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Этапные результаты ортезирования детей после оперативного лечения врожденной деформации позвоночника (предварительное сообщение)

© И.А. Редченко[1, 3], С.В. Виссарионов[1], М.Г. Гусев[2], Г.А. Леин[1, 2], И.В. Павлов[3, 4]

[1] Национальный медицинский исследовательский центр детской травматологии и ортопедии имени Г.И. Турнера, Санкт-Петербург, Россия;
[2] Сколиолоджик.ру, протезно-ортопедический центр, Санкт-Петербург, Россия;
[3] Северо-Западный научно-практический центр реабилитации и протезирования «Ортетика», Санкт-Петербург, Россия;
[4] Малое инновационное предприятие «Стилиан», Санкт-Петербург, Россия

Обоснование. После оперативного лечения врожденных деформаций позвоночника наблюдается тенденция к деформации незафиксированных металлоконструкцией (ниже- и вышележащих) сегментов позвоночного столба, что может привести к повторному оперативному вмешательству. Для предотвращения сколиотических компенсаторных противодуг ряд специалистов после хирургического лечения назначают различные виды ортезов на туловище, но клинические доказательства результативности ортезирования в научной литературе освещены недостаточно.

Цель — оценка годовых результатов ортезирования туловища после оперативного лечения детей с врожденной деформацией позвоночника на фоне нарушения формирования позвонков (заднебоковые полупозвонки) функционально-корригирующими ортезами для воздействия на сколиотическую компенсаторную противодугу.

Материалы и методы. Двадцати пяти пациентам в возрасте от 2 до 12 лет (10 мальчиков и 15 девочек) проведено оперативное лечение врожденной деформации позвоночника на фоне заднебоковых полупозвонков в грудном (13) и поясничном (12) отделах, снабженных функционально-корригирующими ортезами на туловище. Результаты ортезирования туловища оценены через 3, 6 и 12 мес. при помощи термодатчиков времени ношения ортеза, рентгенографического и статистического методов.

Результаты. Через 3 мес. пребывания в ортезе зафиксирована коррекция около 50 % величины исходной компенсаторной противодуги как грудной, так и поясничной локализации, а через 6 мес. коррекция составляла 60 %. Через 12 мес., когда выполнен рентгеновский снимок без ортеза, в грудных противодугах без корсета фиксировали и сохраняли коррекцию на уровне 40 %. В поясничных противодугах без ортеза отмечен возврат к исходной величине деформации, то есть коррекция происходила, но без ортеза не фиксировалась. Только у одного из 25 пациентов (4 %) была проведена повторная операция с целью увеличения протяженности металлофиксации.

Заключение. Наблюдение за группой пациентов (25 детей) в течение 12 мес. после оперативного лечения врожденной деформации позвоночника на фоне заднебоковых полупозвонков в грудном и поясничном отделах позволило доказать целесообразность применения функционально-корригирующего ортеза на туловище с целью коррекции противодуги деформации.

Ключевые слова: дети; врожденная деформация позвоночника; хирургическое лечение; ортезирование.

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Stage results of the use of orthoses in children after surgical treatment of congenital spine deformity (Preliminary report)

© Ignatiy A. Redchenko[1, 3], Sergei V. Vissarionov[1], Maxim G. Gusev[2], Grigoriy A. Lein[2], Ivan V. Pavlov[3, 4]

[1] H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, Saint Petersburg, Russia;
[2] The Prosthetic and Orthopedic Center "Scoliologic.ru", Saint Petersburg, Russia;
[3] North-West Scientific and Practical Center for Rehabilitation and Prosthetics "Orthetika", Saint Petersburg, Russia;
[4] Small innovative enterprise "Stylian", Saint Petersburg, Russia

BACKGROUND: After surgical treatment of congenital spinal deformities, we can see the progression of deformities of the spinal column segments free from metal structures, which leads to the need for reoperation. Without sufficient scientific evidence, several specialists after surgical treatment use various orthoses on the body to prevent scoliotic compensatory changes.

AIM: This study aims to assess the results of body orthosis after surgical treatment of children with congenital spinal deformity with the impaired formation of the vertebrae, using orthoses, compensatory deformity after one year of treatment.

MATERIALS AND METHODS: Twenty-five patients aged 2 to 12 years (10 boys and 15 girls) after surgical treatment of congenital deformity of the spine in the thoracic regions (13) and lumbar regions (12), wearing body orthoses. The results were assessed at 3, 6, and 12 months using thermal sensors for the orthosis wearing time by X-ray and statistical methods.

