt EE, Topp R, Mehbod AA, Winter RB.** Surgical outcomes of decompression, decompression with limited fusion, and decompression with full curve fusion for degenerative scoliosis with radiculopathy. Spine. 2010;35:1872–1875. DOI: 10.1097/BRS.0b013e3181ce63a2.
8. **Chen PG, Daubs MD, Berven S, Raaen LB, Anderson AT, Asch SM, Nuckols TK.** Surgery for degenerative lumbar scoliosis: the development of appropriateness criteria. Spine. 2016;41:910–918. DOI: 10.1097/BRS.0000000000001392.
9. **Ploumis A, Liu H, Mehbod A, Transfeldt E.** Can radiographic measurements of degenerative lumbar scoliosis predict clinical symptoms? Scoliosis. 2009;4(Suppl 1):O54. DOI: 10.1186/1748-7161-4-S1-O54.
10. **Ploumis A, Liu HA, Mehbod AA, Transfeldt EE, Winter RB.** A correlation of radiographic and functional measurements in adult degenerative scoliosis. Spine. 2009;34:1581–1584. DOI: 10.1097/BRS.0b013e31819c94cc.
11. **Fairbank JCT, Pynsent PB.** The Oswestry Disability Index. Spine. 2000;25:2940–2952. DOI: 10.1097/00007632-200011150-00017.
12. **Ware JE, Kosinski M, Keller SD.** SF-36 Physical and Mental Health Summary Scales: A User`s Manual. Boston, MA, Health Assessment Lab, 1994.
13. **Cobb JR.** Outline for the study of scoliosis. Instructional Course Lectures. 1948;5:261–275.
14. **Schwab FJ, Lafage R, Liabaud B, Diebo BG, Smith JS, Hostin RA, Shaffrey CI, Boachie-Adjei O, Ames CP, Scheer JK, Burton DC, Bess S, Gupta MC, Protopsaltis TS, Lafage V.** Does one size fit all? Defining spinopelvic alignment thresholds based on age. Spine J. 2014;14(11 Suppl):S120–S121. DOI: 10.1016/j.spinee.2014.08.299.
15. **Le Huec JC, Hasegawa K.** Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. Eur Spine J. 2016;25:3630–3637. DOI: 10.1007/s00586-016-4485-5.
16. **Steurer J, Roner S, Gnannt R, Hodler J.** Quantitative radiologic criteria for the diagnosis of lumbar spinal stenosis: a systematic literature review. BMC Musculoskelet Disord. 2011;12:175. DOI: 10.1186/1471-2474-12-175.
17. **Rao G, Brodke DS, Rondina M, Bacchus K, Dailey AT.** Inter- and intraobserver reliability of computed tomography in assessment of thoracic pedicle screw placement. Spine. 2003;28:2527–2530. DOI: 10.1097/01.BRS.0000092341.56793.F1.
18. **Dindo D, Clavien PA.** What is a surgical complication? World J Surg. 2008;32: 939–941. DOI: 10.1007/s00268-008-9584-y.
19. **Tan GH, Goss BG, Thorpe PJ, Williams RP.** CT-based classification of long spinal allograft fusion. Eur Spine J. 2007;16:1875–1881. DOI: 10.1007/s00586-007-0376-0.
20. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org.
21. **Anand N, Kong C, Fessler RG.** A staged protocol for circumferential minimally invasive surgical correction of adult spinal deformity. Neurosurgery. 2017;81:733–739. DOI: 10.1093/neuros/nyx353.
22. **Zhang HC, Yu HL, Yang HF, Sun PF, Wu HT, Zhan Y, Wang Z, Xiang LB.** Short-segment decompression/fusion versus long-segment decompression/fusion and osteotomy for Lenke-Silva type VI adult degenerative scoliosis. Chin Med J (Engl). 2019;132:2543–2549. DOI: 10.1097/CM9.0000000000000474.
23. **Kleinstueck FS, Fekete TF, Jeszenszky D, Haschtmann D, Mannion AF.** Adult degenerative scoliosis: comparison of patient-rated outcome after three different surgical treatments. Eur Spine J. 2016;25:2649–2656. DOI: 10.1007/s00586-014-3484-7.
24. **Liu Z, Zhao QH, Wu XZ, Song R, Yuan G, Tian JW.** [Short fusion and long fusion for degenerative lumbar scoliosis with lumbar stenosis]. Zhonghua Yi Xue Zaq Zhi. 2012;92:1751–1755. Chinese.
25. **Cho KJ, Suk SI, Park SR, Kim JH, Kim SS, Lee TJ, Lee JJ, Lee JM.** Short fusion versus long fusion for degenerative lumbar scoliosis. Eur Spine J. 2008;17:650–656. DOI: 10.1007/s00586-008-0615-z.
26. **Hosogane N, Watanabe K, Kono H, Saito M, Toyama Y, Matsumoto M.** Curve progression after decompression surgery in patients with mild degenerative scoliosis: J Neurosurg Spine. 2013;18:321–326. DOI: 10.3171/2013.1.SPINE12426.
27. **Tsutsui S, Kagotani R, Yamada H, Hashizume H, Minamide A, Nakagawa Y, Iwasaki H, Yoshida M.** Can decompression surgery relieve low back pain in patients with lumbar spinal stenosis combined with degenerative lumbar scoliosis? Eur Spine J. 2013;22:2010–2014. DOI: 10.1007/s00586-013-2786-5.
28. **Lee N, Yi S, Shin DA, Kim KN, Yoon DH, Ha Y.** Progression of coronal Cobb angle after short-segment lumbar interbody fusion in patients with degenerative lumbar stenosis. World Neurosurg 2016;89:510–516. DOI: 10.1016/j.wneu.2016.01.051.
29. **Houten JK, Nasser R.** Symptomatic progression of degenerative scoliosis after decompression and limited fusion surgery for lumbar spinal stenosis. J Clin Neurosci. 2013;20:613–615. DOI: 10.1016/j.jocn.2012.06.002.
30. **Tribus CB.** Degenerative lumbar scoliosis: evaluation and management. J Am Acad Orthop Surg. 2003;11:174–183. DOI: 10.5435/00124635-200305000-00004.
31. **Simmons ED.** Surgical treatment of patients with lumbar spinal stenosis with associated scoliosis. Clin Orthop Relat Res. 2001;(384):45–53. DOI: 10.1097/00003086-200103000-00007.
32. **Seo JY, Ha KY, Hwang TH, Kim KW, Kim YH.** Risk of progression of degenerative lumbar scoliosis. J Neurosurg Spine. 2011;15:558–566. DOI: 10.3171/2011.6.SPINE10929.
33. **Basankin IV, Ptashnikov DA, Masevnin SV, Afaunov AA, Giulzatyan AA, Takhmazyan KK.** Significance of various risk factors for proximal junctional kyphosis and instability of instrumentation in surgical treatment for adult spinal deformities. Hir Pozvononoc. 2021;18(1):14–23. DOI: 10.14531/ss2021.1.14-23.
34. **Silva FE, Lenke LG.** Adult degenerative scoliosis: evaluation and management. Neurosurg Focus. 2010;28:E1. DOI: 10.3171/2010.1.FOCUS09271.
35. **Mlyavykh SG, Bokov AE, Aleynik AYa, Yashin KS.** Compare of outcomes of minimally invasive and open surgical techniques in patients with symptomatic lumbar spine stenosis on the background of scoliotic deformity. N.N. Priorov Journal of Traumatology and Orthopedics. 2019;(4):33–42. DOI: 10.17116/vto201904133.
36. **Saavedra-Pozo FM, Deusdara RAM, Benzel EC.** Adjacent segment disease perspective and review of the literature. Ochsner J. 2014;14:78–83.

