SURGICAL TREATMENT OF PATIENTS WITH SCOLIOSIS OF THE FIRST DECADE OF LIFE: LITERATURE REVIEW

M.V. Mikhailovsky, V.A. Suzdalov, M.A. Sadovoy
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

The paper presents a second part of literature review on basic methods of treatment of patients with infantile and juvenile scoliosis. Particular attention is paid to the results of treatment with the use of various instrumentation and with a possibility of stage correction.
Key Words: infantile scoliosis, juvenile scoliosis (Early Onset Scoliosis – EOS), surgical treatment.

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Dual Growing Rods

Harrington [13] was the first to describe the possibility of spine deformity correction without arthrodesis. Dual growing rods technique involves placing claw anchors at the end vertebrae of the scoliotic curve, while rods are passed subfascially or subcutaneously. The idea of the technique is to provide a corrective force, maintaining the achieved correction result, and the possibility of the spine to continue growing. The rods are joined together via the connector, which is regulated by loosening the adjusting screw. Correction is achieved by distraction between the construct poles (Fig. 1). Staged operations with lengthening of the growing rods are performed with a specific time interval: the recommended period is 6 months [28]. Sankar et al. [24] investigated the relationship between the frequency and efficiency of stage corrections. The authors examined 38 patients with the follow-up period of 3.3 (2–7) years. Stage corrections were carried out on an average 6–8 months after. As a result of the first intervention, the scoliotic curve was reduced from 74° to 36°, with its value decreasing after each subsequent distraction, while the length of T1–S1 spinal segments was increasing. This could be due to the formation of spontaneous bone blocks at the segments not involved in fixation, and affected the result of final correction. Later, the method of lengthening of the growing rods with the use of electromagnetic waves was developed that did not require surgical intervention [2], which was only recently approved for use in the United States (Fig. 2). The cost of the treatment using magnetically controlled growing rods is high. However, it becomes comparable to the conventional technique with time. In Russia, this treatment method is not applied due to the high cost and the absence of analogues. Authors from the USA [22] conducted an analysis of the total cost of using both methods in 1,000 patients for a period of 6 years. The conventional technique requires reoperations under general anesthesia. Magnet distraction of the rods is conducted in a non-invasive manner in the doctor's office. The authors concluded that magnet usage provides significantly fewer cases of deep surgical infection and revision surgeries.

To date, there are no clear indications for the use of growing rods technique in patients with spinal deformities. However, most researchers agree with the fact that, at the time of the start of treatment, patients should have a significant residual potential of skeletal growth, progressive spinal deformity, and the deformity should be mobile or its mobility can be achieved by frontal release [3, 4, 28, 29].

Akbarnia et al. [4] presented the results of a multicenter study, which included 23 patients with a follow-up period of at least 2 years. According to the authors, the average initial value of the primary scoliotic curve decreased from 82° to 38° after treatment. Moreover, the total extension of the spine reached 9.6 cm (1.24 cm per year), while the space available for the lungs increased from 0.87 to 1.0. This value reflects the potential for lung development and is calculated by the ratio of the height of both hemithoraces multiplied by 100 and expressed as a percentage [10]. The authors reported 13 complications developed in 11 patients, 4 of which required unplanned interventions, and came to the conclusion that dual growing rods technique is safe and effective. The complication rate is comparable to that for the single rod technique.

Finally, Thompson et al. [27] compared the results of using dual growing rods with the single rod technique.