RESULTS: After three months of wearing the brace, we saw a correction of about 50% of the value of the initial compensatory deformity. After six months, both thoracic and lumbar, the correction was 60%. After one year, when performing an X-ray image without an orthosis, in thoracic deformities without a brace, the correction stabilized and remained at the level of 40%. In lumbar deformities without a brace, the original deformity returned, i.e., the correction occurred but was not fixed without the orthosis. Only one of 25 patients (4%) required a second operation to increase the fixation's duration.

CONCLUSION: The results of observing a group of patients (25 children) for one year after surgical treatment of congenital spine deformity showed a positive effect of a functionally corrective orthosis on the body to correct secondary deformities.

Keywords: children; congenital malformation of the spine; surgical treatment; orthotics.

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BACKGROUND

Isolated developmental abnormalities of the vertebrae represent one of the causes of congenital deformities of the thoracic and lumbar spine. The prevalence of congenital scoliosis ranges from 2% to 3% in the structure of all scoliotic deformities [1, 2]. Although developmental abnormalities of the spinal column in children are not common, with a progressive nature of the course, this disease leads to an increase in the scoliotic and kyphotic curve of the deformity. A number of publications demonstrated that the rate of progression of congenital scoliosis reaches 50% [3, 4].

Patients with compensatory deformity curvature, as opposed to the main congenital curve, are especially difficult to assess the progression rate and further prognosis of the treatment efficiency. In this patient population, even after adequate correction of the main congenital curve, compensatory deformity often progress, the function of external respiration is impaired, and persistent pain syndrome or neurological deficit appears. All this leads to repeated staged surgical interventions aimed at correcting secondary curves and elimination of the above disorders. Numerous studies [5–7] have established [5–7] that the positive result of treatment of patients with congenital deformity of the spinal column in case of an isolated impairment of vertebra formation depends directly on the timeliness of detecting this pathology and performing surgical intervention at an early age. Surgical treatment consists of the removal of the abnormal vertebral body with adjacent discs, radical correction of the congenital curvature with the hardware, and stabilization of the minimum number of spinal motion segments involved in the pathological curve. During the intervention, the restoration of the physiological sagittal profile of the spinal column is desirable.

If questions on the timing and methods of surgical treatment of congenital spinal deformities in case of vertebral malformations are practically resolved at this stage and there are no diametrically opposed views on approaches in Russian and international literature [8, 9], then this cannot be said with regard to the use of trunk orthosis. The use of trunk orthoses after surgical treatment in this patient population is discussed mainly by international experts [10–14]. Most of them recommended that postoperative orthotics can be effective for controlling or slowing the progression of compensatory scoliotic curves developing proximal or distal to the main curve of congenital scoliosis. In principle, international authors have evaluated the results of such orthotics on the basis of studies in groups of up to 10 patients. In Russian studies on surgery, there is practically no data on the need for subsequent orthosis in the presence of compensatory deformity, which often requires staged surgical treatment in the future [15, 16]. Considering the above background, complex treatment of pediatric patients with isolated congenital abnormalities of the vertebrae, including surgical treatment and orthotics, remains relevant and needs to be investigated.

This study aimed to evaluate the annual results of using trunk orthosis after surgical treatment of pediatric patients with congenital deformity of the spine with impaired vertebra formation using functional corrective orthoses to correct the scoliotic compensatory curve.

MATERIALS AND METHODS

The inclusion criteria of the patients were an isolated posterolateral semivertebra in the thoracic or lumbar spine and absence of abnormalities in the development of the spinal canal and spinal cord or neurological disorders. This study examined 25 patients aged 2–12 years (10 boys and 15 girls) with congenital kyphoscoliosis having an isolated abnormal posterolateral semivertebra of the thoracic (n = 13) and lumbar (n = 12) spine. The localization and number of semivertebrae in the thoracic region were Th_2 (n = 1), Th_5 (n = 2), Th_7 (n = 2), Th_9 (n = 1), Th_{10} (n = 2), Th_{11} (n = 1) and Th_{12} (n = 4) and that in the lumbar spine were L_1 (n = 2), L_2 (n = 3), L_3 (n = 5), and L_4 (n = 2).

