SURGICAL TREATMENT OF PROGRESSIVE IDIOPATHIC SCOLIOSIS IN ADOLESCENTS AGED 10–14 YEARS: LITERATURE REVIEW

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Objective. To perform a systematic review of publications devoted to the evaluation of the results of surgical treatment of adolescents with idiopathic scoliosis aged 10—14 years.
Material and Methods. Publications on surgery for adolescent idiopathic scoliosis for the last 40 years were analyzed taking into account different treatment approaches. The long-term results of surgical correction and complications occurred at different stages of the vertebrology development were reviewed based on the data of 23 publications including data on 826 patients aged 10 to 14 years in the period of active growth.
Results. The prevalence of anterior interventions such as discectomy and anterior spinal fusion at the early stages of the scoliosis surgery development was justified. This was due to the lack of instrumentation at that time to prevent postoperative progression of scoliotic deformity in growing patients. The occurrence of crankshaft phenomenon was prevented by performing intraoperative spine release and subsequent stabilization owing to the formation of interbody bone block.
Conclusion. Despite the fact that the method of total transpedicular fixation occupies a leading position at the present stage of scoliosis surgery evolution, the anterior spinal release remains relevant and necessary stage of surgical treatment of patients with severe and rigid spinal deformities at any age. The need for anterior intervention is determined not by the prevention of possible postoperative progression, but by the magnitude of spinal deformity, that is, anterior surgery is performed to mobilize severe and rigid scoliotic deformity.
Key Words: progressive idiopathic scoliosis, incomplete growth, transpedicular fixation, adolescent idiopathic scoliosis, surgical treatment, long-term results, spinal deformity, quality of life, scoliosis, spine.
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The last two decades have been characterized by the rapid development of surgical methods for treating scoliotic spinal deformities.

The largest number of patients with spinal deformities belongs to the group of idiopathic scoliosis, with 80–90 % of deformity cases being detected in adolescence [1, 2].

According to Asher et al. [3], in adolescents, spinal curvature of 10° or more occurs in approximately 2.5 % of cases. Moreover, only 0.25 % of cases are characterized by progression of the scoliotic curve to such an extent that it requires surgical treatment. Untreated adolescent idiopathic scoliosis does not increase mortality, although it can progress to 100° or more. Most patients with untreated idiopathic scoliosis are functioning at a normal level or close to it in comparison with a group of adolescents without this pathology.

According to the SRS classification of idiopathic scoliosis [4], scoliosis in adolescents aged 10–18 years is allocated to a separate group. This division is due to the fact that each of the scoliosis forms differs from the others not only in the age of detection but also in the nature of the disease course, prognosis, and the treatment methods.

Of greatest interest to us are the patients aged 10–14, who are classified by the WHO as early adolescents. DiMeglio et al. [5] described the spine growth rate for different age periods in 1989. From birth to the age of 5, the spine growths at a rate of a little more than 2 cm per year, in the period of 5 to 10 years of age, the growth rate is 1 cm per year, then an increase in the growth rate is noted: up to 2 cm per year. This fact confirms the presence of a period of active hormonal release, which stimulates a sharp acceleration of growth. This phase lasts for about three years.

In 1977, Winter [6] noted that, on average, the growth ends at the age of 14 in girls and at the age of 16 in boys. It is also known that, by the age of 15 in girls, the structure of bone tissue corresponds to that in adults. Thus, it is necessary to consider patients aged 10–14 with idiopathic scoliosis as a homogeneous group belonging to the early adolescent period [7] requiring treatment that would be aimed at correcting the deformity itself, preventing its progression and significant effect on the further patient's growth.

In 1973, Dubousset [8] stated that one of the criteria for successful surgical treatment of this group of patients is the prevention of the crankshaft phenomenon. For this purpose, a two-stage treatment has been proposed, which includes periapical epiphysio-

desis and posterior fusion with the use of segmental instrumentation [9].

At the same time, discectomy and anterior spinal fusion are aimed at intraoperative release of the spine and its subsequent stabilization due to the formation of the interbody bone block, which prevents the crankshaft phenomenon [10].