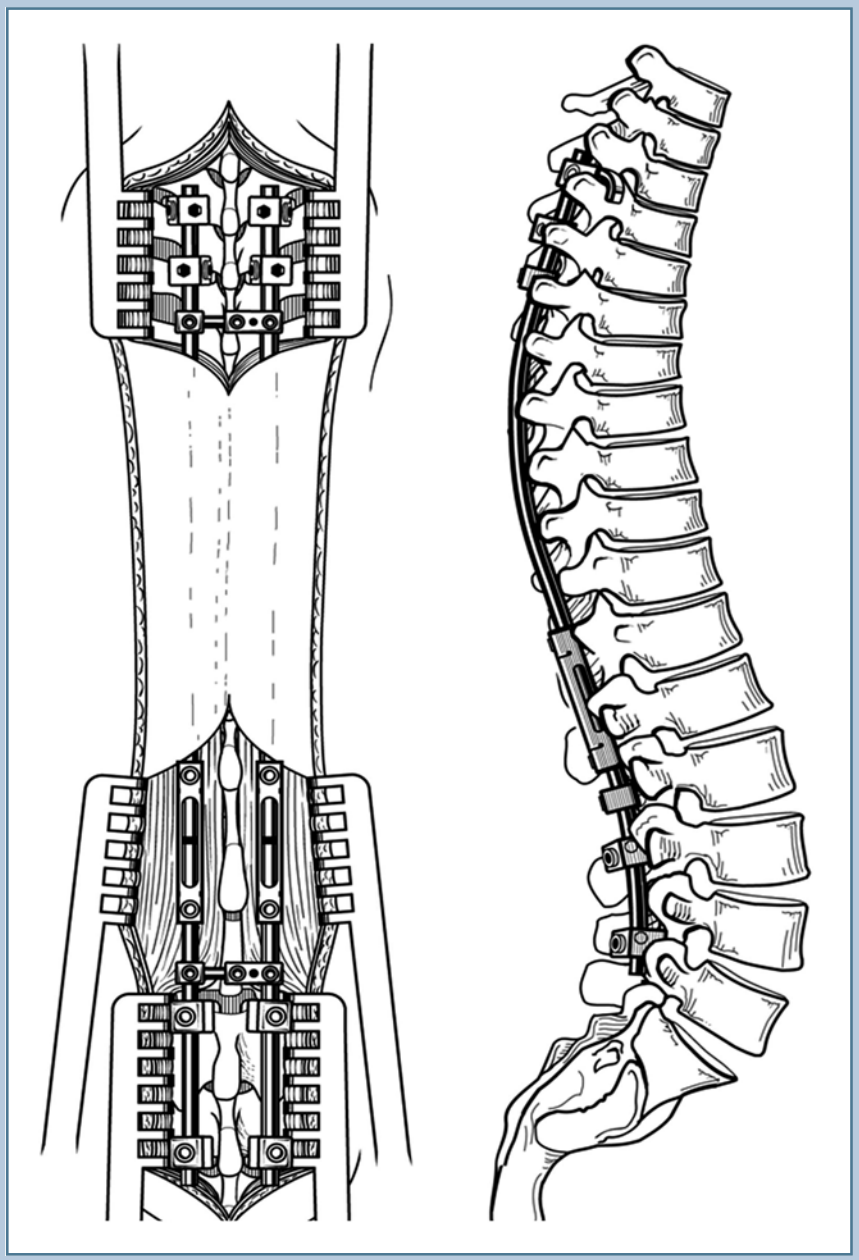

Fig. 1
Growing rods technique by Akbarnia et al. [4]

Fig. 2
Magnetically controlled growing rods technique according to Cheung et al. [11]

Stage correction was performed every 6 months regardless of the scoliotic curve progression. The studied patients (n = 28) were divided into three groups according to the type of surgery: I – surgery using one rod and fusion at the top of the curve; II – using single rod technique; III – with implantation of two rods. The correction results turned out to be significantly worse in Group I (23 %) than in Group III (71 %). Total extension of the spine was 12.1 cm in Group III and 6.4 cm in Group I. The authors concluded that the use of two growing rods in more severe deformities provided better results without the loss of correction, while the conduction of additional spinal fusion at the top of deformity is inefficient.

It should be noted that the current interest in this technique is quite high.

