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A novel approach to surgical treatment of adolescent idiopathic scoliosis in skeletally immature patients

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ABSTRACT

Purpose: Describe the surgical technique and experience using the LSZ growing system in skeletally immature patients for two–stage surgical treatment of adolescent idiopathic scoliosis (AIS).

Methods: Eleven skeletally immature patients who underwent two-stage surgical treatment of AIS in our center were retrospectively analyzed. Patients initially treated with the LSZ growing system were observed for an average of 40.5 months (range 23–64 months) and for 4 years after planned replacement of the LSZ growing system with a standard pedicle screw system.

Results: The average preoperative angle of the main thoracic curve was 64.55 ± 3.21°, and that of the lumbar curve was 46 ± 5.52°. After instrumentation using the LSZ growing system, the thoracic curve was corrected to 17.63 ± 5.14°, and the lumbar curve to 9.2 ± 5.45°. The correction percentages were 72.52 ± 8.35 and 80.59 ± 10.77, respectively. After planned replacement of the LSZ system with a pedicle screw system, the angle of the thoracic curve changed to 11.45 ± 4.84°, and the lumbar curve to 6.4 ± 4.72°. The percentages of final correction were 82,1 ± 7,91 and 85,64 ± 5,47, respectively. The difference in the "LSZ growth coefficient" was 0.063 ± 0.037, which indicates continued growth of the spine along the instrumented region. None of the patients had neurological or infectious complications.

Conclusion: Our study demonstrates the safety and effectiveness of 2-stage treatment of AIS using the LSZ system, which allows for spine growth during the period between stages.

1. Introduction

Scoliosis is defined as a three-plane structural deformity of the spine and trunk with a Cobb angle ≥ 10° and axial rotation. Adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis.[1] Approximately 10 % of diagnosed cases of idiopathic scoliosis require conservative treatment and approximately 0.1–0.3 % require surgical treatment.[2]

The main conservative method of AIS treatment is rigid individualized bracing. Bracing is most effective in skeletally immature AIS patients with deformities in the range of 25–40°.[2,3] In cases of deformity progression to more than 50°, regardless of the degree of bone maturity, surgical treatment is indicated. In most cases, definitive fusion with pedicle screw systems is used, which has proven itself effective and reliable.[4,5]

In recent years, there has been an active development of growth-friendly spine systems, that allow for the growth of the spine in the right direction, and help to prevent spinal deformity progression as well as delay the time to definitive spinal fusion.[6] For the most part, these systems are used in patients with early-onset scoliosis (EOS), but there are also reports of their implementation in skeletally immature AIS patients.[7,8]

In 2014 a group of authors[9] have described a classification system of growth friendly spinal implants and identified 3 categories of implants based upon the forces of correction. Distraction-based systems – where spinal deformity is corrected by distractive force that acts on the spine through anchors at the top and the bottom of the construct (traditional

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Abbreviations

AIS adolescent idiopathic scoliosis
EOS early-onset scoliosis
SD standard deviation

growing rods, vertical expandable titanium rib prosthesis, and magnetic growing rods); compression – based systems – where deformity is corrected via compressive force applied to the convexity of the curve, causing convex growth inhibition (vertebral body staples and vertebral body tethering); guided growth systems – where deformity is corrected using translation force at the time of initial surgery and anchors are not rigidly attached to the rods, allowing the anchors to slide over the rods when the spine is growing (Luque trolley and Shilla). All these approaches have certain technical advantages over the others, however, most of them are associated with a number of drawbacks and complications, rendering the problem of surgical treatment of the growing spine largely unsolved.

The purpose of this article is to describe the surgical technique and preliminary results of using the novel LSZ growing system as a two–stage surgical treatment of AIS.

2. Materials and methods

This article presents a retrospective review of 11 patients (10 female, 1 male) who underwent 2-stage surgical treatment of AIS in our center. The patients were followed-up after LSZ growing system treatment (1st stage) for an average of 40.5 months (range 23–64 months) and for 4 years after the replacement of the LSZ growing system with the standard pedicle screw system (2nd stage).

All patients were diagnosed with AIS. The following inclusion criteria were used: 1. Major thoracic curve. 2. Major thoracic Cobb angle between 60° and 70°. 3. Normal thoracic kyphosis profile. 4. Risser score less than 2. 5. Meet the follow-up period requirements. The type of deformity according to the Lenke classification was not used as an inclusion criterion due to the limited cohort of patients. According to the Lenke classification, the distribution of patients was as follows: 5 patients with type IAN, 3 patients with type IBN, 2 patients with type IICN and 1 patient with type IIICN. Patients excluded from the study included those that: 1. had a major lumbar curve. 2. had a Risser score more than 2. 3. did not qualify for the established follow-up period. 4. continued treatment in a different medical center.

The duration of the surgical interventions, blood loss, intra- and postoperative complications were documented. The deformity Cobb angle was evaluated before the start of treatment, after the placement of the LSZ system, before the replacement of the LSZ system, after replacement with the pedicle screw system, and 4 years after the last surgery.

The continued growth of the spine after index LSZ surgery was estimated using the "LSZ growth coefficient" introduced by us, which is expressed in relation to the distance between the point of contact of the proximal and distal laminar hook to the length of the plate, measured on X-rays of the spine. This coefficient was measured on X-rays after the implantation of the LSZ growing system and before the replacement of the LSZ growing system. An increase in the value of the "LSZ growth coefficient" measured before replacing the LSZ growing system relative to the value of the "LSZ growth coefficient" measured after the initial installation of the LSZ growing system indicates an increase in the distance between the proximal and distal laminar hooks and, as a result, allows to assess the amount of growth of the spine.

