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SURGICAL CORRECTION OF SEVERE FORMS OF IDIOPATHIC KYPHOSCOLYOSIS IN CHILDREN

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Background. Significant results have been achieved through the use of hybrid and transpedicular metal structures. However, when spinal systems are implanted during surgery in patients with severe forms and idiopathic scoliosis, a number of limitations arise. Not only the performance of corrective maneuvers during the operation but also the creation of mobility on the top of the main arc accompany the strategies of surgical treatment. Traditionally, mobilizing discectomy at the top of the spark is performed in patients with idiopathic scoliosis. Pedicle subtractional vertebrotomy and Ponte and Smith-Petersen osteotomy are most common in neuromuscular scoliosis and spinal deformity, with a predominance of the kyphotic component. Problems with correction of extremely low and "neglected" forms and idiopathic scoliosis in children remain.

Aim. The present study aimed to provide a comparative analysis between using transpedicular spinal systems alone and in combination with a wedge osteotomy of the apical vertebra to correct spinal deformity in children with extremely severe right-sided idiopathic thoracic scoliosis.

Materials and methods. The surgical treatment results of 20 children 15 to 17 years old with extremely severe forms of right-sided idiopathic thoracic kyphoscoliosis were included in the analysis. All patients underwent standard preoperative examination, including radiology, computed tomography, magnetic resonance imaging, and neurophysiological studies. The patients were divided into two groups according to the method used during the second stage of surgical treatment — correction of deformity with the transpedicular system (1) alone or (2) in combination with a wedge osteotomy of the apical vertebra.

Results. Patients from the first group showed an amount of scoliotic and kyphotic component correction ranging from 25% to 62% and from 21% to 56%, respectively. In patients from the second group, who underwent additional wedge osteotomy of the apical vertebrae during the operation, correction of the scoliotic and kyphotic components ranged from 36% to 74% and from 50% to 70%, respectively.

Conclusion. In children with idiopathic thoracic kyphoscoliosis, performing a wedge corpectomy of the apical vertebral body is an effective additional mobilizing component, which allows achieving significant correction of both scoliotic and kyphotic curve components, restoring the physiological profile of the spine and body balance during the surgical intervention, and maintaining the achieved result during the long-term observation period.

Keywords: idiopathic scoliosis; kyphosis; children; "severe" deformity; transpedicular fixation; corpectomy.

ХИРУРГИЧЕСКАЯ КОРРЕКЦИЯ ТЯЖЕЛЫХ ФОРМ ИДИОПАТИЧЕСКОГО КИФОСКОЛИОЗА У ДЕТЕЙ

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Обоснование. В последние годы в лечении детей с тяжелыми деформациями позвоночника достигнуты значительные результаты благодаря использованию гибридных и транспедикулярных металлоконструкций. Однако у пациентов с тяжелыми формами идиопатического сколиоза возникает ряд ограничений при имплантации спинальных систем во время проведения хирургического вмешательства. При ригидных деформациях тактика хирургического лечения предусматривает не только выполнение корригирующих маневров в ходе операции, но и создание мобильности на вершине основной дуги. Традиционно пациентам с идиопатическим сколиозом выполняют мобилизирующую дискэктомию на вершине искривления. Педикулярную субтракционную вертебротомию, остеотомию по Ponte и Smith-Petersen чаще используют при нейромышечном сколиозе и деформациях позвоночника с преобладанием кифотического компонента. Коррекция крайне тяжелых и запущенных форм идиопатического сколиоза у детей по-прежнему остается важной и актуальной проблемой.

Цель — провести сравнительный анализ коррекции деформации позвоночника у детей с крайне тяжелыми формами правостороннего идиопатического сколиоза грудного отдела позвоночника с использованием транспедикулярных металлоконструкций и в сочетании с клиновидной резекцией вершинного позвонка.

Материалы и методы. Проведен сравнительный анализ результатов хирургического лечения 20 детей в возрасте от 15 до 17 лет с крайне тяжелой формой правостороннего идиопатического кифосколиоза грудной локализации. Всем детям выполняли стандартное предоперационное обследование, включающее лучевое исследование (рентгенологическое и компьютерную томографию), магнитно-резонансную томографию и нейрофизиологическое исследование. Все пациенты были разделены на две группы, которые различались методикой второго этапа хирургического лечения: коррекцию деформации пациентам второй группы выполняли транспедикулярной системой в сочетании с клиновидной резекцией тела апикального позвонка.