The ways of instrumentation arrangement, fixation levels, and evaluation of the obtained results have been actively studied. The authors report that laminar and pedicle hook fixation in the thoracic region is more reliable compared to pedicle-rib and lamina-rib fixation when choosing proximal anchor sites [15]. Distal fixation to the iliac crest allows one to achieve more pronounced correction of the primary scoliotic curve and pelvic misalignment compared with the fixation to the pelvis [20]. The use of pedicle fixation in children at the age of 5 years does not affect the growth of the spinal canal and does not cause iatrogenic stenosis [16]. Recently, there have been reports on the use of a modified technique of growing rods: sliding-growing rod technique. The concept of this method is as follows. Cranial and caudal claw anchors are formed on the two vertebral segments using pedicle fixation and spinal fusion. Screws are installed at the intermediate segments without fixation in order to ensure spinal growth. Rods are placed in the proximal claw anchor, intermediate screws and caudal claw anchor and joined by a domino connector predominantly in the distal region. Distal rods are fixed in the connector, while the proximal ones are not. Unlike conventional technique, the use of this method provides dynamic fixation allowing self growth of the spine, fewer complications, and improved respiratory function [12]. Assessment of the obtained results of treatment (instrumentation length) can be reliably performed not only by X-ray method but also using ultrasound [14]. X-ray examination after each extension is not necessary when using magnetically controlled rods. Indications appear with increased extension interval of up to 6 months or in the presence of clinical evidence and complaints about instrumentation instability [30].

Shilla Procedure

Unlike dual growing rods, there is no need of stage correction when using Shilla procedure. Furthermore, the top of the scoliotic curve is instrumented with fixing screws, corrected and blocked. Unconventional sliding polyaxial pedicle screws are implanted at the end vertebrae of the scoliotic curve. This allows unblocked regions of the spine to grow along the rods by sliding on them (Fig. 3). There are not enough data in the literature on its use due to the novelty of the procedure. McCarthy et al. [19] conducted an experimental study of the technique in animal models. As expected, spine growth was increased by an average of 4.8 cm in cranial and caudal directions 6 months after implantation of instrumentation. A large number of complications was found in the form of worn out sliding screws and fractured rods.

In the framework of the 2nd International congress on early onset scoliosis and growing spine, McCarthy et al. [17] presented the results of the treatment of 10 patients with spinal deformities of different etiology using Shilla procedure and with the average follow-up period of 2 years (Table 1). Dynamics of the primary scoliotic curve was as follows: 70.5° prior to surgery, 27.0° immediately after surgery, and 34.0° at the end of the follow-up. The space available for the lungs was increased by an average of 13 %, while the spinal growth was increased by 12 %. The authors emphasize the fact that stage correction is required each 6 months when using the conventional technique of dual growing rods. Shilla procedure allowed avoiding 49 staged surgeries in 10 patients in the course of treatment. Later, McCarthy and McCullough [18] presented the results of the treatment of 40 patients using Shilla procedure with a 5-year follow-up period. The study was conducted within the framework of SRS. A total of 3 patients turned out to be unavailable for the further treatment: there were 2 deaths not related to spinal surgery, and 1 patient changed residence. Evaluation of the results was carried out retrospectively; indications, etiology, number of interventions, clinical data, and complications were taken into account. Surgery was performed at the average age of 6 years (range: 23 months to 11 years). Average initial value of the scoliotic curve was 67°, which reached 64 % after surgery. Correction persisted at the level of 40 % by the end of the follow-up. Space available for the lungs increased by an average of 30 %, extension of the thoracic (T1–T12) spine was increased by an aver-

