DOI: https://doi.org/10.17816/vto109921

The use of the apparatus of an intelligent system with biofeedback in the evaluation of preoperative preparation of a patient with type I diastematomyelia: clinical case

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ABSTRACT

BACKGROUND: Diastematomyelia is a rare congenital anomaly of the spinal cord, characterized by its cleavage in the spinal canal, which can be combined with spinal deformity. When correcting scoliotic deformity, patients with this anomaly have a high risk of developing neurological disorders due to its fixation. Therefore, its preliminary mobilization surgically is necessary. In the upcoming corrective surgery, an important role is also played by preoperative halo-traction training in combination with therapeutic physical culture.

CLINICAL CASE DESCRIPTION: A clinical case of the use of the «Tergumed 3D» intelligent biofeedback system in assessing the effectiveness of preoperative halo-gravity traction in combination with mobilizing therapeutic physical culture in a patient with complex spinal deformity against the background of congenital malformation (type I diastematomyelia) to prepare for surgical correction is presented.

CONCLUSION: The results of this study suggest that the combination of physical therapy and halo-traction can be effectively used for preoperative preparation of patients with rigid scoliotic deformities and spinal anomalies. It help analyze preoperative preparation in patients with congenital spinal deformities.

Keywords: diastematomyelia; halo-traction; physical therapy; «Tergumed 3D».

To cite this article:
Kolesov SV, Tsykunov MB, Bagirov SB, Semenduev SV, Morozova NS. The use of the apparatus of an intelligent system with biofeedback in the evaluation of preoperative preparation of a patient with type I diastematomyelia: clinical case. *N.N. Priorov Journal of Traumatology and Orthopedics.* 2022;29(2):161–172. DOI: https://doi.org/10.17816/vto109921

Received: 26.08.2022 **Accepted:** 27.09.2022 **Published:** 29.11.2022

DOI: https://doi.org/10.17816/vto109921

Применение аппарата интеллектуальной системы с биологической обратной связью в оценке предоперационной подготовки пациентки с диастематомиелией I типа: клинический случай

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АННОТАЦИЯ

Обоснование. Диастематомиелия — это редкая врождённая аномалия спинного мозга, характеризующаяся его расщеплением в позвоночном канале, которая может сочетаться с деформацией позвоночника. При проведении коррекции сколиотической деформации у пациентов с этой аномалией высок риск развития неврологических нарушений в связи с его фиксацией, поэтому необходима предварительная его мобилизация хирургически. В предстоящей корригирующей операции немаловажную роль также играет предоперационная галотракционная подготовка в сочетании с лечебной физической культурой.

Описание клинического случая. Представлен клинический случай применения аппарата интеллектуальной системы с биологической обратной связью «Tergumed 3D» в оценке эффективности предоперационной галогравитационной тракции в комбинации с мобилизирующей лечебной физической культурой у пациентки со сложной деформацией позвоночника на фоне врождённой аномалии развития (диастематомиелии I типа) для подготовки к оперативной коррекции.

Заключение. Использование этого аппарата позволяет предположить, что комбинация лечебной физической культуры и галотракции может быть эффективно применена для предоперационной подготовки пациентов с ригидными сколиотическими деформациями и аномалиями позвоночника. Его применение помогает анализировать предоперационную подготовку у больных с врождёнными деформациями позвоночника.

Ключевые слова: диастематомиелия; галотракция; лечебная физическая культура; «Tergumed 3D».

Как цитировать:
Колесов С.В., Цыкунов М.Б., Багиров С.Б., Семендуев С.В., Морозова Н.С. Применение аппарата интеллектуальной системы с биологической обратной связью в оценке предоперационной подготовки пациентки с диастематомиелией I типа: клинический случай // Вестник травматологии и ортопедии им. Н.Н. Приорова. 2022. Т. 29, № 2. С. 161–172. DOI: https://doi.org/10.17816/vto109921

Рукопись получена: 26.08.2022 **Рукопись одобрена:** 27.09.2022 **Опубликована:** 29.11.2022