The patients and their legal representatives gave informed consent to participate in the study. All patients received surgical treatment according to the following technique. The abnormal vertebral body along with its superior and inferior discs was removed through the anterolateral approach, the half-arc of the semivertebra was removed through the dorsal approach, and the local congenital curvature was corrected with a multi-support hardware. The intervention was completed with the formation of posterior local fusion and corporodesis with an autologous bone. After surgery, patients were put on their feet after 5–7 days, and a functionally corrective brace was worn to influence the free compensatory curve.

The follow-up period of patients, during which functional corrective orthoses were used to influence compensatory curves, was 1 year.

To assess the initial status and results of surgical treatment, an X-ray examination of the spine in the upright position in frontal and lateral projections from Th_1 to L_5 was performed. The angular deformity of the spinal column was assessed according to the Cobb method. The reliability of the results before and after surgery, as well as the effectiveness of the orthosis treatment, was confirmed by analysis according to the Wilcoxon test using the statistical software STATISTICA 10 (StatSoft, Inc.).

Impressions were taken from the patient's torso using digital three-dimensional scanning technology. This technology is associated with the speed and non-contact nature of the method in patients who underwent surgery. At the same time, it has no mechanical effect on the body, which is noted during the "conventional" taking of an

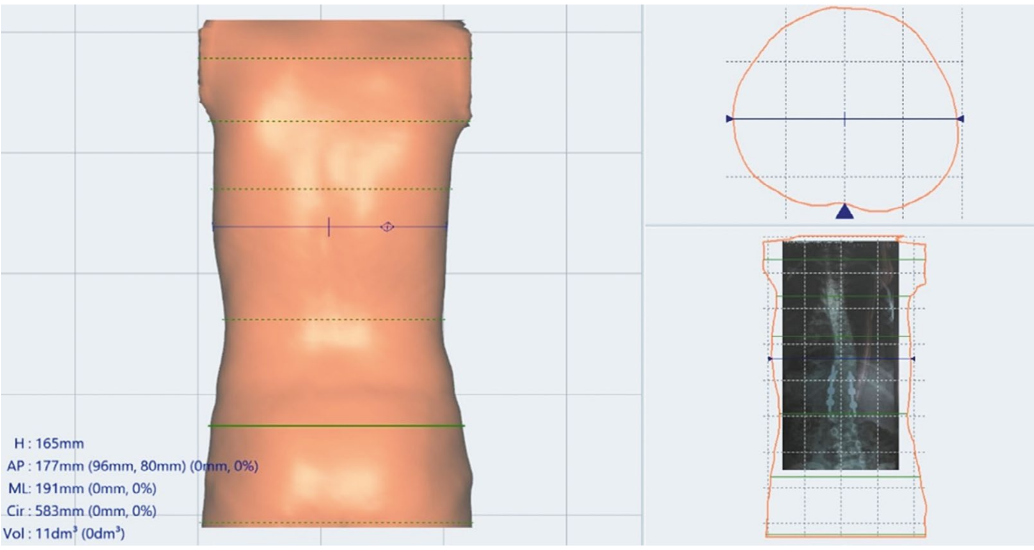

Fig. 1. Scanning image of the patient's body (dorsal plane) and X-ray image of the spine in the Rodin 4D software