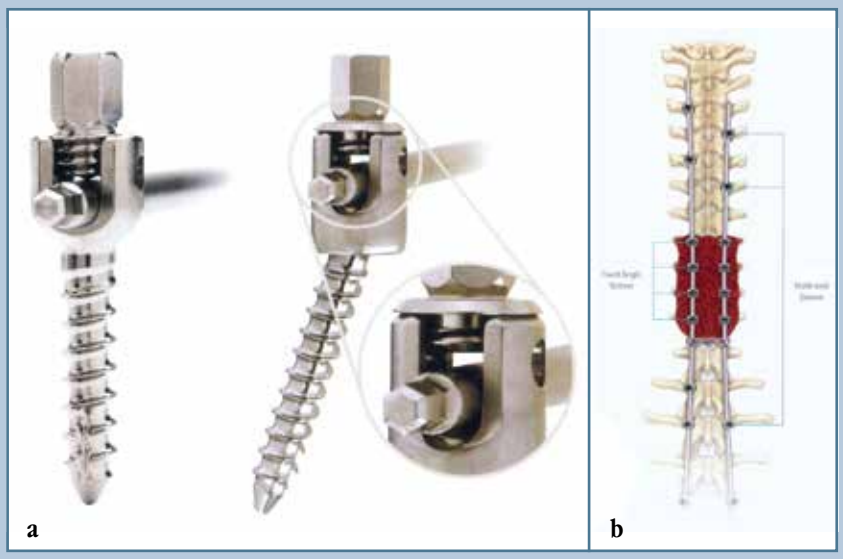

Fig. 3
Shilla procedure: **a** – types of pedicle screws: fixing and sliding polyaxial (materials of "Medtronic"); **b** – instrumentation arrangement (materials of "Medtronic")

Table 1
Summary of the analyzed treatment methods

Analyzed method	Author	Publication year	Number of observations	Observation period, years	Results
Shilla procedure	McCarthy et al. [17]	2009	10	2	Correction achieved: 36.5°; increase in the space available for lungs: 13 %; increase in T1–S1 segment: 12 %; complications: none
	McCarthy и McCullough [18]	2012	40	5	Correction achieved: 40 %; increase in the space available for lungs: 30 %; increase in T1–S1 segment: 10 %; complications: 22 patients (7 patients: >2)
Shilla procedure	Andras et al. [5]	2015	72	4.6	Correction achieved: 24°; increase in T1–S1 segment: 6.4 cm; complication rate: 1.9
growing rods technique					Correction achieved: 37°; increase in T1–S1 segment: 8.8 cm; complication rate: 1.3
Vertebral Stapling	Betz et al. [7]	2003	21	2	Scoliosis not more than 50°: 60 % of patients had stable course; complications: 3 minor
	Betz et al. [6]	2005	39	1	Scoliosis not more than 50°: 87 % of patients had stable course; complications: 1 severe, 5 minor
	Betz et al. [8]	2010	28	3.2	Scoliosis not more than 35°: 77.7 % of patients had stable course; Scoliosis not more than 25°: 85.7 % of patients stable course; treatment of thoracic scoliosis (35 ° or more) is ineffective; complications: 2 minor

age of 8 %, extension of the thoracic and lumbar spine (T1–S1) was increased by 10 %. A total of 62 procedures have been conducted; 346 interventions were performed using conventional distraction. Complications were noted in 22 patients who required repeated interventions; 7 patients had more than two complications. Complications were divided into the following groups: 51 were associated with implants, 4 were associated with poor wound healing, 7 infectious, and 5 related to construct alignment. The authors concluded that the incidence of complications is acceptable, and the technique can be used in most of the nosological forms of spinal deformities. In addition, the patients were allowed to perform normal physical activity. Analysis of the strength characteristics of various constructs was performed within the framework of the study. In early forms of scoliosis, the effective methods are growing rods technique with pedicle fixation [28], VEPTR [9], and Shilla procedure [19]. Growing rods technique and VEPTR are inappropriate in controlled correction of kyphosis [23, 25].

The first comparative multicenter study of the treatment outcomes of patients with infantile and juvenile scoliosis (72 patients) using Shilla procedure (Group I) and double growing rods technique (Group II) has been recently presented for the period of 1995 to 2009 [5]. The group of patients was thoroughly selected from a joint database of 22 centers, including the results of the treatment of 1000 patients with a follow-up of 4.6 years. Dynamics of the main scoliotic curve value is presented in Table 2. In Group I, correction loss value against the background of active growth reached 19° by the end of the observation period, and total correction established 24°. In Group II, there was a 3° improvement, and total correction was higher than in Group I and equaled 37°. Length of the spinal column (T1–S1) measured using frontal radiographs was increased as follows: a 6.4 cm and 8.8 cm increase in Group I and II, respectively.