Результаты. У пациентов первой группы величина коррекции сколиотического компонента деформации варьировала от 25 до 62 %, кифотического — от 21 до 56 %. У пациентов второй группы, которым в ходе операции была выполнена дополнительная клиновидная резекция тела вершинного позвонка, коррекция сколиотического компонента деформации составила от 36 до 74 %, кифотического — от 50 до 70 %.

Заключение. Клиновидная резекция апикального тела позвонка у детей с идиопатическим кифосколиозом грудного отдела позвоночника является достаточно эффективным методом, позволяющим добиться дополнительной мобильности основной дуги искривления, значительной коррекции как сколиотического, так и кифотического искривления, восстановить физиологический профиль позвоночника и баланс туловища.

Ключевые слова: идиопатический кифосколиоз; дети; деформация; транспедикулярная система; корпорэктомия.

Background

According to the literature, up to 80% of spinal column deformities account for scoliotic curvatures (including infantile, juvenile, and adolescent idiopathic scoliosis) [1]. The most common variant of idiopathic scoliosis is a right-sided thoracic type of the deformity. The progressive curvature of this localization during a child's growth often leads to severe and rigid deformities, which constitute a complicated challenge to address even for surgical treatment. In patients with similar forms of idiopathic scoliosis, not only the scoliotic but also the kyphotic component of the curvature is quite pronounced. Currently, correction of spinal deformities in pediatric patients with extremely severe and advanced forms of idiopathic scoliosis remains an important and urgent problem requiring further exploration.

The concept of "severe and advanced forms of idiopathic scoliosis" is based on a quantitative assessment of the size of the main scoliotic arch of deformity, as measured by the Cobb method. In the English-language literature, "severe" forms of scoliosis are considered to be curvatures whose size of the main arch ranges from 70° to 90° [2, 3]. In the Russian-language literature, severe (or advanced) forms of idiopathic scoliosis are considered to be curvatures with an arch greater than 90° as determined using the Cobb method, whereas the concept of "super-severe" forms of scoliosis, which include deformities measured at above 120° by the Cobb method, is also defined [4].

In recent decades, significant success has been achieved in the treatment of pediatric patients with severe spinal deformities through the use of modern hybrid and transpedicular surgical

hardware. For example, the use of hybrid spinal systems in pediatric patients with idiopathic scoliosis has improved the results of treatment in this category of patients, primarily in the context of the correction of the main curvature arch size [5, 6]. However, in patients with severe deformities, fractures of established surgical hardware are often observed during long-term follow-up periods after treatment (ranging from 2.8% to 18%, according to Russian authors [7]), with reports of incomplete bone block along the spinal system, which can lead to the loss of the achieved correction results at two to five years after surgery [8]. Such complications often require repeated surgical interventions aimed at stabilizing the surgical hardware or facilitating the creation of an additional bone block.

The pronounced rigidity of the deformity in patients with similar forms of curvature, even when using various mobilizing surgical techniques on both the front and rear spinal columns, did not enable the achievement of the desired correction of the curvature. Performing an indirect derotational maneuver during surgery only slightly affected the decrease in the scoliotic component of the deformity, without affecting the kyphotic component of the curvature. There are currently no studies in the literature that facilitate a comparative assessment of spinal deformity corrections in patients with idiopathic scoliosis who underwent direct or indirect derotational maneuvers.

Owing to the active introduction of surgical hardware with transpedicular screws in recent years, another improvement has been made in terms of achieving a correction value for spinal deformities in pediatric patients with idiopathic scoliosis. According to a number of researchers, the correction value in pediatric patients achieved with the main curvature arch being 102–136° using these spinal systems reached an average of 57% [9, 10]. However, for patients with severe and extremely severe forms of idiopathic scoliosis, there are a number of limitations inherent with surgical intervention. First of all, the technical complexity and difficulty of placing the support elements of the spinal system in the vertebral bodies at the top of the main arch of a deformity, especially at the concave side of the curvature, can hinder the success of outcomes. Additionally, if transpedicular screws are placed correctly, aggressive correction of the deformity during surgery can lead to fractures of the vertebral bone–supporting structures, creating a risk and prerequisites for neurological disorders [10].