In patients with incomplete growth in the age group of 10–14 years, the issue of choosing the volume and stages of surgical treatment is relevant. This is due to the following reasons:

1) the fact of the continued growth of the musculoskeletal system as one of the causes that determine progression, which, if left untreated, leads to the formation of rigid spinal deformities in the late period; vertebrologists throughout the world are afraid of postoperative progression and, first of all, the development of the crankshaft phenomenon, as evidenced by the abundance of foreign articles on this topic;

2) the general impact of surgical intervention on the further course of the patient's life and the psychological characteristics of this age group; patients who only enter puberty are most sensitive to the opinions of others, to the perception of their appearance, which has an impact on their quality of life, so the question of surgical correction for them is primary. Moreover, the psychological reactions of patients affect the course of the scoliotic disease and its outcome [11].

Nevertheless, with the advent of new methods of spinal deformity correction, including transpedicular fixation, many surgeons question the need for anterior release and spinal fusion in idiopathic scoliosis.

The choice of the method for surgical correction of idiopathic scoliosis in patients with incomplete growth remains controversial at the moment, and predicting the trend towards the progression of idiopathic scoliosis is still one of the most difficult and incompletely studied issues of modern vertebrology. These facts served as the basis for this publication.

The aim of the study is to perform a systematic review of publications devoted to the evaluation of the results of surgical treatment of adolescents with idiopathic scoliosis aged 10–14 years.

The strategy of search and analysis of publications

A systematic review was conducted using MEDLINE/PubMed, Google Scholar, eLibrary medical literature databases and search resources.

At the first stage, publications were selected using the following key words: progressive idiopathic scoliosis, incomplete growth, transpedicular fixation, adolescent idiopathic scoliosis, surgical treatment, long-term results, deformity of the spine, quality of life, scoliosis, spinal deformity, and spine.

The second stage included analysis of the publication abstracts for compliance with inclusion criteria.

At the third stage, full-text versions of articles have been studied.

Publications were included in the systematic review based on the following criteria:

– article publication time (from January 1, 1973 to December 31, 2018);

– an analysis of the surgical treatment of patients with idiopathic scoliosis of 40° or more is presented;

– an analysis of the surgical treatment of patients with a follow-up period of at least 12 months is presented;

– an analysis of the surgical treatment of patients with incomplete bone growth (Risser 0–3) is presented;

– an analysis of the surgical treatment of patients previously not operated on for the underlying disease is presented.

Results

According to the inclusion criteria, 23 publications containing information on 826 cases of surgical treatment were analyzed. Long-term results were traced in the period of 12 to 64 months.

We reviewed the results of surgical treatment of patients with scoliotic spinal deformities using the third-generation posterior segmental instrumentation, anterior release and spinal fusion in combination with the third-generation posterior segmental instrumentation, anterior instrumentation, hybrid posterior instrumentation, transpedicular fixation with total and interval screw placement, hybrid instrumentation with a single corrective rod.

According to some data [12, 13], the use of stepwise correction of the spine with Harrington instrumentation allowed obtaining 41–47 % correction of spinal deformity in patients during active bone growth (5 to 7 distractions were performed). After 5 years from the start of the surgical treatment, less than 40 % of the surgical correction of spinal deformity was preserved. During this period, the spinal growth in the instrumentation area averaged 3.5 cm. The significant disadvantages of this method include the need for repeated interventions, the absence of the derotation effect, frequent technical and infectious complications, instability of the instrumentation, the development of pseudarthrosis in the bone block area.

The 3rd generation posterior segmental instrumentation (Cotrel-Dubousset instrumentation, CDI) was introduced into practice in 1983 and made a revolution in spinal surgery in the whole world [14–16]. Surgeons all over the world using CDI obtained good results for the correction of scoliotic deformities in patients with idiopathic scoliosis and incomplete growth. Moreover, the 3rd generation instrumentation allowed avoiding multistage distractions. However, as described above, many authors came to a consensus that posterior fixation by CDI should be combined with epiphyseal spinal fusion for stabilization of a scoliotic curve and prevention of postoperative progression.

In 1997, Lee et al. [17] published an article with results of surgical correction of scoliosis using posterior instrumentation (CDI) in 63 patients aged 10–11 years in the active growth phase (Risser 0–1) with a postoperative follow-up period of 5 to 16 years. As a result, postoperative progression was observed in almost half of the patients.