Complication rate turned out to be almost identical in both groups: 1.9

Table 2
Dynamics of correction criteria in groups using Shilla procedure and growing rods technique

Correction criteria	Shilla procedure			Growing rods technique		
	prior to surgery	after surgery	at the end of follow-up period	prior to surgery	after surgery	at the end of follow-up period
Primary curve, degrees	69	26	45	72	38	35
Length of T1–S1 segments, cm	29.0	32.5	35.4	26.7	30.1	35.4

and 1.3, respectively (Table 3). Absence of somatosensory evoked potentials was intraoperatively registered in two patients of Group II. Revision surgery was not performed. No neurological disorders were identified postoperatively. One patient was diagnosed with right-sided hemiparesis of the lower extremities with impaired gait after replacement of broken rods and distraction to the initial value. The rods were shortened; neurological disorders were corrected for the period of less than two months. No neurological complications were found in Group I. Rate of revision surgery for complications was 7.2 in Group II, including 6.2 staged interventions per patient. The number of complications associated with implants was significant in both groups (Tables 1, 4, 5). In most cases, revision and staged interventions were planned. The authors note that, to date, a small number of patients have reached sufficient skeletal maturity, and they underwent the final stage of treatment. The observation should be continued in order to more accurately evaluate the results. In general, optimal results of the treatment are achieved in the group with the use of the growing rods technique. However, this became possible with a larger number of surgical interventions. At the same time, a greater number of complications associated with implants was identified in the group using Shilla procedure. The complication rate was equal in both groups.

Vertebral Stapling

This method was developed based on the "Heuter – Volkmann law". The first report on the use of this method dates back to 1951 [21]. The authors were able to create and implant the staples for the first time in experiment with growing dogs. Staples were placed over the intervertebral discs in adjacent growth plates of the neighboring vertebrae. After this procedure, Smith et al. [26] applied the technique in three patients. However, the attempts were unsuccessful due to implant migration. The technique has not been used until recently. The emergence of new implants with shape memory, an improved surgical technique, and metal constructs contributed to its revival. Staples made from titanium nickelide are implanted in a refrigerated state and then maintain a perpendicular position relative to the bone. After they are heated up to the body temperature, correction of deformity curve takes place due to the gradual compression, which reduces the risk of implant migration (Fig. 4). Prof. Ya.L. Tsivyan was the first in the USSR to apply titanium nickelide staples in scoliosis at Novosibirsk Research Institute of Traumatology and Orthopaedics in 1984 (Fig. 5). In total, he has performed three of such surgeries. The staples were implanted via thoracoabdominal access. As a result of surgical intervention, marked correction of spine deformity was achieved (up to 48 %), wedging of the intervertebral discs was corrected at the level of fixation, anterior bone block was formed in 5 months [1].

In 2003, Betz et al. [7] presented the results for 21 growing patients (Risser ≤2) with idiopathic scoliosis (Table 1). Thoracoscopic access to the vertebra bod-

Table 3
Comparative characteristics of complications in groups using Shilla procedure and growing rods technique, %

Type of complication	Shilla procedure	Growing rods technique
Total number	1.9 (0–7)	1.3 (0–9)
Neurological	0	0.1 (0–1)
Iatrogenic	0.03 (0–1)	0.22 (0–2)
Implant associated	1.5 (0–6)	0.7 (0–7)

Table 4
General characteristics of additional interventions in complications associated with implants, %

Type of additional intervention	Shilla procedure	Growing rods technique
Total number	1.8 (0–7)	6.4 (2–14)
Implant revision	1.4 (0–7)	1.5 (0–7)
Unplanned	1.3 (0–6)	0.5 (0–6)
During planned extension	0	0.2 (0–2)
Implant manipulation	0.1 (0–1)	0.8 (0–4)

ies was used. Three minor complications were reported. Then, the authors examined a subgroup of 10 patients with the follow-up of 22.6 months for the stability of the primary curve. The criteria for selection were the progression of the primary curve by 6° and more or up to 50°. Taking into account these criteria, 6 of 10 patients had stable course, four cases had progressing deformity. Only one patient underwent posterior spinal fusion with correction using metal construct.