In patients with rigid deformities, surgical treatment includes not only the use of corrective maneuvers during the surgery, but also efforts to ensure maximum mobility at the top of the main deformity arch, without which an optimal result cannot be achieved. Russian and foreign authors alike have employed various individual options of mobilizing surgical interventions on the spine as well as combinations such as anterior mobilizing disc hypophysectomy, pedicle subtraction osteotomy (PSO), Ponte osteotomy, and Smith–Petersen osteotomy (SPO). Various types of osteotomy are more often performed in correlation with neuromuscular scoliosis and spinal deformities with a predominance of the kyphotic component. Traditionally, when correcting spinal deformities in pediatric patients with severe forms of idiopathic scoliosis, specialists resort to mobilizing discectomy at the top of the main arch and conduct a course of halofemoral or tibial traction. The intervention is completed with dorsal correction of the deformity by a multisupported transpedicular system at 10 to 12 days after the course of traction. However, such an approach does not always enable one to achieve the desired correction value, especially with a pronounced kyphotic component of the curvature [10, 11].

In this study, we aimed to conduct a comparative analysis of spinal deformity correction measures in pediatric patients with extremely severe forms of right-sided idiopathic scoliosis of the thoracic spine using transpedicular spinal systems and in combination with wedge resection of the apical vertebra.

Materials and methods

A comparative analysis of the results of surgical treatment of 20 pediatric patients aged 15–17 with an extremely severe form of right-sided idiopathic kyphoscoliosis of the thoracic spine, type Lenke I, was conducted. 18 girls and two boys were included in this research. All patients underwent a standard examination prior to surgery, including radiology (X-ray and computed tomography), magnetic resonance imaging, and neurophysiological examinations. The value of the main scoliotic arch

of the deformity according to the Cobb method ranged from 120° to 148°, whereas that of the kyphotic component ranged from 90° to 120°. When taking functional X-ray images of the spine, marked rigidity of the deformity was noted, in which the decrease in the size of the main arch of curvature did not exceed 10% of the initial value.

The patients were divided into two groups of 10 people each according to the technique used during the second (final) stage of surgical treatment of spinal deformities. In the first stage, patients of both groups underwent ventral mobilization of the main arch of deformity from a right-sided thoracotomy approach (i.e., discectomy at level 3 or 4 with resection of the heads of the ribs and mobilization of the anterior longitudinal ligament) in combination with fusion at the same level. The number of discs removed depended both on the size of the main scoliotic arch of the deformity and also on its nature (i.e., abrupt or gently sloping) as well as the possibility of their visualization, ease of full access to them, and removal. The surgery was completed by the implementation of halotibial traction. After that, traction was performed for 10–12 days, with a gradual increase in load over time. At the final (second) stage, the existing curvature was corrected in all patients of Group 1 (n = 10 patients) from the dorsal approach by implanting a multisupport surgical hardware system with transpedicular support elements under the control of active three-dimensional computed tomography navigation. If it was not possible to place a transpedicular screw (owing to the small size of the vertebral arch base), a laminar hook with a displaced center was installed at the level of the upper instrumented vertebra. Wedge resection of the apical vertebra with the base facing the convex side of the main arch was performed among the patients of Group 2 (n = 10 patients) via a dorsal access approach, with the preservation of the upper and lower endplates and the instrumental correction of the spinal deformity with a multisupport transpedicular spinal system using a navigation device and under intraoperative neurophysiological control. During the correction, the preserved endplates of the apical vertebra were closed. Long-term follow-up ranged from three to seven years (with an average of five years and two months). X-ray examination was conducted every six months during the first year after the surgery and then annually thereafter.

Statistical processing of the data obtained was performed using online calculators of medical statistics. Processing of the available results included the calculation of the arithmetic mean of the differences of the indicators (M_d), the mean square deviations of the differences of the indicators (σ_d), and confidence intervals (μ). In order to assess the correlation dependence between the two groups, Pearson's correlation coefficient (r) was calculated. Variation series were compared using a paired Student's t-test.

Results

In patients of Group 1, the correction value of the scoliotic component of the deformity ranged from 26% to 62%, whereas that of the kyphotic component ranged from 20% to 56% (Table 1). In the long-term follow-up period assessing fractures and instability of the surgical hardware, no loss of the achieved correction during surgery was noted. In addition, after surgery, no patient showed a neurological disorder.