BACKGROUND

Diastematomyelia is a rare congenital spinal cord anomaly characterized by splitting in the spinal canal along one or more vertebrae and being divided into two columns by an osseous (type I) or fibrous (type II) septum (spur) [1, 2]. The septum can be isolated or combined with other congenital spinal abnormalities such as *spina bifida*, kyphoscoliosis, hemivertebrae, and butterfly vertebrae. The prevalence of congenital spinal deformities ranges from 0.5 to 1 case per 1000 newborns [3, 4], with diastematomyelia diagnosed in 5% of children with congenital scoliosis [5]. If a scoliotic deformity must be corrected in a patient, there is a high risk of neurological disorders due to spinal cord traumatization caused by fixation at the septum or in the caudal regions [6]. As a result, preliminary mobilization of the spinal cord is required by removing this spur. Let us look more closely at the combined defect, diastematomyelia, with kyphoscoliosis. According to some authors, preoperative halo-traction preparation is a well-tolerated and relatively safe procedure in the next-generation corrective surgery for severe kyphoscoliotic spinal deformity [7, 8]. Exercise therapy (ET) methods are used in the preoperative preparation of patients with scoliotic spine deformity to reduce the risk of complications in the early postoperative period and to increase the patient's overall rehabilitation potential [9–11].

The following is a clinical case of surgical treatment of a patient with severe kyphoscoliotic deformity associated with a congenital anomaly, type I diastematomyelia. In conjunction with ET, dosed halo-gravitational traction was used in sitting in a chair and standing in a walking frame during preoperative preparation. We also used mobilizing gymnastics with stretching exercises, hanging (the patient's hanging position), back strengthening of the extensor muscles, and breathing exercises. Classes were held according to an individual program, with an ET instructor-methodologist in the gym. In addition, we used the Tergumed 3D (BEKO, Germany), an intelligent system with biofeedback, to evaluate the preparation, which measures the amplitudes of spinal movements and the static strength of the muscles involved. According to the literature, such devices are primarily used for lumbar pain training and [12–15] to study muscle imbalance in scoliotic deformities [16, 17], but we did not find any studies that included a combination of halo-traction and ET with subsequent measurement mobility on the device with biofeedback for preoperative preparation of patients for scoliotic deformity correction.

CLINICAL CASE

Patient S.A., 22 years old, was admitted to the N.N. Priorov National Medical Research Center of Traumatology and Orthopedics (Moscow) in the spring of 2022 with complaints of kyphoscoliotic spine deformity, recurrent back pain without irradiation up to 7 points on the visual analog scale (VAS). According to the patient, her parents first noticed her spinal deformity when she was three years old. The maximum progression of scoliosis was observed at the age of ten years. Courses of conservative treatment (ET, physiotherapy, acupuncture, and massage) and corseting were performed at Tajikistan's primary healthcare facility, but the deformity steadily worsened. The primary healthcare facility refused surgical treatment. At 16, the patient was diagnosed with a congenital malformation of the spine and spinal cord, concrescence of the vertebral bodies Th_{VII}–$_{VIII}$, type I diastematomyelia at the level of the vertebra Th_{VIII}, and tethered spinal cord syndrome. The patient's parents sought medical attention at one of Russia's clinics, where it was decided to perform surgical treatment consisting of an osteoplastic laminectomy of Th_{VII}–Th_{IX}, removal of the osseous septum of the spinal canal at the level of Th_{VIII}, laminectomy at the level of the vertebrae L_V–S_{III}, transection of the terminal filament, and implantation of pedicle screws at the level of the vertebrae Th_{VIII}–Th_X. As a result, the parents refused to continue treatment at this clinic and sought medical attention elsewhere. The patient was also examined, and type I diastematomyelia was discovered at the vertebrae Th_{XI}–Th_{XII}. Surgery was performed, including resection laminotomy of Th_{XI}–Th_{XII}, resection of the osteofibrous septum of the spinal canal at this level with the elimination of spinal cord fixation and dismantling of screws. Unfortunately, the kyphoscoliotic deformity was not corrected. The patient was released for outpatient aftercare. She was regularly engaged in ET at the primary healthcare facility, but she noticed the emergence of pain syndrome and an increase in the deformity angle. She applied to our institution in April 2022.