Address correspondence to:
Vasilenko Ivan Igorevich
Federal Neurosurgical Center,
132\1 Nemirovicha-Danchenko str., Novosibirsk, 630087, Russia,
i_vasilenko@neuronsk.ru

Received 12.05.2022
Review completed 20.09.2022
Passed for printing 14.11.2022

Ivan Igorevich Vasilenko, neurosurgeon, Department of spinal neurosurgery, Federal Neurosurgical Center, 132/1 Nemirovicha-Danchenko str., Novosibirsk, 630087, Russia, junior researcher, Research Institute of Clinical and Experimental Lymphology, 6 Arbuzova str., Novosibirsk, 630117, Russia, ORCID: 0000-0002-4781-3848, i_vasilenko@neuronsk.ru;

Alexey Vladimirovich Evsyukov, MD, PhD, neurosurgeon, Head of the Clinic of Spine Pathology and Rare Deseases, National Ilizarov Medical Research Center for Traumatology and Ortopedics, 6 M. Ulyanovoj str., Kurgan, 640014, Russia, ORCID: 0000-0001-8583-0270, alexevsukov@mail.ru;

Sergey Olegovich Ryabykh, DMSc, Deputy Director for Education and Regional Relations, National Medical Research Center for Traumatology and Orthopedics n.a. N.N. Priorov, 10 Priorova str., Moscow, 127299, Russia, ORCID: 0000-0002-8293-0521, rso_@mail.ru;

Evgeniya Valeryevna Amelina, PhD in Physics and Mathematics, researcher, Stream Data Analytics and Machine Learning Laboratory, Novosibirsk State University, 1 Pirogova str., Novosibirsk, 630090, Russia, ORCID: 0000-0001-7537-3846, amelina.evgenia@gmail.com;

Yuliy Evgenyevich Kubetsky, neurosurgeon, Head of the Department of spinal neurosurgery, Federal Center of Neurosurgery, 132/1 Nemirovicha-Danchenko str., Novosibirsk, 630087, Russia, ORCID: 0000-0002-7810-3531, yu_kubeckiy@neuronsk.ru;

Ilgiz Ildaroovich Garipov, post-graduate student, National Ilizarov Medical Research Center for Traumatology and Ortopedics, 6 M. Ulyanovoj str., Kurgan, 640014, Russia, ORCID: 0000-0003-4681-7967, ilgizgaripov@ya.ru;

Jamil Afet oglu Rzaev, DMSc, Chief Doctor, Federal Neurosurgical Center, 132/1 Nemirovicha-Danchenko str., Novosibirsk, 630087, Russia, Chair professor, Novosibirsk State University, 2 Pirogova str., Novosibirsk, 630090, Russia, ORCID: 0000-0002-1209-8960, d_rzaev@neuronsk.ru.