For the scoliotic component of the deformity, the correlation coefficient (r) is 0.906 (indicating a very high bond strength) and the dependence of the signs is statistically significant at $p = 0.000507$ ($p < 0.005$).

For the kyphotic component of the deformity, the correlation coefficient (r) is 0.949 (indicating a very high bond strength) and the dependence of the signs is statistically significant at $p = 0.000062$ ($p < 0.005$).

Among patients of Group 2 who underwent additional wedge resection of the apical vertebra body, during the surgery, the correction of the scoliotic component of the deformity amounted to 36%–74%, whereas that of the kyphotic component ranged from 50% to 74% (Table 2). In one patient of this group, neurological disorders were observed after surgery, in the form of acute urinary retention, which completely stopped as a result of drug therapy and physiotherapeutic treatment. No fractures, cases of surgical hardware instability, or any loss of deformity correction achieved during surgery was observed during the long-term follow-up period after surgery in the patients of this group. Depending on the general condition, verticalization of the patients of both groups of the study was performed by the sixth to ninth day after surgery.

Table 1

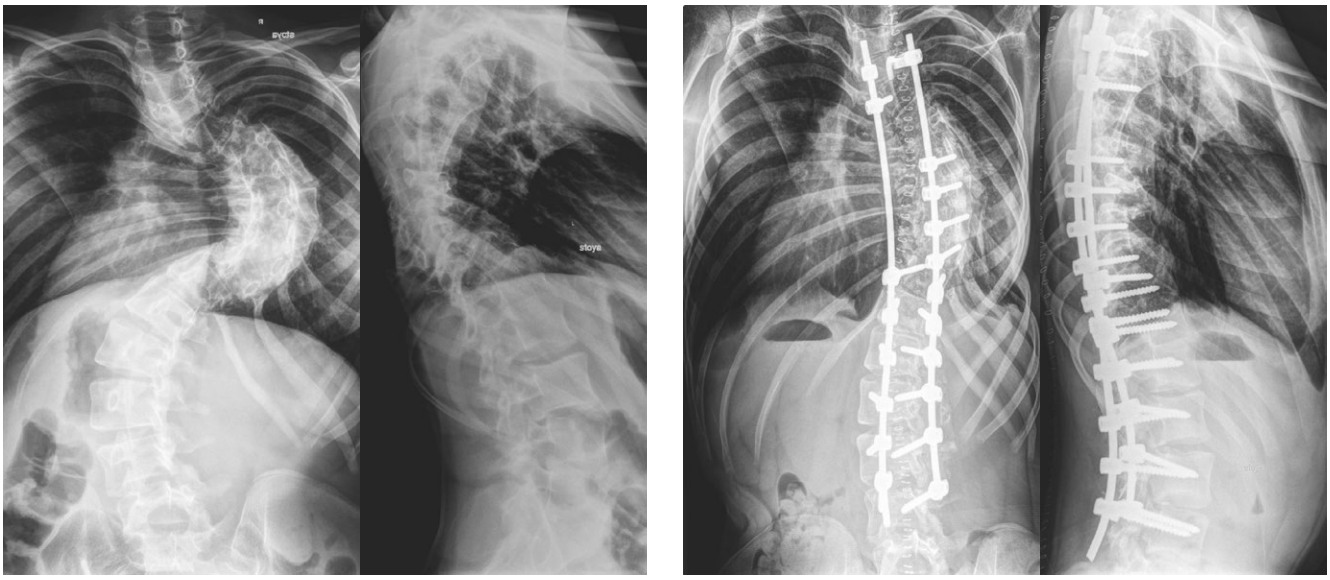
Indicators of scoliotic and kyphotic components of the deformity according to the Cobb method in patients of Group 1 before and after the surgery

No.	Age (years)	Scoliosis value (°)		Amount of scoliosis correction		Kyphosis value (°)		Amount of kyphosis correction	
		Before surgery	After surgery	*n*, °	Relative (%)	Before surgery	After surgery	*n*, °	Relative (%)
1	15	130	76	54	42	104	60	44	42
2	15	148	110	38	26	107	86	21	20
3	17	130	58	72	55	120	92	28	23
4	16	123	47	65	53	90	40	50	56
5	15	128	58	70	55	100	58	42	42
6	17	136	60	76	56	120	90	30	25
7	17	132	62	70	53	118	88	30	25
8	16	120	46	74	62	96	50	46	48
9	15	140	98	42	30	116	82	34	29
10	16	130	62	68	52	110	80	30	27
M ±		131.70 ± 8.084	67.700 ± 21.050			108.10 ± 10.567	73.400 ± 19.323		
σ		9.11	23.4			10.29	18.81		

