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ANALYSIS OF CAUSES OF METAL STRUCTURE DESTABILIZATION IN CORRECTION OF CONGENITAL SPINAL DEFORMATION IN CHILDREN OF A YOUNGER AGE GROUP

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Background. One of the most common vertebral malformations that lead to the occurrence and progression of congenital scoliosis is disorders of vertebral formation. Most specialists adhere to the active tactics of surgical correction of spinal deformity in early childhood.

The aim. To evaluate the variants and causes of the transpedicular spinal system destabilization, which is not related to the violation of its integrity, in the surgical treatment of children with congenital spinal deformities.

Materials and methods. The case histories of 286 children under the age of 6 years undergoing surgical treatment in H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery between 2014 and 2019 were analyzed. Depending on the outcome of the surgical treatment, the patients were divided into groups: the main group ($n = 7$) included those with spinal system destabilization and the control group ($n = 12$) consisted of those without spinal system destabilization. During the study, the sizes of the bases of the arcs adjacent to the abnormal vertebra, the magnitude of the scoliotic and kyphotic components of the deformation, and the correct position of the supporting elements of the spinal system on the Gertzbein scale were determined.

Results. Patients of the studied groups were identified according to their age and the magnitude of scoliotic and kyphotic components of spinal deformity. The average diameter of the arc base in the studied groups varied ($p < 0.05$). In all patients, the complete correction of the congenital curvature of the spine was achieved after surgery. In the long-term postoperative period in patients of the study group after radiation analysis, the malposition of supporting elements relative to the base of the vertebral arch and a loss of correction of spinal deformity by an average of 25° were revealed, which required the repeated surgery in order to restore the stability of the spinal system and to correct deformation.

Conclusions. The reasons for the spinal system destabilization during the correction of the spinal congenital deformations are the peculiarities of vertebral anatomical-anthropometric parameters in the curvature zone, as well as tactical aspects during surgery. The main reason for the spinal system destabilization without violating its integrity is the small size of bases of adjacent vertebral arches relative to the abnormal one. The small size of the bases of the vertebral arches and the significant amount of necessary correction of congenital spinal deformity necessitate the installation of a longer spinal system in order to restore physiological profiles in the curvature zone.

Keywords: congenital scoliosis; monosegmental spinal malformations; hemivertebra; hemivertebra excision; destabilization of metal structure; screw malposition.

АНАЛИЗ ПРИЧИН ДЕСТАБИЛИЗАЦИИ МЕТАЛЛОКОНСТРУКЦИИ ПРИ КОРРЕКЦИИ ВРОЖДЕННОЙ ДЕФОРМАЦИИ ПОЗВОНОЧНИКА У ДЕТЕЙ МЛАДШЕЙ ВОЗРАСТНОЙ ГРУППЫ

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Обоснование. Нарушения формирования позвонков относят к одному из самых распространенных пороков развития позвонков, приводящих к возникновению и прогрессированию врожденного сколиоза. Большинство специалистов предпочитает осуществлять хирургическую коррекцию деформации позвоночника уже в раннем детстве.

Цель — оценить варианты и причины дестабилизации транспедикулярной металлоконструкции, не связанные с нарушением ее целостности, при хирургическом лечении детей с врожденными деформациями позвоночника.

Материалы и методы. Проанализированы истории болезней 286 детей в возрасте до 6 лет с врожденной деформацией позвоночника на фоне изолированного аномального позвонка, проходивших хирургическое лечение в НМИЦ детской травматологии и ортопедии им. Г.И. Турнера в период с 2014 по 2019 г. В зависимости от исходов хирургического лечения пациенты были распределены на группы: в исследуемую группу ($n = 7$) вошли пациенты с дестабилизацией металлоконструкции, в контрольную ($n = 12$) — без дестабилизации металлоконструкции. В ходе исследования определяли размеры оснований дуг позвонков, смежных с аномальным, оценивали величину сколиотического и кифотического компонентов деформации, корректность положения опорных элементов металлоконструкции по шкале Gertzbein.

Результаты. Пациенты не отличались по возрастному показателю, величине сколиотического и кифотического компонентов деформации позвоночника, но различались по такому показателю, как средний диаметр оснований дуг ($p < 0,05$). У всех пациентов после хирургического вмешательства достигнута полная коррекция врожденного искривления позвоночника. В отдаленном послеоперационном периоде у пациентов исследуемой группы после лучевого исследования выявлены мальпозиция опорных элементов относительно основания дуги позвонка и потеря коррекции деформации позвоночника в среднем на 25°. В связи с этим было проведено повторное хирургическое вмешательство с целью восстановления стабильности металлоконструкции и коррекции деформации.