Two years later, Betz et al. [6] reported the results of treating 39 patients. Progression criteria were considered to be a 10° or more curve increase. A total of 87 % of the patients older than 8 years of age with deformities of not more than 50° were successfully cured. The follow-up period equaled at least 1 year. No patient with 30° and smaller deformity was diagnosed with progression. One severe and five minor complications were identified in the group. Despite the fact that results became promising, the authors note the need for a longer observation.

Later, Betz et al. [8] reported the results of the treatment of 28 patients from the group with a follow-up of 3.2 years. The progression criteria were considered to be a 10° or more increase in the curve. All patients had Risser test value of 0–1, scoliotic curve value ranged from 20 to 45°. Treatment of thoracic deformities equaling or less than 35° turned out to be successful in 77.7 %, of 20° and less than 20° deformities – in 85.7 % of cases. Mobile curves were successfully corrected by 50 % and more in 71.4 % of cases. There were no mechanical or neurological complications. There were two complications associated with the formation of a diaphragmatic hernia and a compensatory curve. Pulmonary atelectasis was developed in two cases. The authors conclude that treating deformities of 35° and less is associated with a high risk of postoperative progression : 87 % for lumbar localization and 79 % for thoracic. Treatment of thoracic deformities with magnitude of 35° and more is inefficient.

Treatment of scoliosis in young children is one of the main problems of modern vertebrology. To date, there is no gold standard of conservative or surgical treatment. Conservative treatment usually turns out to be ineffective. However, intervention on the anterior or posterior regions of the spine can cause spinal growth constraint, lead to uncontrolled deformity progression and reduce the space available for the lungs. Efficiency of the presented techniques yet to be tested in the future.

Table 5
Types of complications associated with implants, n

Type of complication	Shilla procedure	Growing rods technique
Rod fracture	24	18
Shilla-misalignment (pull-out) of the screw	13	0
Misalignment (pull-out) of the claw anchor	1	5
Implant bulging	12	1
Shilla-loosening of screw fixation	3	0
Misplacement of the screw	1	0
Loss of proximal fixation	1	0

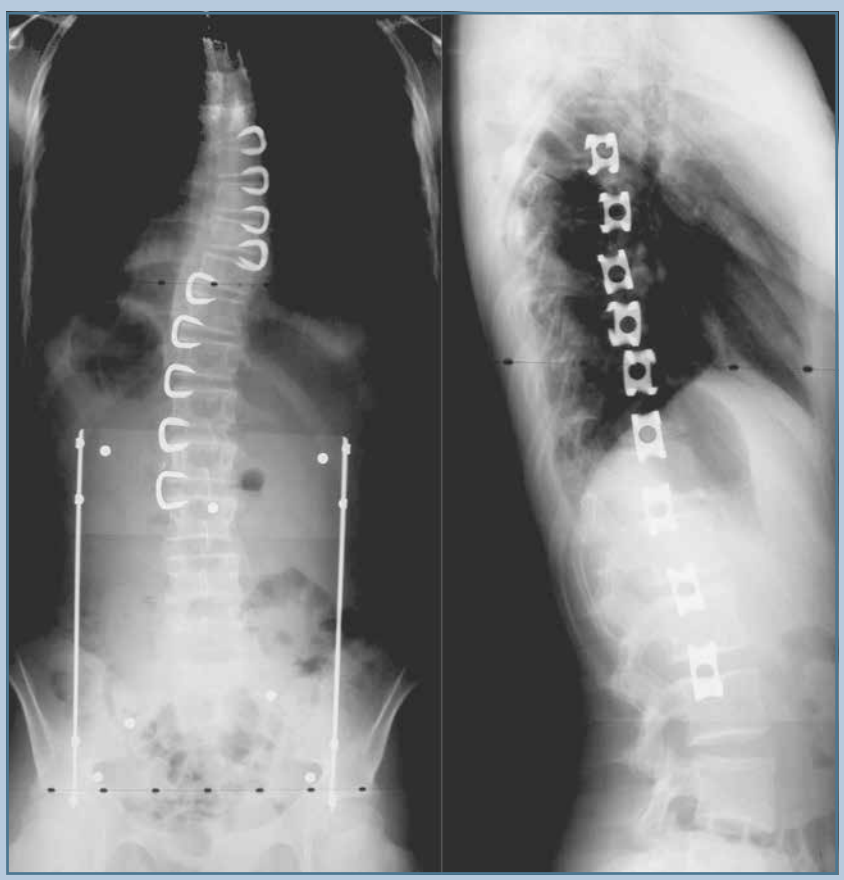

Fig. 4
Spine fixation with the staple technique in a patient with thoracic an lumbar scoliotic curves according to Betz et al. [6]