Table 2

Indicators of scoliotic and kyphotic components of the deformity according to the Cobb method in patients of Group 2 before and after the surgery

No.	Age (years)	Scoliosis value (°)		Amount of scoliosis correction		Kyphosis value (°)		Amount of kyphosis correction	
		Before surgery	After surgery	*n*, °	Relative (%)	Before surgery	After surgery	*n*, °	Relative (%)
1	15	128	36	92	72	96	30	66	69
2	15	130	70	60	46	112	40	72	64
3	16	136	82	54	66	118	42	76	64
4	17	146	94	52	36	120	60	60	50
5	17	138	86	52	38	110	40	70	64
6	16	128	38	90	70	116	42	74	64
7	16	130	64	66	51	100	36	74	74
8	15	142	90	52	37	116	40	76	66
9	17	126	33	93	74	100	38	62	62
10	16	134	74	60	45	110	36	74	67
M ±		133.80 ± 6.630	66.700 ± 23.257			109.80 ± 8.404	40.400 ± 7.763		
σ		6.69	23.26			9.12	10.18		



a *b*

Fig. 1. Radiographs of patient S., aged 17: *a* — before the surgery; *b* — after discectomy, fusion, halotibial traction course, and correction of the deformity by a multisupport surgical hardware system in combination with wedge resection of the vertebral body Th_7

For the scoliotic component of the deformity, the correlation coefficient (r) is 0.897 (indicating a high bond strength) and the dependence of the signs is statistically significant at $p = 0.000696$ ($p < 0.005$).

For the kyphotic component of the deformity, the correlation coefficient (r) is 0.730 (indicating a high bond strength) and the dependence of the signs is statistically significant at $p = 0.019283$ ($p < 0.005$).

Figure 1 presents X-ray images of the surgical treatment of Patient S., who was aged 17 at the time of treatment and who had idiopathic thoracic right-sided scoliosis, at two years after surgery.

Discussion

In recent years, quite good results have been achieved in the surgical treatment of pediatric patients with idiopathic scoliosis. At the initial stages of the development and establishment of these surgical technologies, a result that was 50% of the initial value of the main arch of the deformity was considered significant success in the correction of curvature; however, now, correction values range from 76% to 100% [12]. One of the important points that previously affected deformity correction indicators was the use of surgical hardware with transpedicular support elements. The placement of transpedicular screws under the control of navigation equipment and neurophysiological monitoring has enabled improvements in the achievement of correct and accurate installation of supporting elements of the spinal system in the vertebral bodies along the curvature arch [13, 14]. Further, the use of technology during surgery in the case of various types of idiopathic scoliosis, which facilitates accurate and consistent application of corrective efforts, yields a significant amount of correction of the main arch of the deformity. Studies of Russian and foreign researchers alike reliably confirm this fact [15].

However, the problem of the correction of spinal deformities in pediatric patients with idiopathic scoliosis with extremely severe and sometimes advanced forms of curvature has not been addressed completely and remains an important consideration. Currently, frequently used techniques such as multilevel discectomy at the apex of the main curvature arch, the course of halofemoral or tibial traction, or preceding with the dorsal correction of the deformity do not always lead to the desired result. On the one hand, this is due to limitations in the discectomy level as a result of the pronounced curvature of the main arch; on the other hand, significant rigidity of the main curvature arch occurs because of its large size, which does not enable one to provide an optimal effect, even when using the traction course.

When applying posterior osteotomy in patients with idiopathic scoliosis, it is only possible to influence the size of the deformity kyphotic

component; changing the main scoliotic curvature arch remains impossible in this context.

In our study, the wedge resection of the apical vertebra body enabled us to achieve a significant ($p < 0.005$) increase in the correction of both the scoliotic and the kyphotic components of the curvature as compared with the application of the deformity correction technique using the transpedicular structure. This procedure provides additional mobilization of the deformity at its apex so as to implement significant distraction along the concave side of the curvature, decreasing the scoliotic curve of curvature and contraction along the convex side, with a significant effect on the kyphotic component of the deformity. This mobilizing intervention also enabled us to restore the sagittal profile of the spine to the physiological norm.