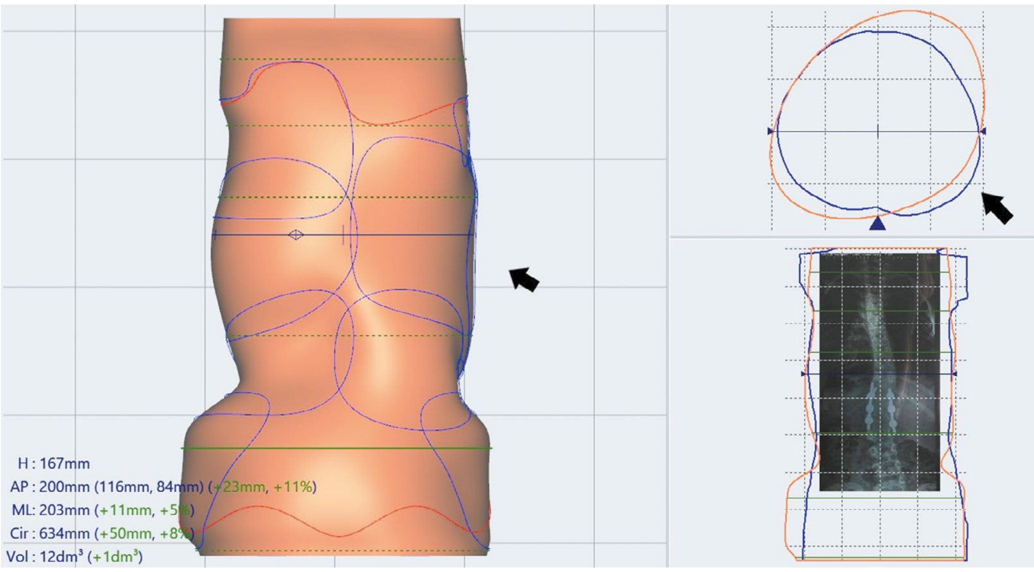

Fig. 2. Completed modeling of a functional corrective orthosis on the trunk with thoracic compensatory curve. On the dorsal plane on the left, the arrow indicates the bandage correcting the thoracic gibbus. On the frontal cut on the right, the arrow indicates the corrective bandage. The brace borders are highlighted in an orange outline, and the body is highlighted in blue

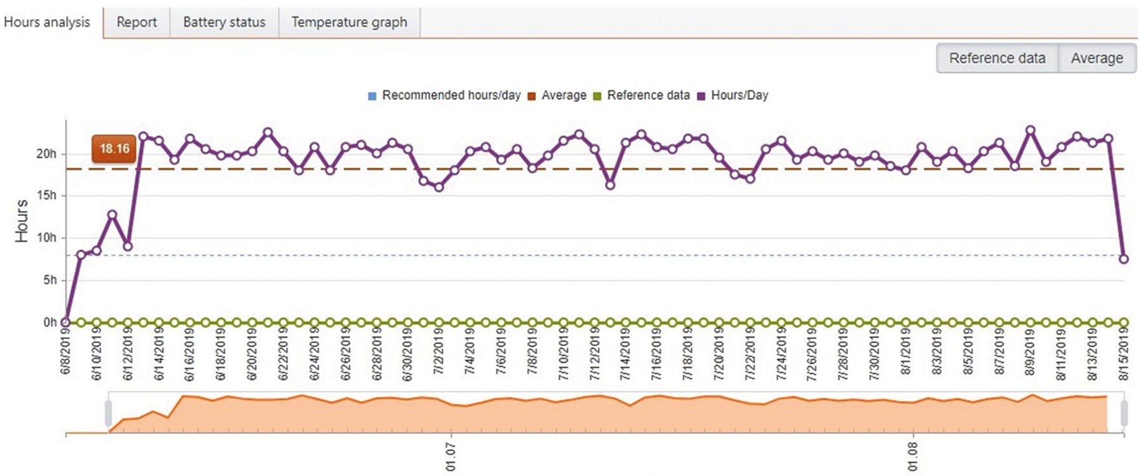

Fig. 3. A graph of temperature curves obtained on the Orthotimer sensor, with an average wearing time of 18 h/day

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impression with the use of plaster bandages. In addition, the amount of time that patients spend in an upright position is significantly reduced, and if necessary, a scan of the body can be performed in the supine position. The resulting scan of the trunk and X-ray image of the spine after surgical treatment (Fig. 1) were loaded into the Rodin4D software package (France).

Functional corrective orthosis on the trunk was modeled in the Rodin 4D software using the computer aided design and manufacturing (CAD/CAM) system Lagarrigue Orthopédie (France) in accordance with the medical and technical requirements based on the method of manufacturing functional corrective braces according to Rigo-Cheneau [17]. The height of the postoperative trunk orthosis in the axillary region should be at maximum and reach the fourth to fifth intercostal space. In cases with surgical hardware in the lumbar spine and thoracic compensatory curve, thoracic bandage of the brace was modeled for corrective action on the ribs corresponding to the apex of the thoracic compensatory curve, and on the opposite side (corresponding to the rib depression area), there was unloading. In the lumbar region, a bandage was virtually created with minimal influence on the hardware structure area, without a counter-unloading area. In principle, the pelvic region in such a brace model was modeled symmetrically, without bandages. The location of the axillary bandages as regards its height is usually asymmetric, depending on the compensatory misalignment of the shoulder girdles and the presence of a curve in the upper thoracic region. Subclavian bandages were also modeled to fix the chest and to correct the formation of the sagittal profile of the spine (Fig. 2).