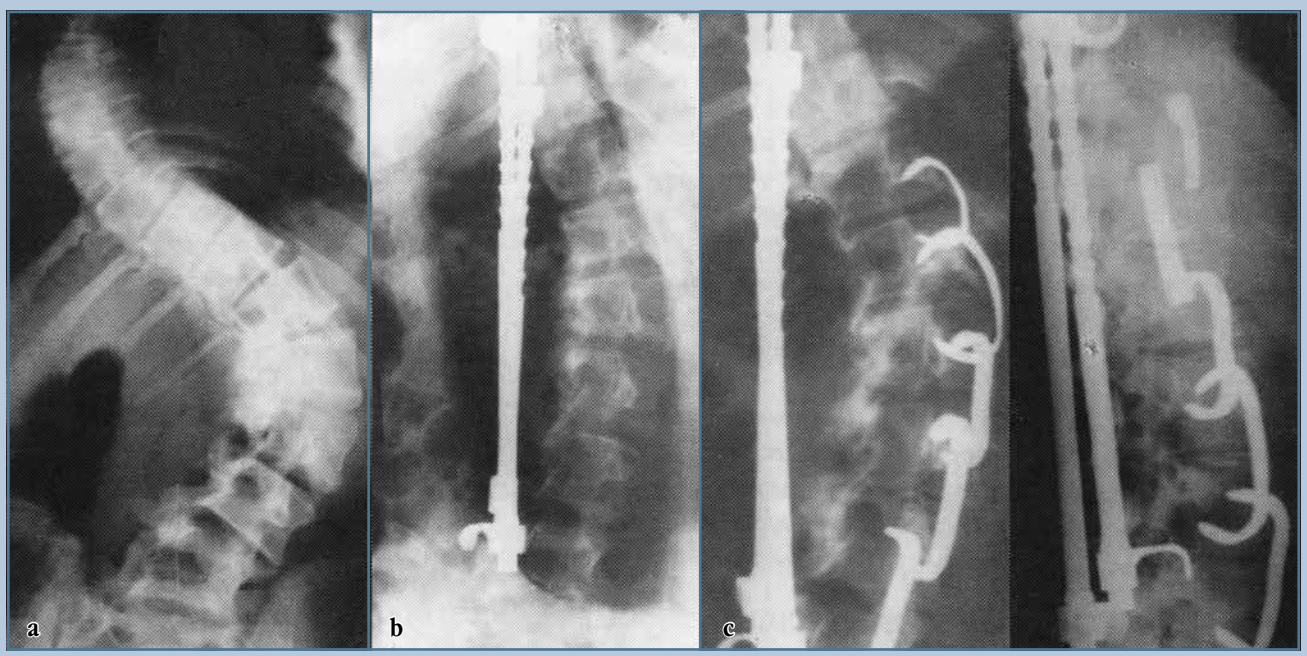

Fig. 5
Radiographs of a patient with grade IV thoracolumbar scoliosis: **a** – prior to surgery; **b** – after the 1st stage of surgery; **c** – after the 2nd stage of surgery

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Address correspondence to:
Mikhailovsky Mikhail Vitalyevich
NIITO, Frunze str, 17, Novosibirsk, 630091, Russia,
MMihailovsky@niito.ru

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Mikhail Vitalyevich Mikhailovsky, MD, DMSc, Prof., chief researcher in the deparment of children and adolescent spine surgery, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia;
Vasily Aleksandrovich Suzdalov, PhD, traumatologist-orthopaedist in the Department of Pediatric Orthopaedics No. 1, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia;
Mikhail Anatolyevich Sadovoy, MD, DMSc, Prof., director, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia.