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Two-stage surgical treatment of large and rigid spinal deformities (anterior mobilization of the curvature and posterior instrumentation of the spine)

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The choice of method of surgical treatment of large and rigid spinal deformities remains debatable. Objective. To evaluate the results of two-stage surgical treatment of large and rigid spinal deformities (anterior mobilization of the curvature and posterior instrumentation of the spine). Methods. Seventeen patients, the average age of which was 17.7 years (from 12 to 38 years), the average follow-up period was 36 months. Distribution of patients by etiology: 13 — idiopathic scoliosis, 2 — neurofibromatosis, and 2 — congenital kyphoscoliosis. All patients underwent two-stage surgical treatment (anterior mobilization of the curvature and posterior correction of the deformity), evaluation of the results of correction and complications was performed retrospectively. Results. The average deformation of the spine in the frontal plane before the operation was 103° ± 10° according to Kob (from 90° to 126°), after the anterior mobilization — 85° ± 8° (from 74° to 104°), which is (17.6 ± 3.3) % of correction (from 13.7 to 24.5 %), and at the time of completion of the posterior correction of the deformity — 40° ± 22° (from 2° to 78°), in percentage terms it amounted to (62.1 ± 20.61) % correction (from 19.6 to 97.8 %). Statistical significance according to the T-criterion had the following indicators: 63.4 ± 19.6 (M ± SD); t = 13.344; p = 0.001. Conclusions. Two-stage surgical treatment of large and rigid spinal deformities is a modern technique for achieving spinal deformity correction and obtaining the desired cosmetic result. Carefully performed anterior mobilization with the subsequent use of the system of stretching the patient in bed, allows to increase the mobility of the spine and gradually adapt the tissues and spinal cord to the next posterior correction of the spine, which significantly reduces the risks of neurological complications, as well as obtaining the most satisfactory correction results.

Вибір методики хірургічного лікування великих і ригідних деформацій хребта залишається дискутабельним питанням. Мета. Оцінити результати двохетапного хірургічного лікування великих і ригідних деформацій хребта (передньої мобілізації викривлення та задньої інструментації хребта). Методи. У дослідження включено 17 пацієнтів, середній вік 17,7 років (від 12 до 38), середній термін спостереження 36 міс. Розподіл осіб за етіологією: 13 — ідіопатичний сколіоз, 2 — нейрофіброматоз і 2 — вроджений кіфосколіоз. Усім пацієнтам проведено двохетапне хірургічне лікування (передня мобілізація викривлення та задня корекція деформації). Ефективність корекції й ускладнення оцінено ретроспективно. Результати. Середня величина деформації хребта у фронтальній площині до операції склала 103° ± 10° за Коббом (від 90° до 126°), після проведення передньої мобілізації — 85° ± 8° (від 74° до 104°), що складає (17,6 ± 3,3) % корекції (від 13,7 до 24,5 %), а на час завершення задньої корекції деформації — 40° ± 22° (від 2° до 78°), у відсотковому значенні це склало (62,1 ± 20,61) % корекції (від 19,6 до 97,8 %). Статистична значущість за Т-критерієм мала такі показники: 63,4 ± 19,6 (M ± SD); t = 13,344; p = 0,001. Висновки. Двохетапне хірургічне лікування великих і ригідних деформацій хребта є сучасною методикою для досягнення їхньої корекції, а також отримання бажаного косметичного результату. Ретельно виконана передня мобілізація з подальшим використанням системи витягнення пацієнта в ліжку дає змогу збільшити мобільність хребта й поступово адаптувати тканини і спинний мозок до наступної задньої корекції хребта, що значно зменшує ризики неврологічних ускладнень, а також отримати максимально задовільні результати корекції. Ключові слова. Великі та ригідні деформації хребта, передня мобілізація хребта, корекція деформації хребта.

Keywords. Large and rigid spinal deformities, anterior mobilization of the spine, correction of spinal deformities

Introduction

Despite significant achievements in recent decades of modern spinal surgery in the treatment of kyphoscoliotic spinal deformities, the issue of surgical correction of large and rigid deformities remains quite debatable and weighty. The progression of spinal curvature depends on the age of its occurrence, the detected amount of deformation at the beginning of treatment, the maturity of bone growth and gender. However, even a timely visit to a doctor and treatment does not stop some deformities, which have a rather malignant rapid course and progression. Thus, scoliotic deformations of the spine that have reached 70° according to Cobb are considered large, and if their mobility is less than 30%, they are considered rigid [1]. Today, modern operating equipment (spinal navigation, neuromonitoring) and polysegmental spinal implants (transpedicular screws, hooks, and fixing rods) make it possible to freely correct 70° spinal deformities. In our study, by the term "large deformations", we mean spinal curvature of 90° according to Cobb and more, and the term "rigidity" remains unchanged. Significant deformations of the spine are not only cosmetic dissatisfaction, but also a rather significant adverse somatic component on the part of the cardiopulmonary system and internal organs, which already affects the quality and length of life.