If the hardware was located in the thoracic region and there was a lumbar compensatory curve in the thoracic region, a bandage was simulated with minimal impact on the ribs, corresponding to the area of the hardware placement, while there was no unloading area on the opposite side. The lumbar bandage was modeled with the impact on the apex of the lumbar compensatory curve and in the unloading area on the opposite side. The pelvic region was virtually created asymmetrically by modeling the derotation pelvic bandage and by the formation of unloading for rotation and displacement of the pelvis from the side opposite to the bandage. The position of axillary bandages as regards its height was modeled asymmetrically depending on the misalignment of the shoulder girdle and the presence of a curve in the upper thoracic region; subclavian bandages were virtually formed to fix the chest and to appropriately form the sagittal profile of the spine.

In accordance with CAD/CAM technology, the groove of the positives for blocking was made from polyurethane foam blanks on a programmed milling machine. Brace blocking was performed by deep vacuum drawing; low-pressure polyethylene with a thickness of 4–5 mm was used as the material for the socket of the orthosis. After fitting on the patient, the finished orthosis was elaborated as necessary, and unloading areas and bandages were assessed clinically in accordance with the brace treatment. The recommended duration of wearing a brace was 18–20 h per day, including nighttime sleep. After the brace was fabricated, to evaluate the initial correction, X-ray images were taken in two views in the upright position. When using the brace for the first time, the correction of the compensatory curves on the frontal images should be at least 50% in comparison with the initial radiological data without orthosis. If the correction indices were insufficient, the pressure in the areas of the deformed curve apex was increased by gluing in additional bandages made of pedilen material.

To monitor compliance with the wearing regimen (Fig. 3), Orthotimer temperature sensors (Germany) were used, which read the body temperature when the orthosis is worn and enable, during the control examination, estimation of the duration of using the orthosis per day up to 6 months, and then the sensors must be replaced.

A follow-up examination of the patient with a trunk orthosis was performed at least once every 3 months. During the follow-up, the patient's body appearance was assessed, anthropometric measurements (height, weight, and volume) were performed, and information from wearing sensors was analyzed. To assess the results of orthosis, X-ray images were taken and analyzed without a brace after 3, 6, and 12 months of use.

Brace were replaced depending on the intensity of the child's growth and weight changes and was associated with the need to change the brace model in accordance with the clinical and radiological presentation of the spinal deformity.

RESULTS

Outcomes following a complex treatment were assessed before and after surgery, as well as at stages of orthotics with and without a brace, based on the values of congenital scoliotic deformity and compensatory curves (according to the Cobb method).

Tables 1 and 2 present the values of the congenital and secondary scoliotic curves before and after surgical treatment.

The magnitude of local kyphotic deformity in patients ranged from 12° to 38° (average, 21.1° ± 4.7°) before surgery and from 1° to 18° (average, 5.4° ± 3.7°) after surgery by the Cobb method. Thus, after surgical treatment, it was possible to correct almost completely the congenital curve of the curvature and create a physiological profile of the spine. In addition, in most cases, when a full correction of the local congenital curve of the curvature was achieved, the value of the compensatory curve decreased.

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Table 1. Size of the congenital scoliotic curve of the spine by the Cobb method at the level of the posterolateral semivertebra before and after surgical treatment

Localization of the posterolateral semivertebra	Size of the congenital scoliotic curve, degrees		Significance level of differences (p)
	Before surgery	After surgery	
Thoracic region	17.3 ± 4.7 (18 to 37)	2.9 ± 2.0 (1 to 15)	0.002
Lumbar region	30.2 ± 6.6 (16 to 45)	2.0 ± 0.5 (1 to 3)	0.001

Table 2. Scoliotic secondary curve of the spine by the Cobb method before and after surgical treatment

Secondary curve localization	Magnitude of secondary scoliotic curve, degrees		Significance level of differences (p)
	Before surgery	After surgery	
Lumbar region	17.4 ± 7.4 (1 to 29)	11.2 ± 4.5 (3 to 19)	0.036
Thoracic region	21.6 ± 10.0 (0 to 41)	15.5 ± 4.5 (8 to 26)	0.074

Table 3 shows the magnitude of the compensatory curve of the thoracic and lumbar spine after surgical treatment, at various stages of orthotics after 3 and 6 months of using a torso orthosis, as well as results after 12 months without orthosis.

After 3 months, in the majority of patients wearing a functionally corrective trunk orthosis, approximately 50% of the initial compensatory curve of both thoracic (p = 0.001) and lumbar localizations (p = 0.007) was corrected. After 6 months of wearing a trunk orthosis, the correction of the thoracic and lumbar compensatory curves increased to 60% of the initial value (p = 0.001 and p = 0.002, respectively). Stage results at 12 months after the start of orthotics, when an X-ray was taken without a torso orthosis, were different depending on the localization of the compensatory curve. In 10 of 13 pediatric patients with thoracic compensatory curves, the magnitude of the deformity curve decreased, and its progression stopped in three children. The average statistical indicators show that, without a brace, the level of correction is somewhat reduced, but the correction is fixed and maintained in comparison with the postoperative compensatory curve at 40% (p = 0.005).

In patients with compensatory curves of the lumbar spine (n = 12), the following annual results were obtained. Progression of the deformity was terminated in eight patients, and the magnitude of the compensatory curve decreased in three cases. In this case, data shown in Table 3 revealed that that after 12 months without wearing a brace, the compensatory curve of patients, on average, had returned to nearly the previous compensatory curve value, that is, correction occurs despite the presence of an orthosis, but when the trunk orthosis was removed, the correction disappeared (p = 0.683). In one patient, due to the non-observance of the mode of using the functional corrective trunk orthosis (according to the wearing sensor, the child wore the orthosis for 2–3 h/day) after 5 months, a significant progression of the compensatory curve was noted, which was the reason for the repeated surgery to increase the length of hardware fixation and the inclusion of a compensatory curve in it.

Data generally indicate positive results of the use of functionally corrective orthoses on the trunk throughout the year to stop the progression and reduce the magnitude of compensatory curves of deformity, provided that they are worn within 16–20 h per day.

Table 3. Magnitude of Cobb compensatory curves for thoracic and lumbar localizations after surgery and at various stages of orthotics

Localization of the secondary curve	Magnitude of the secondary curve after surgery and at various stages of orthotics (degrees)						
	After surgery without a brace	After surgery and wearing of a brace for 3 months	Significance level of differences* (p)	After surgery and wearing of a brace for 6 months	Significance level of differences* (p)	After surgery and 12 months without wearing brace	Significance level of differences* (p)
Thoracic region	15.5 ± 4.5 (8 to 26)	9.0 ± 4.2 (2 to 17)	0.001	6.1 ± 2.1 (2 to 10)	0.001	8.9 ± 3.1 (2 to 20)	0.005
Lumbar region	11.2 ± 4.5 (3 to 19)	5.7 ± 3.2 (1 to 15)	0.007	4.6 ± 1.8 (1 to 14)	0.002	12.2 ± 6.3 (3 to 37)	0.683

* The significance of the differences in the magnitude of the secondary curve was determined in comparison with the indicators measured after surgery without a brace.

All pediatric patients are still under active dynamic supervision, which is planned to be conducted until the end of the period of bone growth.

Clinical case. In a pediatric patient V (6 years old) with congenital kyphoscoliosis of the posterolateral semivertebra L_2, a functionally corrective brace was placed on the trunk 5 days after the surgical treatment. On radiographs of the spinal column before surgery (Fig. 4) focused on the posterolateral semivertebra at the level of L_2 with deformity angles, the lumbar left-sided local scoliotic curve at the semivertebra level was 36°, and the right-sided thoracic secondary curve was 30°. The magnitude of the local and thoracic kyphosis is 23° and 51°, respectively, according to the Cobb method.

Radiographs after surgical treatment showed a radical correction of the local congenital deformity of the thoracic spine, and the hardware position was correct and stable. The right-sided scoliotic compensatory curve at the level of the Th_{11}–Th_7 was 18°.

The results of orthosis are presented in Fig. 5. Radiographs obtained after 6 months of wearing the functional spinal brace revealed the stable hardware position in the thoracic region, with the right-sided compensatory curve correction at the level of the vertebrae Th_{11}–Th_7 up to 6°.

On radiographs obtained after 12 months without a brace, the position of the hardware in the thoracic region is stable. There is no loss of the achieved deformity correction in comparison with the period of orthosis at month 6, with right-sided scoliotic curve at Th_{11}–Th_7 of 10° according to the Cobb method. In this patient, during the surgical intervention, the local congenital deformity curve can be corrected completely, by fixing the minimum number of spinal motion segments and reducing the value of the compensatory curve. The use of a functionally corrective orthosis after the surgery enabled not only to achieving stabilization of the secondary curve, but also correcting its value. The child still uses a brace and will be under active follow-up every 3 months until the end of the bone growth period.