Заключение. Причинами дестабилизации металлоконструкции при коррекции врожденных деформаций позвоночника являются особенности анатомо-антропометрических параметров позвонков в зоне искривления, а также тактические аспекты хирургического вмешательства. Основная причина дестабилизации металлоконструкции без нарушения ее целостности заключается в малых размерах основания дуг соседних позвонков относительно аномального. Малые размеры оснований дуг позвонков и значительная величина коррекции врожденной деформации позвоночника, обусловленная достижением радикального исправления искривления, обусловливают необходимость установки более протяженной спинальной системы с целью восстановления физиологических профилей в зоне искривления.

Ключевые слова: врожденный сколиоз; моносегментарные пороки позвоночника; полупозвонок; резекция полупозвонка; дестабилизация металлоконструкции; мальпозиция винтов.

Most often, in the structure of vertebral abnormalities, leading to a progressive course of congenital deformities, vertebral formation abnormalities occur [1, 2]. Most researchers adhere to the active approach of the surgical treatment of patients with congenital curvature of the spinal column in case of disorder of the formation of the vertebrae at an early age [3–5]. The main objective of the surgery is to remove the body of the defective vertebra with radical correction of the congenital deformity using the surgical hardware and fixation of the minimum number of spinal motion segments but only those involved in the main curvature arch [6–8]. To achieve this goal during surgery, in recent years, a spinal implant with transpedicular support elements has been used. The advantage of the latter consists of the possibility of simultaneous affecting all three columns of the spinal column, which provides a reduction in the length of the hardware fixation and preservation of the stability of the result achieved in the long-term follow-up period [9–11].

It should be noted that in the available literature, there are no data on the analysis of the reasons for the destabilization of the spinal system with transpedicular support elements in the correction of congenital spinal deformity in pediatric patients.

The work aimed to evaluate the options and causes of destabilization of transpedicular surgical hardware, not related to the violation of its integrity, in the surgical treatment of pediatric patients with congenital spinal deformities.

Materials and methods

The study analyzed the case histories of 286 pediatric patients with congenital spinal deformity with a single abnormal vertebra, who received surgical treatment at the Turner Scientific and Research Institute for Children's Orthopedics, from 2014 to 2019. The study group included patients of preschool age, which surgical treatment was complicated by destabilization of the surgical hardware, not associated with a violation of its integrity.

Inclusion criteria. *The criteria for inclusion* of patients in the study were the age of 1 year 2 months to 6 years, the presence of an isolated malformation of the thoracic or lumbar spine, the absence of abnormal development of the spinal canal and spinal cord, the localization of the abnormal vertebra from Th_6 to L_4 level, surgery from the combined (anteroposterior and dorsal) approach, use of only transpedicular surgical hardware for deformity correction, the presence of four support elements for the spinal system, and the length of metal fixation of two neighboring vertebrae relative to the abnormal one.

The exclusion criteria were congenital spinal deformity in the presence of multiple vertebral malformations, localization of the abnormal vertebra at the Th_1–Th_5 and L_5 levels, surgery only from the dorsal approach, use of the laminar and/or hybrid spinal system, and the length of the metal fixation of three or more vertebrae.

The material of the study was represented by the case histories of 19 patients with congenital scoliosis with an isolated semivertebra of the thoracic or lumbar spine. The gender distribution was 10 boys and 9 girls. The average age of the patients was 3 years 7 months (from 1 year 2 months to 6 years). According to the localization of the abnormal vertebra, the distribution implied that the semivertebra was located in the thoracic region (Th_6–Th_{12}) in 11 patients and the lumbar region (L_1–L_4) in 8 patients.

Depending on the outcomes of surgical treatment, the patients were divided into two groups: the study group included patients (n = 7) with destabilization of the surgical hardware in the early postoperative period (up to 6 months), and the control group included patients (n = 12) without destabilization of the spinal system. The control group was formed by a targeted selection of patients comparable in characteristics with the study group patients from a general cohort of operated patients, which corresponded to pseudorandomization.

All patients received a comprehensive clinical and radiation examination before and after surgery, as well as in the process of the case follow-up.