Surgical treatment of severe spinal deformities is associated with a significant risk of developing gross neurological deficits, large blood loss, impaired respiratory function, as well as with the risk of complications due to implants (incorrect insertion of screws, fracture of rods, infectious complications, etc.). In addition, the question of the method of surgical treatment of such large and rigid deformations remains debatable [2]. Today, three main ones are used: a two-stage surgical treatment, when the patient first undergoes anterior mobilization of the main curvature of the spine followed by correction and posterior instrumentation of the spine. The second combines an element of previous long-term spinal halotraction with definitive posterior instrumentation. And the third is the implementation of one-moment correction of the spinal deformity due to the resection of the spinal column and posterior instrumentation. In our study, we evaluate a two-stage surgical treatment of large and rigid spinal deformities (anterior mobilization and posterior instrumentation of the spine), with a bed-extension system between the two treatment stages.

Purpose: to evaluate the results of two-stage surgical treatment of large and rigid spinal deformities (anterior mobilization of the curvature and posterior instrumentation of the spine).

Material and methods

The study was carried out within the scope of implementation of scientific research work at Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Sciences of Ukraine "To study the main errors and complications of transpedicular fixation in spine surgery and to develop measures for their prevention and treatment", state registration No. 0118U006949.

The study included 17 patients with large and rigid spinal deformities who were operated on at Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Sciences of Ukraine for the period from 2015 to 2021. The average follow-up period for patients was 36 months (from 24 to 72 months). The obtained results were evaluated retrospectively. The research was discussed and approved at the meeting of the Bioethics Committee at the State Establishment Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Sciences of Ukraine (Protocol No. 223 dated 20.12.2021).

All patients were required to undergo a standing x-ray of the spine in the sagittal and frontal planes, the mobility of the spine was assessed using functional x-rays in left and right tilts. The magnitude of the spine deformation angle was determined by the Cobb method (Fig. 1).

In order to determine the structure of the spine deformation, the size of the arches and the length of the vertebral bodies, to exclude any intracanal abnormalities of the spine, as well as for the further use of the obtained research result in conducting spinal navigation during the installation of transpedicular screws, all patients underwent computer tomography of the spine (Fig. 2).

All patients underwent surgery in two stages. First, anterior mobilization of the main curvature of the spine was performed: in the position of the patient on the side from the convex side of the spinal deformity, a standard thoracotomy was carried out (two patients had a thoraco-phreno-lumbotomy due to the thoracolumbar localization of the deformity). Mobilization of the spine included dissection of the anterior longitudinal ligament, total discectomy of the four or five most convex discs, resection of the adjacent convex head of the rib in the area of the costo-vertebral articulation. After removing the disc, the adjacent locking plates of the vertebrae adjacent to the disc were removed, to visualize the edges of the vertebrae

from the concave side in depth and the posterior longitudinal ligament backward. The vacated intervertebral space was filled with an autograft obtained from the removed rib during access.

On the 3rd day after the anterior mobilization of the spine, the patient was fitted with an extension system in bed by the head end on the Gleason loop (initial weight along the body axis from 1.5 to 2 kg), and downward by the pelvic girdle (initial weight along the body axis was 4 kg), the weight was gradually increased from 2 to 4 kg depending on the patient's weight and age, and his general condition and pain syndrome, i.e., his tolerance to manipulation, were also assessed. Extraction was carried out around the clock for 12–14 days with breaks for rest, hygienic manipulations and eating.