Fig. 4. Radiographs of the spine in two views of patient V (6 years old). Congenital kyphoscoliosis can be seen on the background of the posterolateral semivertebra L_2, after surgical treatment

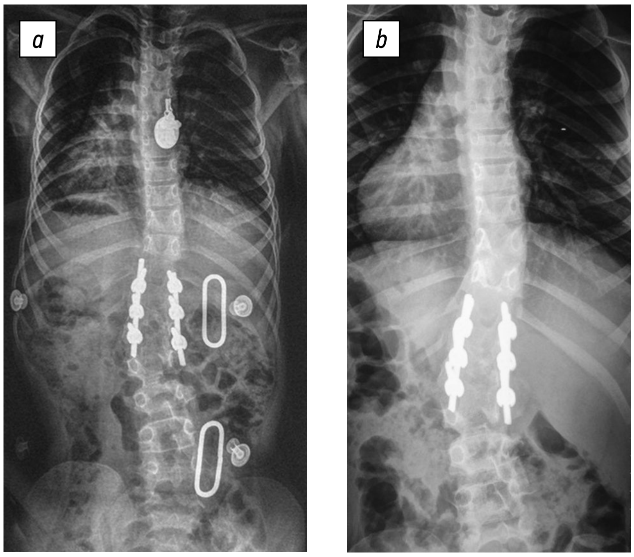

Fig. 5. Radiographs of the spine of a 6-year-old patient. Congenital kyphoscoliosis is observed on the background of the posterolateral semivertebra L_2: *a* — after 6 months in a functional spinal brace; *b* — after 12 months in the upright position without the brace

DISCUSSION

Currently, with progressive congenital kyphoscoliosis, surgical treatment is mainly performed at an early age, which consists in the removal of an abnormally developed vertebra with fixation of a minimum number of spinal motion segments. Many experts tended to believe that the residual compensatory curves in the process of child's growth will progress, following a dysplastic course [15, 16]. In such cases, for a full correction of the main and compensatory curves, hardware fixation should be more extended owing to the presence of compensatory curves. This approach implies multiple surgical interventions during periods of the most active growth spurts and, of course, will slow down the growth rate of the patient's spine segments and imbalances [2].

Some international clinics use a different approach to the treatment of compensatory curves developing above or below the established hardware, namely, orthosis of the trunk with functionally corrective braces. Kaspiris et al. performed the most comprehensive study of the long-term results of conservative and surgical treatment of congenital scoliosis [10]. They recommended using orthoses to prevent secondary deformities that develop above or below the abnormal vertebra; in these cases, orthosis can be continued until the completion of bone growth. Our study supports this approach. Yang et al. [18] considered the occurrence of secondary S-shaped scoliosis in nine patients with various congenital isolated abnormalities of the cervical vertebrae. The average patient age was 11.4 years. The average preoperative deformity was 36.1° ± 14.4°, and after surgical treatment, it was up to 6.9° ± 6.1° ($p < 0.001$). Compensatory scoliosis, in which progression can be compared with adolescent idiopathic scoliosis, appeared within 3 months (4 patients) and within 6 months (5 patients) after the initial surgery with a mean angle of 42.6° ± 12.9°. All nine patients used orthosis, and 4 (44%) of these patients underwent surgical removal of the secondary curves. In this study, only 1 of 25 pediatric patients with orthopedic disorders required removal of the secondary curve within 1 year after surgical treatment of the semivertebrae in the thoracic and lumbar spine.

Only a few studies have demonstrated the mode of using orthoses in the postoperative period. Thus, after removal of the semivertebra in the lumbar spine, King and Lowery [19] indicated that patients used plaster casts or orthoses for 6 months, including in the supine position for the first 6–12 weeks. However, we did not use such approach. Our patients were verticalized immediately after the orthosis was applied, and after a period of getting used to it, they used it for 16–20 h per day.

The Russian scientific literature presents only one report about a clinical case of the successful use of a functionally corrective trunk orthosis in a child with congenital spinal deformity after surgical treatment [20]. In this paper, the annual results of orthosis for 25 patients were presented.