Based on the X-ray of the spine in standard views, prior to surgery, the variant of the abnormality of the vertebral development and its localization were determined, and the magnitude of the scoliotic and kyphotic components of the spinal deformity according to Cobb was evaluated (Table 1).

The diameter of the supporting elements of the spinal system installed was determined according to preoperative calculations of the size of the base of the vertebral arches. After surgery, the residual curvature in the curvature zone and the correctness of the surgical hardware installation were evaluated.

According to multispiral computed tomography (MSCT), the nature of bone pathology was determined prior to the surgery, and the parameters of the bases of the vertebral arches in the defect zone were measured in detail. After the surgery, the correctness of the installed supporting elements of the surgical hardware relative to the arch root was evaluated according to the Grade method, relative to the bone structures according to the method proposed by Gertzbein et al., and the scheme of determining the correctness of the installed screws relative to the bone structures SLIM + V* was used [12, 13]. In addition, during control examinations, the rates of formation of bone block in the intervention site were registered over time.

Surgical intervention was performed to all patients with a combined approach according to the developed methods, depending on the abnormal vertebra localization in the thoracic or lumbar spine [3, 14]. The abnormal vertebra body with the upper and lower discs was removed through the anterolateral approach, and the posterior bone structures of the defective vertebra were removed from the dorsal one with the correction of congenital deformity of the multi-support transpedicular surgical hardware. Supporting elements of the spinal system were installed only on adjacent vertebral bodies relative to the abnormal

*The first part of the abbreviation is the designation of the screw position relative to the outer walls of the arc root, which is evaluated in a certain order: S is the superior (cranial) wall of the arc root, L the lateral (external) wall of the arc root, I the inferior (caudal) wall of the arch root, and M the medial (internal) wall of the arch root. The second part of the abbreviation (V — vertebral body) is the designation of assessment of the position of the transpedicular screw in relation to the anterolateral surface of the vertebral body.

Table 1

Characteristics of the patients under study

Groups		Age at the time of surgery (months)	Localization of abnormal vertebra	Average diameter of the bases of the adjacent vertebrae arches (mm)	Scoliotic deformity, ° by Cobb	Kyphotic deformity, ° by Cobb
1	1	57	L_2	3.8	39	6
	2	25	Th_7	3.9	42	30
	3	36	Th_6	4.1	33	23
	4	36	Th_{10}	4.1	26	45
	5	21	L_2	3.8	39	26
	6	84	Th_7	3.6	35	24
	7	36	Th_{11}	3.6	40	48
***M* ± *m* in the group**		**42.14 ± 8.86**	–	**3.84 ± 0.08**	**36 ± 2.23**	**29 ± 5.81**
2	1	38	Th_{11}	4.3	34	10
	2	40	L_2	5.0	40	26
	3	46	Th_{13}	5.1	42	40
	4	60	L_1	4.9	58	40
	5	24	L_1	4.5	62	40
	6	48	Th_6	4.4	38	24
	7	48	L_2	5.7	42	23
	8	2	Th_6	4.5	32	41
	9	48	Th_{11}	5.2	40	19
	10	35	L_1	5.0	32	15
	11	36	L_1	5.1	24	15
	12	70	Th_7	4.7	36	10
***M* ± *m* in the group**		**42.75 ± 4.01**	–	**4.87 ± 0.12**	**40 ± 3.22**	**29 ± 3.23**

one. The intervention was completed by performing posterior local spinal fusion and corporodesis in the corrected position of the spinal motion segments.

The length of the surgical hardware in all cases was two vertebrae (one spinal motion segment). In all patients, supporting elements of the surgical hardware were installed according to the free-hand technique. After surgery, computed tomography was performed to assess the correctness of the location of the spinal system supporting elements.

Statistical analysis was performed using the Statistica 13 program (StartSoft Inc., Tulsa, USA) and Microsoft Excel 2010. The arithmetic mean (M) and the deviation of the mean ($\pm m$) were calculated. The normality of the sample distribution was tested using the variation coefficient, relative linear deviation, chi-squared test, skewness index, and kurtosis value. To determine the statistical significance of differences in paired measurements, paired Student t-test and Mann–Whitney test were used, and the significance level was taken as $p < 0.05$. To determine the linear relationship, the Spearman correlation criterion (p) was used.