At the end, posterior instrumentation of the spine was performed using a polysegmental transpedicular system based on screws. This stage was carried out with mandatory intraoperative monitoring using the neurophysiological Medtronic NIM-Eclipse system, and the procedure and interpretation of the results obtained during the operation were carried out in accordance with the methodological recommendations of the American Society of Neurophysiologists and studies performed at the State Establishment Professor M.I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Sciences of Ukraine [3, 4]. Transpedicular screws were inserted using the spinal navigation Brainlab system (Germany) [5]. To achieve the maximum correction of the spine, after removal of the posterior elements of the vertebrae, resection of the interspinous and yellow ligaments at the top of the deformity, facetectomy and osteotomy of the posterior column of the vertebrae were performed (Ponte osteotomy). Direct correction was carried out due to derotation or cantilever maneuvers and a combination of compression of the vertebrae from the convex side of the deformation and distraction from the concave side.

After the correction and stabilization of the polysegmental system, decortication of the posterior elements of the vertebrae was performed and autografts were placed as a result of the removed arcuate joints and decortication, and in several patients, autologous material was obtained during the resection of the rib hump at the apex of the spinal deformity.

Data from clinical examinations of patients were processed statistically. The mean (M), standard deviation (SD), and minimum (min) and maximum (max) values of the sample were calculated. The percentage of angle change after anterior mobilization and cor-