The current literature suggests methods for correcting scoliotic deformities with a pronounced kyphotic component in the case of rigid scoliosis in adult patients [16] and deformities of various genesis in pediatric practice. Bridwell, based on his experience and literature on various types of osteotomies in the correction of spinal deformities, analyzed the issues of applying a particular osteotomy method and compared SPO, PSO, and vertebral column resection (VCR) methods. However, in his literature review, he did not address the subject of the correction of spinal deformities in idiopathic scoliosis [17]. A small number of foreign publications are devoted to the application of techniques of different variants of dorsal osteotomy in the correction of spinal deformities in pediatric patients with idiopathic scoliosis.

Bakaloudis et al. were one of the first to describe the experience of osteotomies in kyphoscoliotic deformities in pediatric patients. They presented the PSO results of 12 patients, including nine pediatric patients with idiopathic scoliosis. According to their data, the angle of deformity before surgery in the frontal plane exceeded 90°, whereas that in the sagittal plane was more than 80°. During surgery, the correction of curvature ranged on average from 55% to 70% [18]. Xu et al. obtained similar results upon pursuing severe kyphoscoliotic deformity correction using PSO in young patients (aged 16.9 ± 9.1). In their work, they achieved correction of the scoliotic curvature arch with an average of 64.8%, whereas that for the kyphotic component was 82.6% [19].

In addition, Xie et al. published the results of the correction of rigid kyphoscoliotic spinal deformities of more than 100° using the VCR technique. According to their data, during the intervention, correction of more than two times of the curvature of both the scoliotic and the kyphotic components of the deformity was achieved [20].

Kandwal et al. assessed the efficiency of Ponte osteotomy in adolescents (aged 14–17) with various spinal deformities, including idiopathic scoliosis. The study group included patients with curvatures greater than 100°. The authors used multilevel Ponte osteotomies; the final correction result averaged 76% [21].

Seki et al. conducted a comparative analysis of PSO and Ponte osteotomy for the correction of spinal deformities in pediatric patients with idiopathic scoliosis using dorsal access. The work was aimed at determining the technique that leads to greater mobility at the apex of the deformity; however, in this study, the amount of the initial deformity could not be attributed to severe scoliosis. Despite this, according to the results obtained, Ponte osteotomy showed a better mobilizing effect [22].

In our opinion, in pediatric patients with extremely severe forms of idiopathic scoliosis, in order to achieve an optimal correction result, mobilizing interventions are required along the main arch of the deformity. Various kinds of osteotomy procedures of the bone structures of the vertebrae entering the main arch are possible as mobilization manipulations in patients with a severe variant of the spinal column curvature. Based on the few published data available, the question of the ideal osteotomy variant along the main curvature arch in pediatric patients with severe forms of idiopathic scoliosis remains unresolved; wedge resection of the apical vertebra is an effective auxiliary method to achieve significant mobilization.

Conclusion

Osteotomy of the bone structures of the vertebra is indicated in patients with severe forms of idiopathic scoliosis in order to achieve mobilization of the main arch of the deformity. Wedge resection of the apical vertebral body in pediatric patients with idiopathic kyphoscoliosis of the thoracic spine is a rather effective component for achieving additional mobility of the main arch of the curvature,

which enables one to achieve significant correction of both the scoliotic and the kyphotic curvatures and to restore the physiological profile of the spine and balance of the trunk during surgery.

Additional information

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Conflicts of interest. The authors declare no obvious or potential conflicts of interest related to the publication of this article.

Ethical review. This study was performed in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association as amended by the Ministry of Health of Russia, approved by the Ethics Committee of the Turner Scientific Research Institute for Children's Orthopedics (Protocol No. 4 on 27.11.2018). The authors gathered the written voluntary consent of the patients (or their legal representatives) to participate in the study and publish medical data.

Contribution of the authors

S.V. Vissarionov was involved in the development of the study methodology and writing of all sections of the article and was the leading surgeon-operator.

A.N. Filippova collected the literature data and performed its processing, designed the article, and wrote some sections of the article and the reference list.

D.N. Kokushin took part in data processing, surgical treatment and management of the patients, and amendment of the article.

N.O. Khusainov translated the abstract and information about the authors into English and took part in data processing, surgical treatment, and patient management.

V.V. Murashko and *S.M. Belyanchikov* were involved in data processing, surgical treatment, and patient management.

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