Results

Patients of the studied groups were comparable in terms of age and the magnitude of both the scoliotic and kyphotic components of spinal deformity. However, when comparing the average diameter of the base of the arcs, statistically significant differences were registered ($p < 0.05$). For example, patients in the control group had a larger diameter of the base of the arches (min 4.3 mm; max 5.7 mm) compared with those in the study group (min 3.6 mm; max 4.1 mm).

In all patients after surgery, complete correction of local congenital curvature and restoration of physiological parameters of the frontal and sagittal profiles of the spinal column were noted. The correctness of the installation of the supporting elements of the surgical hardware relative to the cortical laminae of the roots of the arches of the instrumented vertebrae was evaluated in the postoperative period, according to MSCT (in the frontal view; Table 2).

The study also analyzed the correctness of the position of transpedicular screws relative to the outer walls of the roots of the arches and the anterolateral surface of the instrumented vertebrae (Table 3), based on the MSCT data (in the axial and sagittal planes).

When evaluating the correctness of the installed support elements in patients of the control group, the central position of the transpedicular screws (Grade 0) was noted in seven cases (28 screws), and the displacement of the transpedicular screws within Grade 1 was noted in five cases (20 screws). Displacements of supporting elements within Grades 2–3 and simultaneous damage to several walls of the base of the arch in patients of the control group were not registered during our study (Tables 2 and 3).

In four cases of the study group, support elements (16 screws) were located in the center

Table 2

Assessment of correctness of the installed support elements of the surgical hardware according to the methodology of Gertzbein et al.

Groups		Position of the surgical hardware screws relative to the center of the arch root, Grade
1	1	2
	2	2
	3	1
	4	0
	5	2
	6	2
	7	3
2	1	1
	2	0
	3	0
	4	0
	5	1
	6	0
	7	1
	8	0
	9	1
	10	0
	11	0
	12	1

Note. Grade 0 (full correct), the transpedicular screw is completely located in the root of the arch; Grade I, displacement of the transpedicular support element relative to the cortical layer of the arch root by up to 2 mm; Grade II, screw displacement by 2 to 4 mm; Grade III, displacement by more than 4 mm.

Table 3

Assessment of the position of the supporting elements of the surgical hardware relative to the bone structures of the vertebra

Groups		Number of displaced screws	Damage of the walls of the arch roots, according to SLIM + V*				
			S	L	I	M	V
1	1	3	+	+		+	
	2	2		+	+		
	3	1					+
	4	1					+
	5	1	+	+	+		+
	6	2	+		+	+	
	7	1					+
2	1	2			+		
	2	1					
	3	2					
	4	2					
	5	2			+		
	6	1					
	7	1					+
	8	1		+			
	9	1			+		
	10	2					
	11	2					
	12	1	+				+

Note. S is the superior wall of the arch root; L is the lateral wall of the arch root; I is the inferior wall of the arch root; M is the medial wall of the arch root; V is the vertebral body. *See footnote on p. 17.

of the arch root (Grade 0), and in two cases (8 screws), the position of the transpedicular screws shifted within Grade 1, and in one case (4 screws), the degree of the displacement of the supporting elements corresponded to Grade 2.

The study revealed an inverse correlation dependence of the correctness of the installed support elements of the surgical hardware on the diameter of the base of the vertebral arches adjacent to the abnormal one (Spearman correlation coefficient was equal to −0.06).

In six cases in the study group, the transpedicular screw perforated the anterior cortical lamina of the vertebra, but given the literature, this complication relates rather to technical errors in choosing the length of the support element than to complications of its installation [15].