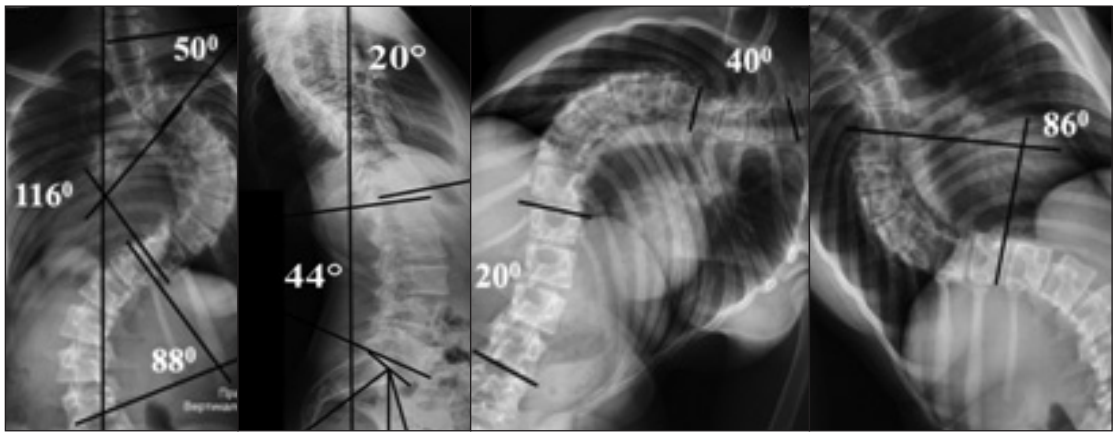

Fig. 1. Radiography and radiometry of spine deformation

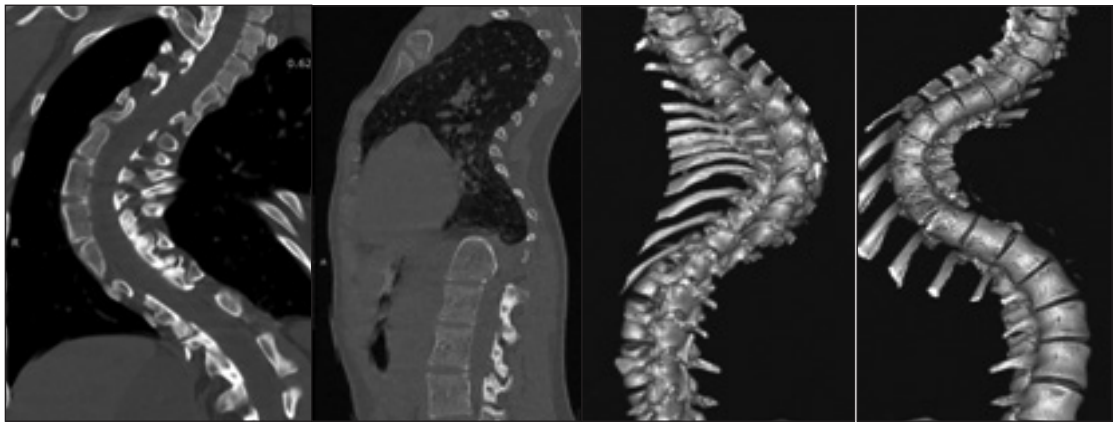

Fig. 2. Computed tomography of the spine

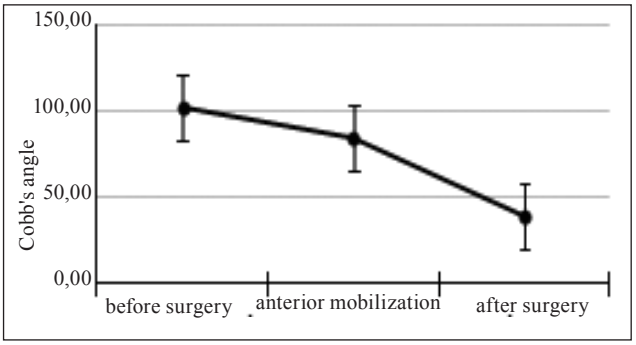

Fig. 3. Diagram of average values of deformation in the frontal plane before surgery, after anterior mobilization and intervention

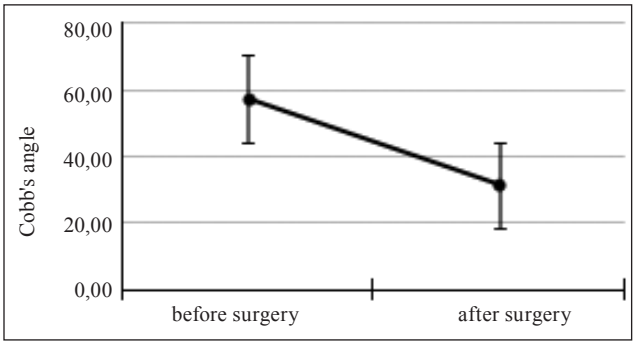

Fig. 4. Diagram of average values of thoracic kyphosis before and after surgery

Table 1

Deformation of the spine in the frontal plane

Before surgery	After anterior mobilization			After posterior instrumentation		
Cobb's angle, M ± SD min÷max	Cobb's angle, M ± SD min÷max	correction, %	statistical significance M ± SD	Cobb's angle, M ± SD min ÷ max	correction, %	statistical significance M ± SD
103 ± 10 90 ÷ 126	85 ± 8 74 ÷ 104	17.6 ± 3.3 13.7 ÷ 24.5	18.2 ± 4.7 t = 17.276 p = 0.001	40 ± 22 2 ÷ 78	62.1 ± 20.6 19.6 ÷ 97.8	63.4 ± 19.6 t = 13.344 p = 0.001

rection of spinal deformity in relation to the initial value was determined. The comparison of the magnitude of the angles was carried out using the T-test for repeated measurements with the calculation of the difference in means (M ± SD), the critical value of the criterion (t) and the level of statistical significance (p).

Processing was carried out in the package of MS Excel software.

Results

The average age of the patients was 17.7 years (from 12 to 38 years). The etiology of spinal deformities is divided as follows: 13 patients with idiopathic scoliosis, 2 patients with neurofibromatosis and 2 patients with congenital kyphoscoliosis.

The average value of the main curvature of the spine deformation in the frontal plane was 103° ± 10° according to Cobb (90°–126°). After anterior mobilization of the spine and two-week stretching in bed — 85° ± 8° (74°–104°), which is (17.6 ± 3.3) % of correction (from 13.7 to 24.5 %). When comparing the angles using the T-test, the following results were obtained: 18.2 ± 4.7 (M ± SD); t = 17.276; p = 0.001. The final corrective stage of surgical treatment made it possible to reduce the curvature of the spine to an average of 40° ± 22° (from 2° to 78°), in percentage terms it was (62.1 ± 20.61) % correction (19.6–97.8 %). Statistical significance according to the T-criterion had the following indicators: 63.4 ± 19.6 (M ± SD); t = 13.344; p = 0.001 (Table 1, Fig. 3).

Table 2

Value of thoracic kyphosis

Before surgery	After surgery		
Cobb's angle, M ± SD, min÷max	Cobb's angle, M ±SD , min÷max	correction, %	statistical significance, M ± SD
58 ± 21 24.0 ÷ 92.0	32 ± 14 14.0 ÷ 74.0	40.3 ± 24.0 5.1 ÷ 82.9	25.9 ± 20.7 t = 5.170 p = 0.001

The average value of thoracic kyphosis before surgical treatment was 58° ± 21° according to Cobb (from 24° to 92°). Since in our study the emphasis was on the assessment of the main curvature of the spinal deformity in the frontal plane, then after anterior mobilization we did not take an intermediate picture in the sagittal plane of the patients, with the exception of 2 patients in whom the deformation in the sagittal plane prevailed (one with congenital curvature and the other with neurofibromatosis). After correction of spinal deformity, the average value of thoracic kyphosis was 32° ± 14° (14.0°÷74.0°), and this is (40.3 ± 24.0)% of correction (5.1÷82.9%). T-test angles were 25.9 ± 20.7 (M ± SD); t = 5.170; p = 0.001 (Table 2, Fig. 4).