Postural spondylograms revealed left-sided thoracolumbar degree IV kyphoscoliosis, with a scoliotic deformity angle of 70° in the thoracic region, 90° in the lumbar region, local kyphosis angle of 73° in the thoracolumbar transition, and 5.7 cm of negative sagittal imbalance (SVA, sagittal vertical axis) (Fig. 1).

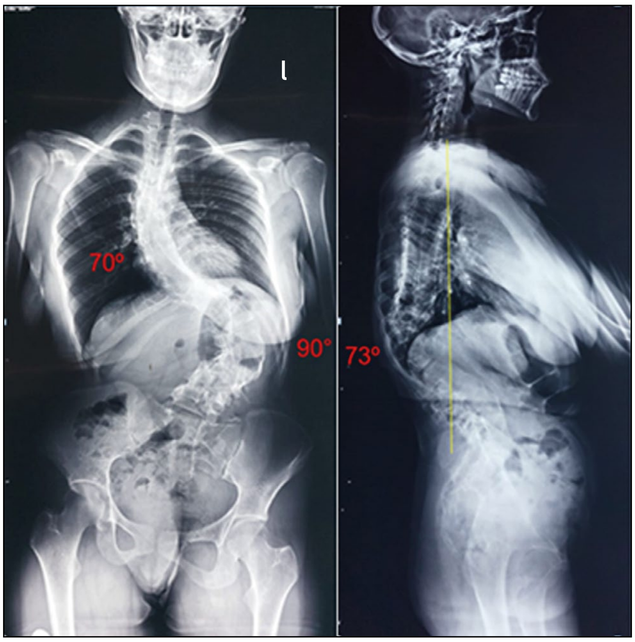

Fig. 1. Postural spondylograms upon admission.

During the preoperative planning stage, the patient underwent a traction test, and the magnitude of the deformity angles was corrected to 53°, 73°, and 64°, respectively. The thoracic mobility index (MI) was 0.76, the lumbar mobility index (MI) was 0.81, and the local kyphosis index was 0.88. A CT scan was also performed, from which a 3D spine model was printed, and areas of previous surgical interventions (laminectomy) were visualized, where potentially high risks of dural membrane damage when approaching posterior elements existed (Fig. 2).

Because of the severity of the deformity, its rigidity, the revision of the surgical intervention, and the high risk of neurological complications with simultaneous correction, it was decided to perform preoperative halo-gravitational traction in a chair and a walking frame in conjunction with mobilizing ET at stage 1, and interventions to correct and stabilize the spine at stage 2. Traction was established in the chair at a sitting posture the next day after the halo ring was installed. After 3 days, dosed halo-traction was added in a walking frame. From the first day following ring installation, the patient began to visit the gym, where ET sessions were performed according to an individual program to mobilize the spine, increase muscle strength of the back extensor muscles, and improve the functions of external respiration. There were 28 days of traction, with 12 ET sessions. The patient was checked daily for neurological traction complications. After preoperative halo-gravitational preparation and ET, a traction test of the spine was performed again, and the magnitude of scoliotic curves decreased to 45° (MI=0.64) in the thoracic region and 68° (MI=0.76) in the lumbar region, whereas local kyphosis decreased up to 58° (MI=0.79; Fig. 3).

A study was conducted using an intelligent system apparatus with biofeedback on the day after the halo ring installation and the day before stage 2 of the surgery to assess the parameters of muscle strength and spine mobility (Figs. 4, and 5; tables 1, 2).