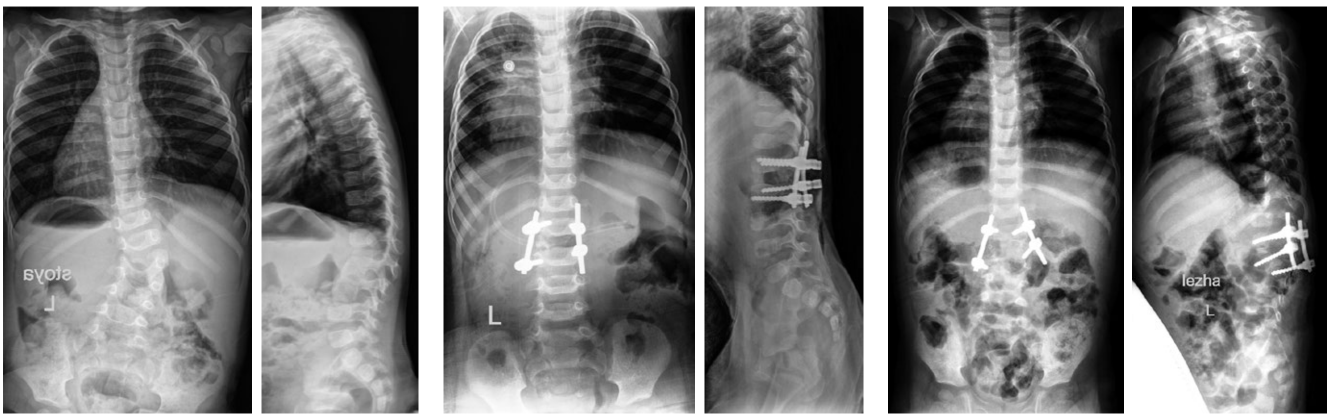
In the majority of cases in patients of the study group, the displacement of the transpedicular screws was accompanied by damage to at least one wall of the base of the arch, but despite the small size of the bases of the vertebral arches, which almost corresponded to the diameter of the transpedicular screw, the support elements were installed correctly (Table 2). In our opinion, such critical dimensions of the bone structures of the vertebrae have become one of the reasons for the surgical hardware destabilization.

In the period from 3 to 6 months after surgery, parents of all the pediatric patients in the study group noted a deterioration in the form of appearance of spinal curvature in the intervention area. There was an asymmetry of the triangles of the waist, the different height of the angle of scapulae, and the presence of a muscular embankment. This was the reason for visiting the hospital and conducting a follow-up examination. After a radiation study, the displacement of the supporting elements of the spinal system relative to the base of the vertebral arch was revealed, as well as the eruption of the bone structures of the base of the vertebral arches and bodies in the area of the transpedicular support elements, and the loss of correction of spinal deformity, which reached from 15° to 44° according to Cobb ($M = 25 \pm 5.7°$).

Based on the results of computed tomography, malposition of one screw was detected in four cases and two screws in two cases, and malposition of three or more screws was noted in one patient. There were no fractures of the rods or transpedicular screws.

It should be noted that in all patients with a congenital spinal deformity in the area of the defect, pronounced values of the scoliotic and/or kyphotic components of the curvature were recorded (Table 1). During corrective manipulations, this caused significant pressure of the transpedicular screws on the bone structures of the vertebral bodies. Despite the fact that some of the supporting elements were installed correctly, a sufficiently small length of metal fixation and small sizes of the base of the vertebral arches contributed to the eruption of the base of the arches and crushing of the trabeculae of the bone of the vertebral bodies, which led to the destabilization of the spinal system (see Figure).

Because of the current situation, all patients underwent repeated surgery (within 3 to 6 months



a *b* *c*

Radiographs of patient S., 1 year 9 months, with congenital kyphoscoliosis of the lumbar spine with the presence of the posterolateral semivertebra L_2: *a* — before surgery, the scoliosis angle was 39°, and the kyphosis angle was 26°; *b* — after extirpation of the semivertebra with a combined approach and through correction of congenital deformity; *c* — destabilization of the surgical hardware

Table 4

Changes in time of correction of spinal deformity during restoration of surgical hardware stability

Patients	Spinal deformity at the time of surgical hardware destabilization, ° by Cobb		Residual spinal deformity after restoration of the surgical hardware stability, ° by Cobb	
	Scoliotic component	Kyphotic component	Scoliotic component	Kyphotic component
1	41	30	1	0
2	39	30	1	0
3	29	44	0	0
4	39	40	0	0
5	22	18	0	0
6	15	0	0	0
7	0	40	0	0

after the first surgery) only with the dorsal approach, aimed at stabilizing the surgical hardware and additional correction of the deformity that occurred. The surgical hardware stability was restored by installing additional support transpedicular bearing elements one vertebra above and below the spinal system installed previously, thereby achieving complete correction of the scoliotic and kyphotic components of the deformity (Table 4).

Discussion

The transpedicular spinal system enables to achieve complete correction of congenital deformity after removal of the abnormal vertebral body with support only of neighboring intact vertebral bodies relative to the defective one [3, 14, 16]. However, when installing transpedicular surgical hardware, there are several technical difficulties and problems, as well as the risk of various kinds of complications, primarily of a neurological nature [17, 18].