The obtained calculation results are statistically significant and testify to their reliability.

During the two-stage surgical treatment, the following complications were recorded: superficial (3 patients) and deep inflammation of the postoperative wound (1 patient), fracture of the fixation rod two years after the operation (1 patient), fracture

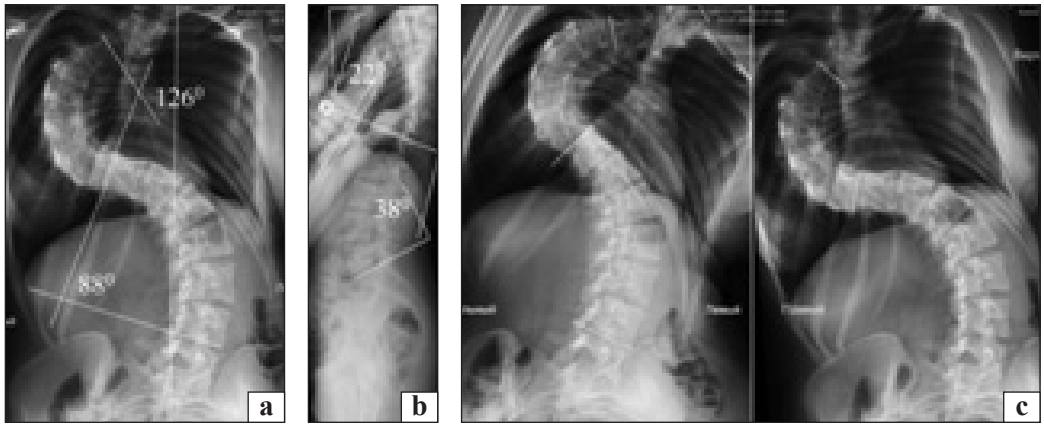

Fig. 5. Radiographs of the spine before surgery: front (a), profile (b) and functional (c)

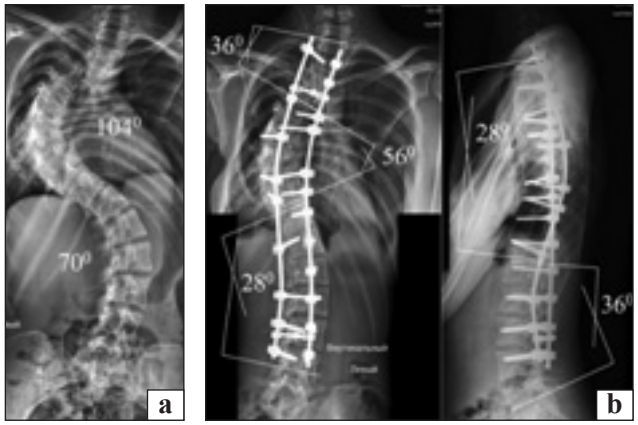

Fig. 6. Radiographs of the spine after surgery: a) anterior mobilization and extension; b) deformation correction

of the distally located transpedicular screw (1 patient) and in one patient motor evoked potentials were lost during the corrective maneuver, however, after the correction was weakened, the indicators were restored to control levels, without further neurological complications in the postoperative period. Only one patient with a fracture of the fixing rod underwent revision surgery: the rod was replaced with a stiffer one and additional bone plastic was performed at the top of the deformity.

The results obtained in our study show the indisputable effectiveness of phasing during surgical intervention of large and rigid spinal deformities. First of all, the key to the success of this treatment method is careful anterior mobilization of the main curvature of the spine. The key points are the implementation of a total discectomy, dissection of the longitudinal ligaments of the spine, resection of the rib heads of the spine-costal joint. Secondly, in the postoperative period, carrying out dosed stretching in bed for the head end on the Gleason loop for two weeks, makes it possible to increase the efficiency of anterior mobilization and mobility of spinal deformity, as well as to make adaptation of tissues and spinal cord to the future correction of the spine. This is clearly shown in clinical example No. 1, where the average values of the main curvature of the spinal deformity in the frontal plane before the operation are 103° ± 10° according to Cobb (from 90° to 126°), and after anterior mobilization and two-week stretching — 85° ± 8° (from 74° to 104°), which accounted for (17.6 ± 3.3) % of the correction (from 13.7 to 24.5%). The achieved mobility made it possible to obtain quite significant indicators of the final correction of the spinal deformity, on average up to 40° ± 22° (from 2° to 78°), in percentage terms this amounted to (62.1 ± 20.61) % correction (from 19.6 up to 97.8%).