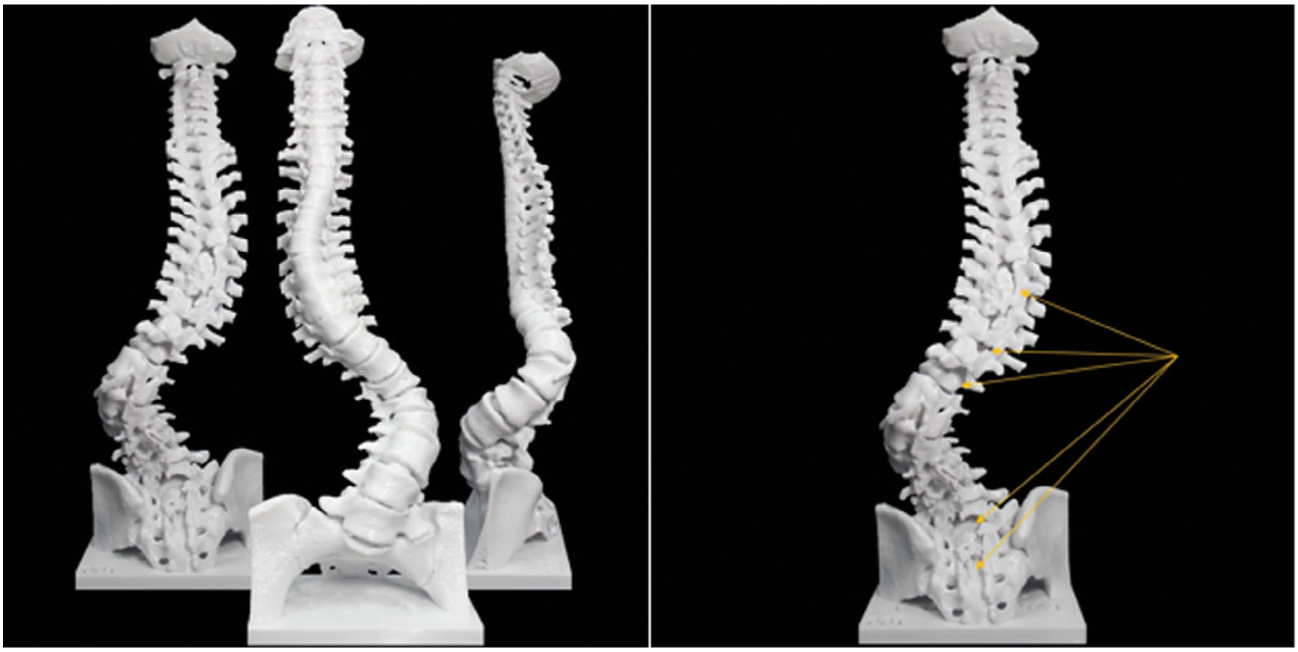

Fig. 2. 3D model of the patient's spine (rear view). Depicted as preoperative planning. The arrows depict defects in the posterior elements of the spine.

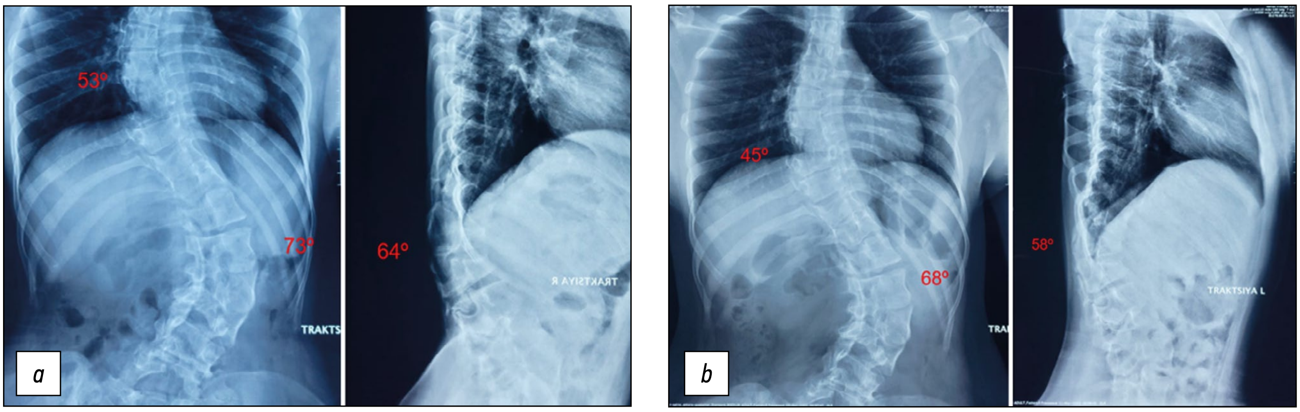

Fig. 3. Functional radiographs of traction tests (*a*) before the preoperative preparation and (*b*) after its completion in 28 days.