According to our data, after 1 year of wearing functional corrective orthoses, lumbar compensatory curves are more difficult to correct or stabilize than thoracic compensatory curves. In general, in this group of patients, the radiographs obtained without an orthosis revealed a return to the initial values of the scoliotic curve deformity after 12 months of wearing it. This is due to the anatomical and physiological aspects of the lumbar spine and its mobility compared with the thoracic segment, which is confirmed by Dubousset in pediatric patients with idiopathic scoliosis [21].

CONCLUSION

Following radical surgical treatment in a group of patients with congenital kyphoscoliosis, it was possible to correct the local deformity, restore the sagittal profile, and reduce the compensatory curve value. Fixation of the minimum number of spinal motion segments of the spinal column at the level of the abnormally developed vertebra provided favorable conditions for the further growth of the child, while maintaining the mobility of significant spine segments. Owing to the use of functional corrective orthoses on the trunk in the structure of the complex treatment of pediatric patients with congenital spinal deformities, the progression of compensatory curves during the child's growth can be stopped, and they were even corrected completely in some patients without additional staged surgical interventions.

Follow-up of the use of braces within 1 year revealed that they had a stabilizing and corrective effect on the compensatory curve. In the course of the study, correction of compensatory curves in the thoracic spine was more efficient than that in the lumbar spine. We understand that follow-up of patients 1 year after the surgery does not allow making a final conclusion, so this study must be extended. However, early results are promising. Despite the arrest of progression and, in some cases, a decrease in the magnitude of the compensatory curve deformity, all patients should continue to wear functionally corrective orthoses until the completion of bone growth.

ADDITIONAL INFORMATION

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Author contributions. *I.A. Redchenko* collected and analyzed data, reviewed the literature, performed orthotics for patients, and wrote the text of the article. *S.V. Vissarionov* performed surgical treatment of patients, formulated aims and objectives, and performed staged and final editing of the text. *M.G. Gusev* created the article design, performed the data analysis, and edited the text. *G.A. Lein* and *I.V. Pavlov* performed orthotics for the patients and collected and analyzed the data.

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ОБ АВТОРАХ

***Игнатий Александрович Редченко**, аспирант;
адрес: Россия, 195253, Санкт-Петербург, ул. Стасовой д. 1 лит. Б;
ORCID: https://orcid.org/0000-0001-6055-6295;
eLibrary SPIN: 2072-1986; AuthorID: 1004672;
e-mail: ria@scoliologic.ru

Сергей Валентинович Виссарионов, д-р мед. наук, профессор, член-корр. РАН;
ORCID: https://orcid.org/0000-0003-4235-5048;
eLibrary SPIN: 7125-4930;
e-mail: vissarionovs@gmail.com

Максим Геннадьевич Гусев, канд. мед. наук;
ORCID: https://orcid.org/0000-0002-7976-0795;
eLibrary AuthorID: 863901;
e-mail: llp@scoliologic.ru

Григорий Аркадьевич Леин, канд. мед. наук;
ORCID: https://orcid.org/0000-0001-7904-8688;
eLibrary AuthorID: 863879;
e-mail: lein@scoliologic.ru

Иван Викторович Павлов, канд. мед. наук;
ORCID: https://orcid.org/0000-0002-0412-6351;
eLibrary AuthorID: 863900;
e-mail: johnkorset@yandex.ru

AUTHOR INFORMATION

***Ignatiy A. Redchenko**, MD, PhD Student;
address: 1B Stasovoj str., Saint Petersburg, 195253, Russia;
ORCID: https://orcid.org/0000-0001-6055-6295;
eLibrary SPIN: 2072-1986; AuthorID: 1004672;
e-mail: ria@scoliologic.ru

Sergei V. Vissarionov, MD, PhD, D.Sc., Professor, Corresponding Member of RAS;
ORCID: https://orcid.org/0000-0003-4235-5048;
eLibrary SPIN: 7125-4930;
e-mail: vissarionovs@gmail.com

Maxim G. Gusev, MD, PhD;
ORCID: https://orcid.org/0000-0002-7976-0795;
eLibrary AuthorID: 863901;
e-mail: llp@scoliologic.ru

Grigoriy A. Lein, MD, PhD;
ORCID: https://orcid.org/0000-0001-7904-8688;
eLibrary AuthorID: 863879;
e-mail: lein@scoliologic.ru

Ivan V. Pavlov, MD, PhD;
ORCID: https://orcid.org/0000-0002-0412-6351;
eLibrary AuthorID: 863900;
e-mail: johnkorset@yandex.ru