Clinical example No. 1

A 19-year-old patient D., diagnosis: IV degree idiopathic thoracic scoliosis (type 4CN according to the Lenke classification). Radiographs (Figs. 5, 6) and appearance of the patient (Fig. 7) before and after surgical treatment.

Staged correction of spinal deformity allows to significantly improve the appearance of the patient not only due to the improvement of digital indicators of the curvature angles and balance of the spine, but also due to the reduction of the rib hump thanks to the derotating maneuver directly during the correction of the deformity (clinical example No. 2).

Clinical example No. 2

A 12-year-old patient, diagnosis: neurofibromatosis, large rigid thoracolumbar spine deformity. Appearance of the patient before (Fig. 8) and after surgical treatment (Fig. 9). Radiographs before and after achieving correction of spinal deformity (Fig. 10).

Discussion

Having analyzed the sources of literature on the two-stage surgical treatment of large and rigid spinal deformities, we found that not so many studies have been conducted on this topic [2]. A prospective clinical and radiological study of 33 patients with se-

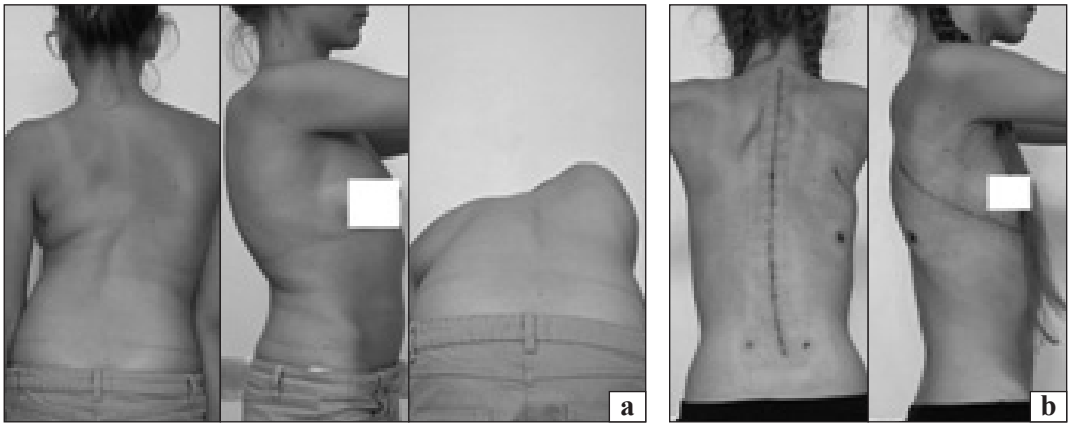

Fig. 7. Appearance of patient D.: before (a) and after (b) surgery

Fig. 8. Appearance of the patient before surgery

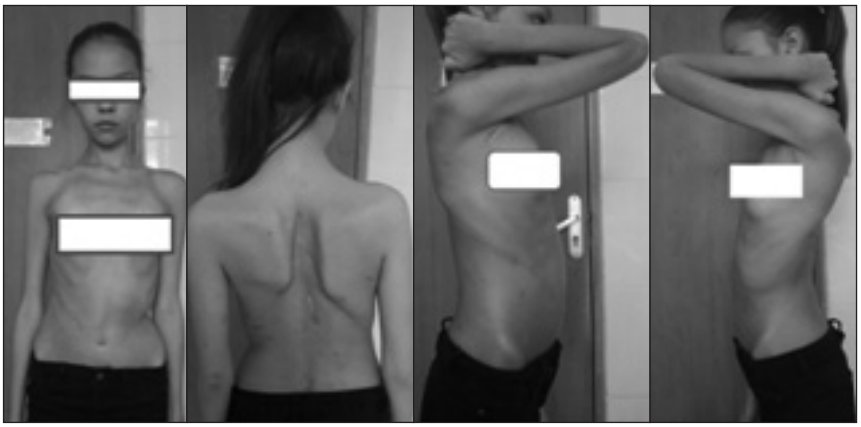

Fig. 9. Appearance of the patient after surgery

vere and rigid idiopathic scoliosis (the average Cobb angle was 93°, and the mobility of the deformity was 23%) was performed, who underwent combined anterior and posterior spinal instrumentation with a minimum follow-up period of 2 years. All patients underwent anterior mobilization and instrumentation of the major curvature with a ventral Zielke construct and posterior correction with a transpedicular construct. The preoperative values of the deformity varied from 80° to 122°.