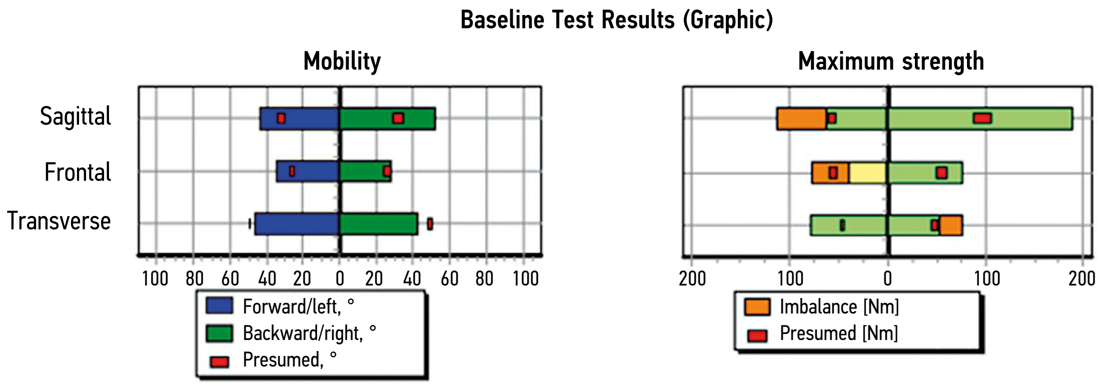

Fig. 4. Research results at the beginning of preoperative preparation (screenshots from the program).

Table 1. Research results at the beginning of preoperative preparation (screenshot from the program)

Test program	
Parameter	**Value**
Repetitions (maximum strength)	3
Pause between repetitions, s	10
Repetition time, s	7
Repetitions (Mobility)	3
Execution mode	Bilateral synchronous

Mobility Test Results

	Angle, °								Imbalance		
Plane	**Motion**	**Presum.**	**Meas.**	**%**	**Motion**	**Presum.**	**Meas.**	**%**	**[°]**	**%**	**[°]**
Sagittal	Abd. flex.	32	43	135	Back ext.	32	53	166	10	19	–
Frontal	Later. flex.	26	35	135	Later. flex.	26	29	111	–	17	6
Transverse	Torso rotat.	49	46	94	Torso rotat.	49	43	88	–	7	3

Maximum Strength Test Results

	Rotation moment [Nm]								Imbalance		
Plane	**Direction**	**Presum.**	**Meas.**	**%**	**Direction**	**Presum.**	**Meas.**	**%**	**[Nm]**	**%**	**[Nm]**
Sagittal	Forward	58	63	109	Backward	97	190	197	51	45	–
Frontal	Left	55	40	73	Right	55	78	141	38	49	–
Transverse	Left rotation	48	78	163	Right rotation	48	55	115	–	29	23

The amplitude of spinal movements and static force during the procedures were measured in the sagittal, frontal, and axial planes. As a result of preoperative preparation, the changes were noted, namely in the sagittal plane, an increase in the amplitude of spine flexion by 2° (5% more than the initial value) with a decrease in extension by 3° (11% less than the initial one). The tilt range to the right increased by 7° (a 27% increase in mobility), while the tilt range to the left increased by 2° (an increase by 9%). Rotations in the axial plane increased significantly, increasing by 28° (57%) to the right and 31° (64%) to the left. The results show an increase in the amplitude of spine motion in all directions except extension, with differences of more than 50% in the axial plane. The static strength of the muscles involved in spine flexion increased by 20 Nm (32%), while extension increased by 10 Nm (10%). When bending to the right, muscle strength increased by 27 Nm (49%) and by 42 Nm (76%) when bending to the left. Muscle strength increased by 21 Nm (43%) during the right rotation and 11 Nm (22%) during the left rotation. The findings show increased muscle strength in all directions of spine movement, even during extension, where volume was found to be reduced. This demonstrates the effectiveness of ET methods in strengthening the extensor muscles of the back and the rotator muscles of the spine (lateral and medial lumbar intertransverse muscles, lumbar multifidus muscle, long and short rotator muscles of the lower back, multifidus muscles of the lower back, spinalis thoracis, quadratus lumborum) as well as the abdominal muscles (rectus abdominis, external and internal oblique abdominal muscles).

The surgery was carried out with 6 kg of intraoperative halo-traction and intraoperative neuromonitoring.