Several studies provide descriptions of possible complications after the use of transpedicular surgical hardware for correction of congenital spinal deformity. For example, Ruf and Harms reported complications resulting from the transpedicular spinal system installation in 28% of cases, including three fractures of the base of the vertebral arches, three fractures of the rods, and two cases of the deformity correction loss [19]. Zhang et al. registered complications in 10.8% of cases (two fractures of the base of the vertebral arches, two fractures of the rods, one case of loss of correction of spinal deformity, and one persistent surgical wound), for which repeated surgical interventions were performed [20].

The multifactorial nature of this problem consists both in the characteristics of the congenital defect itself and in the surgical aspects [21]. From our point of view, several factors determine the occurrence of the spinal system destabilization. First of all, these are small sizes of the bases of the vertebral arches (practically corresponding to the diameter of the transpedicular screw), a significant amount of the necessary correction of the scoliotic and/or kyphotic components of the deformity to achieve a radical correction of congenital curvature, as well as localization of the abnormal vertebra in the transitional areas of the spine (kyphosis apex and thoracolumbar transition). A short length of metal fixation (one spinal motion segment) contributed to a significant load in the surgical area. The combination of these factors resulted in destabilization of the spinal system and, eventually, the loss of the correction achieved during the surgery. Most probably, the correctness of the installed support elements, within the permissible error (Grades 1–2), does not affect the spinal system destabilization. In our study, destabilization of the surgical hardware occurred in patients with supporting elements installed correctly.

At the same time, it should be noted that the localization of abnormal vertebrae (the apex of thoracic kyphosis and the area of the thoracolumbar junction) and the magnitude of the curvature scoliotic and kyphotic components were equal in the comparison groups. The only difference in the presented groups was the size of the bases of the vertebral arches. In the group of patients with destabilization of the spinal system, the average size of the base of the arches of the intact vertebrae relative to the abnormal one was 3.84 ± 0.08 mm, which almost corresponded to the diameter of the transpedicular screw. In patients whose surgical hardware remained stable throughout the entire period of the bone block formation, the average size of the base of the arches of the vertebrae adjacent to the abnormal one was 4.87 ± 0.12 mm. In our opinion, short fixation (of only two vertebrae located on either side of the abnormal one) of the spinal motion segment in the area of the defect induced significant strain on both the surgical hardware itself and the bone structures of the vertebral bodies, which resulted in the spinal system destabilization. In view of the foregoing, in the correction of congenital deformity and fixation of the spinal motion segments in the region of the thoracic kyphosis apex and in the area of the thoracolumbar transition with small sizes of the base of the vertebral arches adjacent to the abnormal one, more extensive metal fixation is necessary to not only restore the physiological profile in these areas but also maintain reliable stabilization of this zone throughout the entire period of the bone block formation.

Conclusion

Destabilization of the surgical hardware during correction of congenital spinal deformities is caused by both the features of the anatomical and anthropometric parameters of the vertebrae in the curvature zone and the approach aspects of the surgical intervention. The main cause of destabilization of the surgical hardware without violating its integrity is the small size of the base of the arches of neighboring vertebrae relative to the abnormal. When choosing the length of metal fixation, it is necessary first of all to take into account the size of the base of the arches of adjacent intact vertebrae relative to the defective one, the magnitude of the scoliotic and kyphotic components of congenital deformity, and the localization of the abnormally developed vertebra. The small size of bases of the vertebral arches and the significant amount of necessary correction of congenital spinal deformity necessitate the installation of a longer spinal system to restore physiological profiles in the curvature zone.

Additional information

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Conflict of interests. Not claimed.

Ethical statement. This study was discussed and approved by the ethics committee of the Turner Scientific and Research Institute for Children’s Orthopedics (protocol No. 2019/10 of 10/25/2019). Patients and their representatives gave informed consent to participate in the study and publish personal data.

Author contributions

D.N. Kokushin who performed surgical treatment of patients was involved in the writing and stage editing of the article text.

S.V. Vissarionov performed surgical treatment of patients, created the objective statement, and was involved in the staged and final editing of the article text.

M.A. Khardikov and *V.V. Ilyin* performed data collection and analysis, literature review, and the writing the text of the article and its design.

N.O. Khusainov and *A.N. Filippova* performed surgical treatment of patients and data collection and analysis.

All authors made a significant contribution to the research and preparation of the article and have read and approved the final version before its publication.

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