The correction of the main curvature in the frontal plane was on average 67%. In all but three patients, the sagittal contour of the spine was restored. There were no neurological complications or deep wound infections [6].

The results of the corrective possibilities of the two-stage (anterior mobilization and posterior instrumentation) surgical treatment of large spinal deformities of more than 100° according to Cobb are as follows: the preoperative angle was 116.6° (from 101° to 124°), after anterior mobilization it was reduced to 74.0° (from 54° to 86°), this amounted to 29.4 % of the correction. The final postoperative deformity angle after posterior instrumentation was 26.5° (from

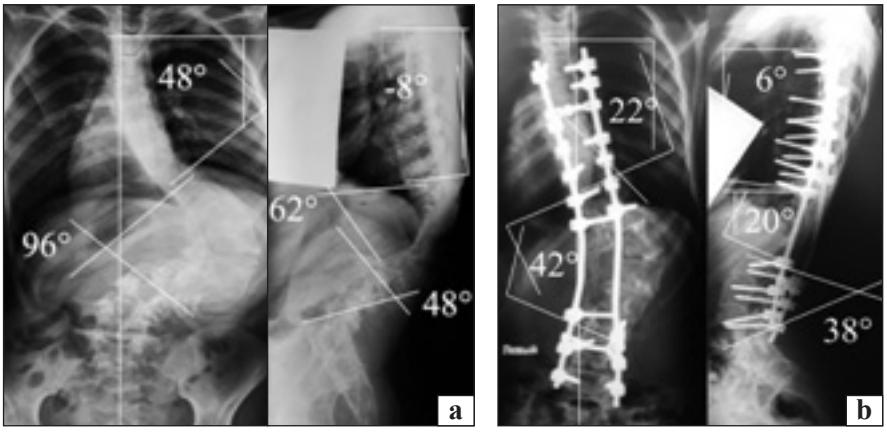

Fig. 10. Radiographs of the spine before (a) and after (b) surgery

22° to 32°), which determined 76% of the correction. Complications that were detected during the study were considered insignificant [7].

The safety and effectiveness of the given method of surgical treatment of such spinal deformities is presented in the study of a series of clinical examples [8].

Innovative high-tech development of the industry in the medical field makes it possible to offer new surgical procedures. Compared with traditional techniques, uniportal video-assisted thoracoscopic surgery is gaining popularity in thoracic surgery due to reduced invasiveness, blood loss, pain, and faster recovery. Our retrospective study aimed to apply this technique to the treatment of severe thoracic scoliotic spinal deformities with limited flexibility. All patients underwent uniportal video-assisted thoracoscopic anterior curvature mobilization followed by posterior instrumentation. The average indicators of the final frontal and sagittal corrections were (70 ± 19) % and (71 ± 23) %, respectively. For the first time, we evaluated the safety and effectiveness of the minimally invasive technique of anterior curvature mobilization in the treatment of severe forms of thoracic scoliosis, providing comparable corrective results, less postoperative pain syndrome, faster recovery and a good cosmetic effect without significant complications [9].

Several studies have focused on the use of halotraction initially before surgical correction or as a step after anterior mobilization of curvature followed by posterior instrumentation [10–14].

In the study of A.F. Levytskyi et al. [10] the angle of deformation before surgical treatment was 112.24° ± 4.41° ($P > 0.01$). In all patients, the scoliotic deformity was rigid: during the traction test, the correction of the deformity occurred within 15–20 %. The average duration of spinal traction was 46 days ($P > 0.01$). After halotraction, the angle of deformation was 86.14° ± 2.63°, and 47.25° ± 3.21° at the final stage of correction. The average correction of spinal deformity was equal to (57 ± 12) %. Transitory neurological deficit was observed in 2 patients (6.6 %), with inflammation of soft tissues around the rod in 3 (9.9 %).