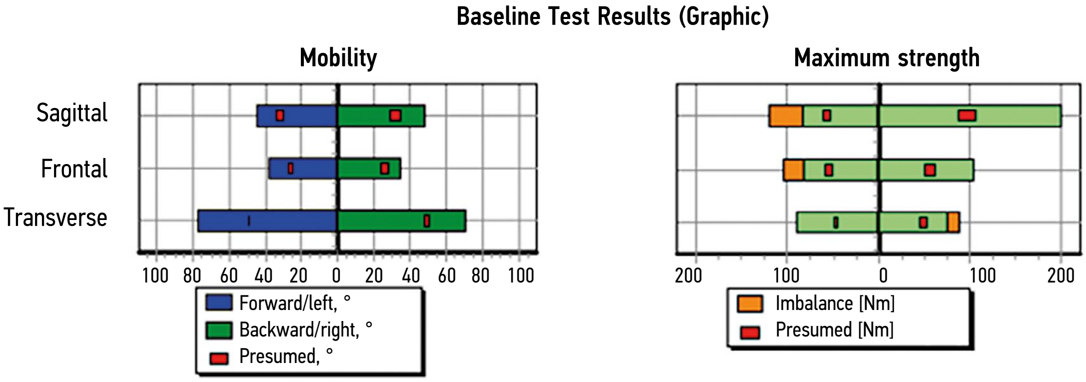

Fig. 5. Research results after a course of physical therapy and halo-traction (screenshots from the program).

Table 2. Research results after a course of physical therapy and halo-traction (скриншот из программы)

Test program	
Parameter	**Value**
Repetitions (maximum strength)	3
Pause between repetitions, s	10
Repetition time, s	7
Repetitions (Mobility)	3
Execution mode	Bilateral synchronous

Mobility Test Results

	Angle, °								Imbalance		
Plane	**Motion**	**Presum.**	**Meas.**	**%**	**Motion**	**Presum.**	**Meas.**	**%**	**[°]**	**%**	**[°]**
Sagittal	Abd. flex.	32	45	140	Back ext.	32	50	155	5	10	–
Frontal	Later. flex.	26	37	144	Later. flex.	26	36	138	–	3	1
Transverse	Torso rotat.	49	77	158	Torso rotat.	49	71	145	–	8	6

Maximum Strength Test Results

	Rotation moment [Nm]								Imbalance		
Plane	**Direction**	**Presum.**	**Meas.**	**%**	**Direction**	**Presum.**	**Meas.**	**%**	**[Nm]**	**%**	**[Nm]**
Sagittal	Forward	58	83	143	Backward	97	200	207	37	31	–
Frontal	Left	55	82	149	Right	55	105	190	23	22	–
Transverse	Left rotation	48	89	185	Right rotation	48	76	158	–	15	13

A posterior median incision was used to gain access to the surgical area. At the T_{III}–L_V level, the spine was corrected and stabilized with metal structures, and posterior spinal fusion with autogenous bone was performed. The total amount of blood lost was 1100 ml. The postoperative wound was healed by primary intention. On the control postural spondylograms, there was a satisfactory correction of scoliotic deformity of the thoracic region (45°), lumbar spine (66°), and local kyphosis at the level of the thoracolumbar transition (36°); the sagittal balance of the spine was significantly improved, the imbalance was leveled, SVA = 0 cm (Fig. 6). The visual improvement in the back profile was also recorded (Fig. 7).

DISCUSSION

Most authors agree that treating severe kyphoscoliotic spinal deformity is always difficult and fraught with neurological complications. Three-column osteotomy has been used as a standard surgical technique for several decades, according to Bo Shi et al. [18]. It can, however, cause serious complications such as spinal cord injury and the development of neurological deficits up to plegia. According to Rinella et al. [7], rapid correction of severe scoliosis may increase the risk of neurological complications, particularly if there is a significant kyphotic component. Furthermore, as in our patient, a history of intraspinal pathology or previous spinal surgery increases the risk of neurological deficit after spinal stabilization.

According to Qiao et al. [19], the three-column vertebral osteotomy had favorable results in treating severe kyphoscoliosis, but with a high rate of perioperative complications of about 30.3%.