Dubousset et al. [18] analyzed 39 cases of surgical correction of scoliotic spinal deformity in Risser 1 patients performed in one step using posterior instrumentation (CDI) only. In all cases, an increase in a scoliotic curve was noted in the long-term follow-up period. According to the authors, this circumstance is an inevitable consequence of continued spinal growth in conditions of posterior instrumental fusion without development of pseudarthrosis of the bone block or violation of the integrity of spinal hardware. The authors indicate that, in order to achieve stable correction in patients with incomplete bone growth, anterior fusion in combination with posterior instrumental fixation is required.

Tao et al. [19] in their study presented the results of the correction of spinal deformity in 67 patients with idiopathic scoliosis during incomplete bone growth. All patients were divided into 3 groups depending on the surgical treatment method used: hybrid instrumentation or total transpedicular fixation with interval and sequential arrangement of screws. At the end of the postoperative follow-up period, which amounted to 36 months, the following results were obtained: postoperative progression of scoliotic deformity was noted in 33 % of the cases in the first group, while the phenomenon was absent in the groups 2 and 3.

Lapinksy et al. [20] analyzed the results of surgical treatment of a number of patients dividing them into two groups. Group 1 included 14 Risser 0–1 patients with incomplete growth who underwent anterior spinal fusion in combination with posterior instrumental correction with hook systems; group 2 was comprised of 12 patients who underwent only posterior instrumental hook fixation. In group 1, the average age of the patients was 10.7 years, the average postoperative follow-up period was 37 months, group 2 was characterized with the average age of 11.1 years and the average postoperative follow-up period of 64 months. The magnitude of correction of the main curve was 77 % in group 1 and 63 % in group 2. By the end of the follow-up period, postoperative progression did not exceed an average of 10° in group 1, while correction loss significantly exceeded 10° in group 2. The authors came to the conclusion that a two-stage approach with the use of anterior spinal fusion and posterior instrumental fixation is required to prevent the development of the crankshaft phenomenon.

Roberto et al. [21] presented the data of a retrospective study that included 86 patients with idiopathic scoliosis during active bone growth. All patients underwent posterior spinal fusion. Postoperative progression was ⩽10° in 62 (72 %) patients, 11–15° in 18 (21 %) patients and ⩾16° in 6 (7 %) cases. The authors conclude that, in order to prevent the development of the crankshaft phenomenon in patients in the period of incomplete bone growth, it is necessary to combine the anterior and posterior stages of surgical correction.

Betz et al. [22] conducted a comparative analysis of the results of surgical correction of idiopathic scoliosis between two groups of patients with a minimum postoperative follow-up period of 24 months: group 1 consisted of 78 patients who underwent surgical correction using anterior instrumentation; group 2 included 100 patients with surgical correction using third-generation segmental instrumentation. All patients had curve types ranging from II to V according to King's classification and the average initial deformity of 57°. The average age of the patients in both groups was 14 years. The average magnitude of postoperative correction was 58 % in group 1 and 59 % in group 2. Complications in the postoperative period included: pseudarthrosis in 4 (5 %) patients in group 1 and in 1 (1 %) patient in group 2, violation of the integrity of spinal instrumentationin 24 (31 %) patients in group 1 and in 1 (1 %) patient in group 2. Postoperative correction loss of more than 10° was observed in 18 (23 %) patients of group 1 and in 12 (12 %) patients of group 2.

Technological progress does not stand still, and, instead of hook fixation, hybrid and total pedicle screw instrumentation combining the advantages of CDI with the reliability of transpedicular fixation have appeared [23, 24].

Our colleagues from St. Petersburg [25] used transpedicular spinal systems for correction of thoracolumbar and lumbar idiopathic scoliosis and received a 90.3 % correction of the thoracolumbar curves and a 87.5 % correction of lumbar curves, while the average magnitude of residual deformities was 5.5° and 7.2°, respectively.

Some authors note that the use of only posterior segmental hybrid instrumentation in adolescents aged 10–14 years can provide the same correction of rigid idiopathic scoliosis with a magnitude exceeding 75° as when performing a two-stage surgical intervention with releasing discectomy [26]. Other surgeons for the correction of Lenke 1 spinal deformity in patients with incomplete growth aged 10–14 years prefer total pedicle screw fixation instead of using hybrid instrumentation [27].

Tsirikos et al. [28] published the data obtained from a retrospective study that included 99 patients with idiopathic thoracic scoliosis (mean age 12.8 years). Patients underwent surgical correction of scoliotic deformity using a single-rod hybrid instrumentation. The average postoperative correction of the main curve was 62 % (range, 73° to 28°). The average duration of surgical aid was 153 minutes, the average intraoperative blood loss was 530 mL. The postoperative follow-up period was 3.2 years (range, 2 to 12 years). According to the authors, this technique for the correction of idiopathic scoliosis allowed achieving satisfactory results with a short duration of surgical aid, low intraoperative blood loss and a low incidence of postoperative complications.

O'Donnell et al. [29] presented the results of surgical correction of Lenke type 5 idiopathic scoliosis (thoracolumbar/lumbar curve). A total of 149 adolescents were operated on. In 51 cases, posterior segmental instrumentation (group 1) was used, anterior instrumentation (group 2) was used in 98 cases. There were no demographic differences between the groups. The initial average magnitude of the main curve was 44.2° in group 1 and 48.2° in group 2. The average number of instrumented segments

was 5.9 in group 1 and 4.6 in group 2. The duration of surgery was 223 minutes in group 1 and 297 minutes in group 2. In group 1, the duration of postoperative hospital stay was 6.1 days in group 1 and 5 days in group 2. The correction rate of the main curve was similar between the groups 2 years after surgical treatment (66 % in group 2, 62 % in group 1). The authors noted the absence of any significant differences in clinical outcomes or the frequency of complications between the groups.

Richter et al. [30] presented the results of surgical correction of idiopathic scoliosis in growing patients with 40° to 90° deformities of Lenke type 1 (main thoracic curve) and Lenke type 5 (thoracolumbar/lumbar curve) using anterior instrumentation and spinal fusion. A 60–70 % frontal correction was achieved. Spontaneous correction of secondary curves of about 40 % and restoration of the physiological profile were also noted. According to the study results, the authors concluded that the magnitude of the correction and the quality of spinal fusion are comparable with the results of the surgery using modern transpedicular systems.

Kim et al. [31] conducted a comparative analysis of the results of surgical treatment of 52 adolescents with idiopathic scoliosis. All patients were divided into 2 equal groups depending on the surgical technique used. Pedicle screw fixation was used in group 1; hook fixation (CDH) was used in group 2. The average initial magnitude of the main curve was 63° in group 1 and 66° in group 2. The average age of the patients was 14.8 years in group 1 and 14.2 years in group 2. There were no significant differences in the sagittal balance indices, the duration of the surgical aid and the volume of intraoperative blood loss between the groups.

Group 1 included 19 females and 7 males; 20 patients had a normal sagittal profile (T5–T12, 10° to 40°), 6 patients had hyperkyphosis (T5–T12 more than 40°). Patients were distributed based on localization of the main curve and according to Lenke classification: type 1 group included 14 (54 %) patients, type 2 group included 7 (27 %) patients, there were 1 (3 %), 2 (8 %), 2 (8 %) patients in type 3, 4 and 5 groups, respectively.

Group 2 included 23 females and 3 males. The patients had a similar ratio in localization of the main curve according to Lenke; 20 patients had a normal sagittal profile (T5–T12, 10° to 40°), hypokyphosis was observed in one patient (T5–T12, less than 10°), hyperkyphosis was noted in 5 patients (T5–T12, more than 40°).

Immediately after surgical treatment, the mean magnitude of the main curve was 16° in group 1 patients and 33° in group 2 patients. Thus, the mean magnitude of correction was 76 % in group 1 and 50 % in group 2.

Two years after surgery, the loss of correction was less in group 1 (5.4 %) than in group 2 (8.0 %).

As a result of this study, the authors came to the following conclusions:

– the use of segmental transpedicular instrumentation in comparison with hook instrumentation allows achieving a greater correction of the primary and secondary curves in adolescent patients with idiopathic scoliosis;

– indicators of pulmonary function are higher in patients who underwent surgical treatment using transpedicular instrumentation;

– according to the survey (SRS-24), no significant differences in the quality of life between the patients of the first and the second groups were revealed;

– good sagittal balance was achieved and maintained in patients of both groups in the absence of intraoperative neurological complications.