In the study of T. Garabekyan et al. [13] the average duration of traction was 77 days. The average angle of the main curvature according to Cobb before applying halotraction was 101° (62°–130°), with 58° (26°–91°) after the final posterior correction of the deformity. The mean improvement in baseline curvature measurement was 43% immediately after posterior correction and 38% at final follow-up ($P = 0.001$). The overall complication rate was 19 %, including 2 patients with pin loosening and 2 with superficial pin site infections.

In other studies, similar correction results ranging from 35 to 58 % were obtained [14]. Various complications associated with halotraction have been reported: rod loosening, infection around the rods, brain abscess (although rare), cranial nerve palsy, and other neurological adverse events.

In contrast to two-stage methods of surgical treatment of spinal deformities, resection of the spinal column at the apex of the deformity is used exclusively through the posterior approach. Posterior release of ligaments and facet joints is performed through a posterior approach, and posterior laminectomy and pediculectomy are performed to complete the circular resection of the spinal column [15]. This approach has become the standard of care for severe, rigid spinal deformities in recent decades, since stable multisegmental designs and advanced equipment such as intraoperative monitoring and spinal navigation have been used in spinal surgery. L. Lenke et al. [15] in their study reported the results of surgical treatment of 43 severe, rigid spinal deformities in children and adults. The average radiological correction of the main curvature of the spine was 57° (69 %) in case of scoliosis, 45° (54 %) in general kyphosis, 49°

(63 %) in local angular kyphosis, and 109° (56 %) in conditions of combinations of kyphoscoliosis. The average blood loss for all patients was 1103 ml and varied from 250 to 3100 ml, and the duration of the operation was 9 hours 37 min. A few patients had changes and/or loss of spinal cord monitoring data: 7 (18 %) lost intraoperative neurogenic evoked potential monitoring during correction and returned to baseline after surgery. There were postoperative neurological complications in 2 patients with transient paralysis of nerve roots. Somatic complications in 11 patients were also examined in detail, none of which led to catastrophic consequences and revision interventions.

A systematic literature review was conducted in the case of spinal column resections due to spinal deformities [16]. 7 studies (390 patients) were included in the analysis. The average operation time was 430 minutes, and the estimated blood loss was 2,639 ml. The average amount of correction was 64.1° for scoliosis and 58.9° for kyphosis (61.2 and 63.1 %, respectively). The overall prevalence of complications was 32 % (12–54 %). The most common were neurological complications, which accounted for 8 %. The risk of spinal cord injury was 2 %, the frequency of revision interventions — 6 % (1–13 %), infectious complications — 2 % (1–4 %), complications due to implants — 2 % (0–6 %).

Therefore, the presented modern methods of surgical treatment of severe and rigid spinal deformities showed comparable results regarding the correction of the deformity, which ranges from 52 to 78 %. In our study, we obtained 62 % correction of the main curvature of the spine. Carrying out anterior mobilization of the spine allows to obtain up to 30 % correction, in our case this figure was 17.6 %.

During the performance of our study, there were no gross neurological complications due to the use of neuromonitoring and spinal navigation. In only one case, there was a fracture of the fixing rod in the remote period, which required a revision intervention. The disadvantage of halotraction is the exhausting and long duration of this stage (from 24 to 77 days), the possible risk of serious problems from the brain (abscess) and infectious complications at the sites of the rods, as well as neurological ones. The technique of posterior spinal resection is a powerful surgical procedure for the treatment of severe spinal deformities, but it carries the risk of excessive blood loss (up to 3 L) and serious irreversible neurological changes. It is more acceptable for gross, local angular deformities, and the decision to perform such an operation must be balanced and performed by an experienced surgical team.

Conclusions

Two-stage surgical treatment of large and rigid spinal deformities (anterior mobilization of curvature and posterior instrumentation of the spine) is a modern technique for achieving correction of spinal deformity in the frontal and sagittal planes, as well as for obtaining the desired cosmetic result. Carefully executed anterior mobilization with subsequent use of the patient's bed extension system allows for increased mobility of the spine and gradual adaptation of the tissues and spinal cord to the next posterior correction, which significantly reduces the risks of neurological complications, and also helps to obtain the most satisfactory correction results.

Conflict of interest. The authors declare no conflict of interest.

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TWO-STAGE SURGICAL TREATMENT OF LARGE AND RIGID SPINAL DEFORMITIES (ANTERIOR MOBILIZATION OF THE CURVATURE AND POSTERIOR INSTRUMENTATION OF THE SPINE)

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