In contrast, Kandwal et al. [20] maintain in their report that the key to correcting severe kyphoscoliosis is still three-column vertebrectomy, which provides 360° mobilization

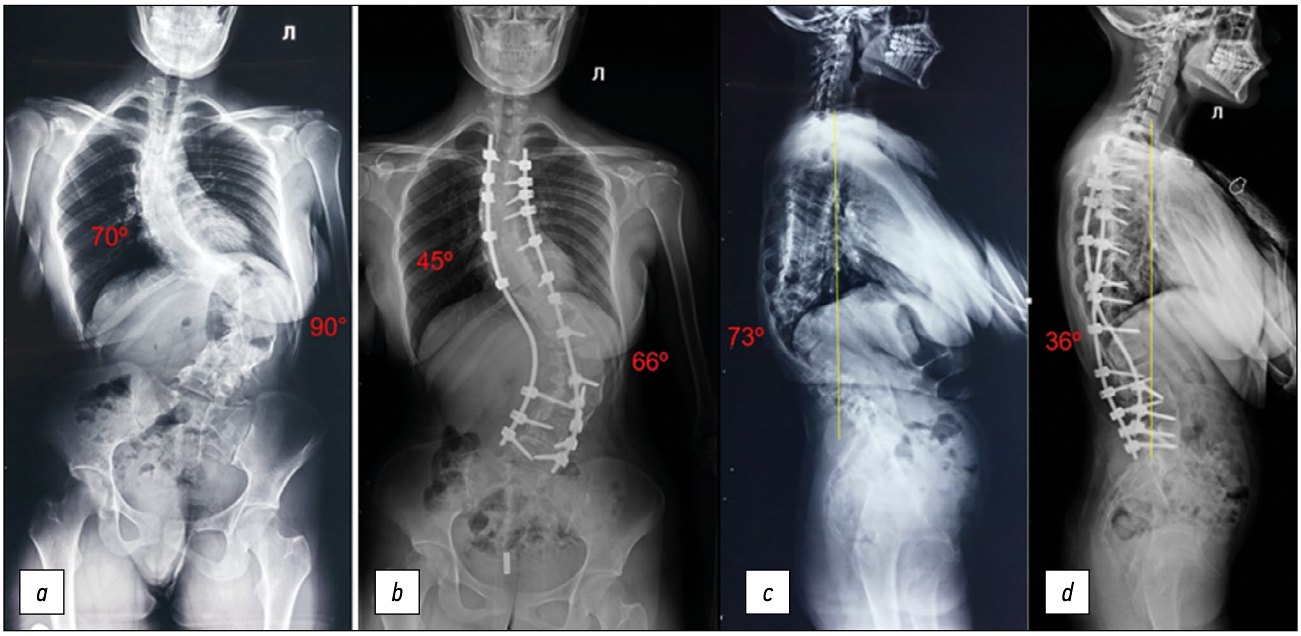

Fig. 6. Postural spondylograms in 2 projections (*a*, *b*) before surgery and (*c*, *d*) after.

of the spinal column, despite the role of spinal osteotomy and approach of surgical correction. However, they agree that this lengthens the surgery and increases the risk of neurological deficits and complications due to significant blood loss. Although the role of the anterior release has faded insignificantly over the last decade, they believe the issue is still debatable.

According to Mehrpour et al. [21], the combined anterior and posterior technique is a classic treatment for severe rigid scoliosis, but it is associated with a significant risk of morbidity and mortality. Furthermore, they note that posterior access improves lung function more than open or endoscopic anterior releases, particularly in patients with compromised respiratory function. Additional anterior technique lengthens the operating time, increases surgical trauma, and lengthens the inpatient stay. Surgeons use various techniques, including halo-gravitational traction, to reduce these risks. Several reports in the literature describe the successful correction of severe spinal deformities with halo-femoral, halo-pelvic, and halo-gravity traction.

McIntosh et al. [22] advocate halo-gravitational traction and report that it can eliminate the need for multiple

Fig. 7. The appearance of the patient (*a*, *b*) before the operation and (*c*, *d*) after.

segmental osteotomies or spinal column resection, lowering the neurological risk for these patients.

Yang et al. [23] performed a meta-analysis on halo-gravitational traction in treating severe spinal deformity. The authors concluded that halo-gravitational traction could be used as an additional method in the surgical treatment of severe spinal deformity. This is supported by the fact that in the analyzed material in patients with halo-gravitational traction, the average volume of intraoperative blood loss was 1521.6 ml, and the prevalence of neurological deficit was 1%, which was lower than in patients with a three-column osteotomy (2012 ml and 5% for PSO; 2737 ml and 4% for VCR). They also stressed that surgical treatment of severe spinal deformity remains difficult despite significant technological advances and modern equipment. However, the use of halo-gravitational traction is still debated by experts because the extent of correction that can be achieved using halo-gravitational traction is unknown due to inconsistencies revealed in the literature. However, this suggests that halo-gravitational traction can improve the patient's preoperative nutritional status and pulmonary function, and that gradual traction can also help reduce the risk of neurological complications during surgery.

Two meta-analyses also show that halo-traction training improves the respiratory function and nutritional status of patients in this cohort. Yang et al. [24] examined seven studies involving 189 patients who received halo-gravitational traction therapy prior to surgery and concluded that it improves the degree of deformity and lung function in patients with severe scoliosis. Furthermore, halo-gravitational traction is an effective method for increasing perioperative patient tolerance to surgical intervention. Wang et al. [25] confirmed these findings by conducting a meta-analysis of 12 studies involving 372 patients and concluding that halo-traction improves lung function and nutritional status, reduces the risk of overcorrection-induced neurological damage, and may aid in the partial correction of spinal deformity.

Corrective ET can also be used to reduce spinal deformity and improve quality of life, according to the findings of a systematic review and meta-analysis by Gámiz- Bermúdez et al. [26]. The authors reached this conclusion after reviewing 7 randomized controlled trials involving 236 patients.

In our opinion, using halo-traction in conjunction with ET helps to improve the functional state of the patient prior to spine surgery. Our department's experience indicates that patients who received preoperative halo-traction and ET adapt quickly during the postoperative period. However, how can the outcomes of such training be assessed? In everyday practice, specialists must rely on various functional tests performed using radiation research methods, such as bending tests and spine traction tests, to assess the mobility of the deformity. These research methods only determine the magnitude of the deformity angle and its mobility in the frontal plane, but they provide no information on the functional state of the spinal muscles, range of motion in three planes, muscle strength, or the effectiveness of preoperative preparation.

There are few reports on the use of intelligent system devices with biofeedback. Only three articles were found in the PubMed database, and none were about assessing the range of motion and muscle strength of patients with spinal deformities. One study used an intelligent system rehabilitation apparatus to assess isometric strength and muscle imbalance in lumbar pain patients [27]. Wilczyński et al. discovered that therapy on the Tergumed 700 system increased the strength of the lumbopelvic complex muscles, compensating for their imbalance, and was beneficial in treating osteochondrosis. The Tergumed rehabilitation device was used to directly assess the isometric strength of the spinal muscles in two other articles [28, 29].

The use of an intelligent system with biofeedback enabled the assessment of the initial muscle condition and range of motion in a patient with severe spinal deformity, as well as the results of preoperative preparation for the upcoming surgical correction of spinal deformity, in the clinical case demonstrated. Due to the scarcity of methods for assessing the functional state of the muscles involved in the spinal movement, the use of an intelligent biofeedback system in patients with severe deformities should be investigated further.

CONCLUSION

Our findings suggest that the combination of ET and halo-traction methods can be used effectively for preoperative preparation of patients with rigid scoliotic deformities and spinal anomalies to improve the results of surgical intervention, reduce the risk of postoperative complications, and increase the patients' rehabilitation potential. An intellectual system with biofeedback apparatus can assess preoperative preparation in patients with congenital spinal deformities. Further research and expansion of indications for the use of the device on a larger sample of patients, in our opinion, is required.

ADDITIONAL INFO

Author contribution. Thereby, all authors made a substantial contribution to the conception of the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Funding source. Not specified.

Competing interests. The authors declare that they have no competing interests.

Consent for publication. Written consent (signed in May, 2022) was obtained from the patient for publication of relevant medical information and all of accompanying images within the manuscript.

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