Burton et al. [32] provided the data of a retrospective clinical study, which proves the effectiveness of surgical correction in patients with idiopathic scoliosis of thoracic localization greater than 70° using only posterior segmental instrumentation. In total, the study included 50 patients operated in two clinics in the period of 1989 to 1999. The duration of the postoperative follow-up period was at least 2 years (2–11 years). The average age of patients included in the study was 14.4 years. The initial curve was 75° (70–88°). The mean magnitue of deformity was 25° (10–46°) after surgery and 27° (11–46°) at the end of the postoperative follow-up period. Thus, postoperative correction equaled 64 %. In the postoperative period, one case of pseudarthrosis was registered; in one case, removal of the instrumentation was required due to persistent pain in the patient.

In their study, Arlet et al. [33] showed that, in order to achieve satisfactory results of surgical correction, the combination of anterior and posterior interventions in patients with rigid scoliotic deformities ranging from 70° to 90° during the period of active bone growth is not necessary, and the use of posterior segmental instrumentation is sufficient. The authors analyzed the results of a study including 15 patients with idiopathic scoliosis with a main thoracic scoliotic curve and an average deformity magnitude of 78.5° operated on using third-generation posterior segmental instrumentation. At the same time, the average mobility index was 32.5 % (19–42 %). The average age of the patients was 13.6 years. The average postoperative follow-up period was 32 months (18–64 months). The average number of instrumented vertebrae was 12 (range, 10 to 14). The postoperative magnitude of the main curve according to Cobb was 34.8° (range, 25 to 45°), i.e., postoperative correction equaled 54 % (40.0–67.1 %). In patients with initial hypokyphosis, the kyphotic curve was corrected to an average degree of 11° to 18°. Three out of 15 patients experienced complications: one case of excessive intraoperative blood loss, one case of early and one case of late surgical site infection were noted. One patient developed the adding-on phenomenon.

Our colleagues [34] demonstrated the results of surgical correction in patients with severe scoliotic deformities exceeding 90°. Four groups of surgeries were formed depending on the volume of surgical intervention: group I (3 patients) with correction of spinal deformity using third-generation segmental instrumentation (CDI); group II (4 patients) with skeletal traction from calvarial bones to supramalleolar areas in combination with correction of spinal defor-

mity using third-generation segmental instrumentation (CDI); group III (14 patients) underwent a combination of anterior release with interbody fusion and correction of spinal deformity using third-generation segmental instrumentation (CDI); group IV (58 patients) underwent skeletal traction from calvarial bones to supramalleolar areas, anterior release with interbody fusion, correction of spinal deformity using third-generation segmental instrumentation (CDI). The initial magnitude of scoliotic deformity was 109.0° (90–149°) in all groups. Postoperative deformity correction was 55.0° (50.5 %). The average deformity magnitude was 58.4° (14–96°) in the long-term postoperative period. With an average follow-up of 1.3 years, the postoperative progression of the main scoliotic curve from the achieved correction was 3.4° (6.2 %).

The authors also evaluated the deformity magnitude in the lateral flexion position. In group I, the deformity in the lateral flexion position decreased from 122.3° to 93.0°, it equaled 67.3° after surgery; in group II, it decreased from 116.8° to 99.0° and to 70.8° after surgery; in group III, it decreased from 106.4° to 85.5° and to 59.6° after surgery; in group IV, the initial magnitude was 107.9°, 90.8° in the lateral flexion position and 50.2° after multistage surgery.

Conclusion

Modern surgical techniques are aimed at achieving the best correction while preserving a greater number of vertebrae free of instrumentation, a good cosmetic effect and the return of patients to their previous physical activity.

The prevalence of anterior interventions such as discectomy and anterior spinal fusion at the early stages of the scoliosis surgery evolution was justified. This was due to the lack of instrumentation at that time to prevent postoperative progression of scoliotic deformity in growing patients. The occurrence of crankshaft phenomenon was prevented by performing intraoperative spine release and subsequent stabilization owing to the formation of interbody bone block.

With the advent of new generations of instrumentation, in most cases, many surgeons question the need for anterior release and spinal fusion in idiopathic scoliosis.

Despite the fact that the method of total transpedicular fixation occupies a leading position at the present stage of scoliosis surgery evolution, one should not neglect anterior spinal fusion. The need for anterior intervention is determined not by the prevention of possible postoperative progression but by the magnitude of spinal deformity, i.e., anterior surgery is performed to mobilize severe and rigid scoliotic deformity. Anterior release remains a relevant and necessary stage of surgical treatment in patients with severe and rigid spinal deformities at any age.

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