Patients were referred for follow-up examinations at 3,6,12 months after the 1st stage of surgery, and consequently 1 time a year before the 2nd stage of surgery. After completing the 2nd stage of treatment, patients were also observed for a period of 3,6,12 months and then 1 time per year. The recommended replacement time for the LSZ growing system was 24–36 months from the moment of its implantation, depending on the age of the patient at the time of initial surgery. Some patients ignored our recommendations, which is why the replacement of the LSZ occurred at a later date. X-rays of the spine were performed at each follow-up examination of patients.

Descriptive statistics methods were used to analyze the obtained data. Categorical variables were expressed as quantity (n) and percentage (%), and continuous variables were expressed as mean ± standard deviation (SD).

2.1. Surgical technique

A standard posterior approach to the spine is performed. The bases of the spinous processes and the laminae of the vertebrae are exposed. The facet joints are not exposed. Then laminar hooks are fixed to the laminae next to the bases of the spinous processes. The original design of the hook (its curvature and the tip shape) ensures that the hook slides along the bone, pushing aside the underlying tissues (yellow ligament and dural sac), without causing mechanical injury. The bolt that is introduced through the threaded hook base, perforates the lamina and reaches the hook's apposing part at the moment of fixation. The laminar hook base represents a special platform on which the plate will be rested (Fig. 1A and B). This type of laminar hook fixation ensures its stability and excludes displacement during both the installation of the plate and the subsequent deformity correction. The size and shape of the hook's curvature as well as the length of the inner (inserted under the lamina) and outer (located above the lamina) parts of the hook exclude the possibility of spinal canal stenosis (Fig. 2a). Fig. 2 demonstrates the placement of LSZ laminar hooks from different viewpoints. Next, a rectangular 6 × 4 mm plate is installed (Fig. 3). The length of the plates is adjusted intraoperatively according to the length of fixation and expected growth of the spine. Plates are bent by special tools according to deformity shape. After the plates are modeled, they are positioned along the spine and held in place using special clips. Then, as the setscrews are tightened, the plates are approximated towards the hook bases, providing three-dimensional correction of the spine. The clip has a plate housing element that slightly exceeds the height of the plate, preventing rigid plate fixation and allowing for free movement of the hooks along the plate in the longitudinal direction as the spine grows. A special lock is installed on the plates, preventing longitudinal dislocation of the entire plate from the hooks. Finally, the wound is closed in layers and drains are placed.

During the second stage (definitive fusion) surgery, an approach similar to the index surgery is performed. Scar tissue is excised, the LSZ system is dismantled. After exposure of the facet joints, standard pedicle screw stabilization of the spine is performed with partial resection of the facet joints, then the correction of spinal deformity is done in three planes using standard techniques and tools. Along the length of the construct, posterior fusion is performed using autologous graft material. The wound is closed in layers and drains are placed.

3. Results

3.1. Patient demographics

Of the 11 fully tracked patients, there were 10 females. The average age at the time of the index LSZ surgery was 12.2 ± 0.87. All patients had a major thoracic curve with or without a lumbar compensatory curve. All patients had incomplete bone growth. Seven patients (63,6 %) had Risser score 0, two patients (18,2 %) had Risser score 1 and two patients (18,2 %) had Risser score 2.

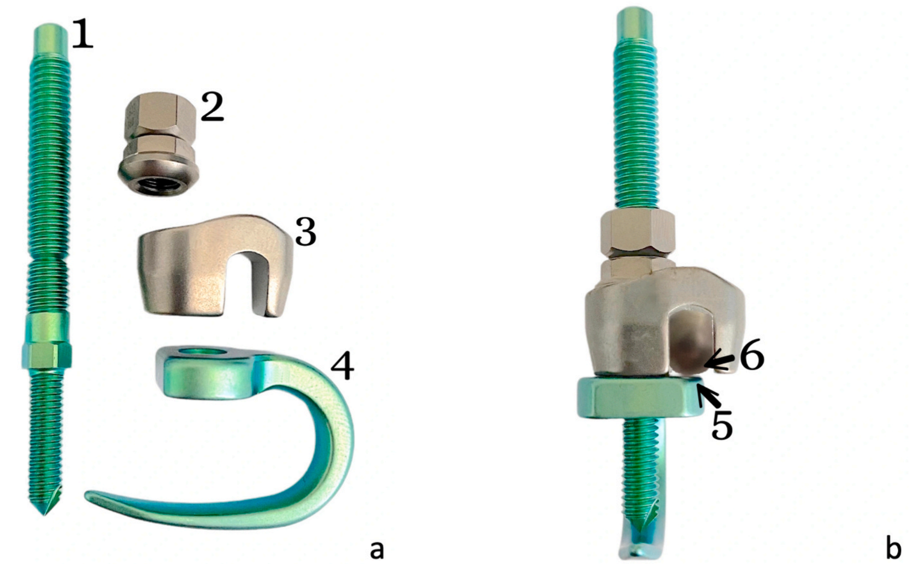

Fig. 1. The appearance of the LSZ system. a – Laminar hook for the lumbar spine, disassembled view; 1 –bolt; 2 – set screw; 3 – clip; 4 – laminar hook. b – Assembled laminar hook, (view relative to the axial plane of the plate) 5 – threaded hook base; 6 – end tip of the plate. Note that the clips do not fasten the plates to the hook base (5), allowing them to move freely along the plate in the longitudinal direction as the spine grows.

Fig. 2. Outline of LSZ laminar hook placement on a plastic vertebra model. a – axial view, b – sagittal view, c – posterior coronal view.

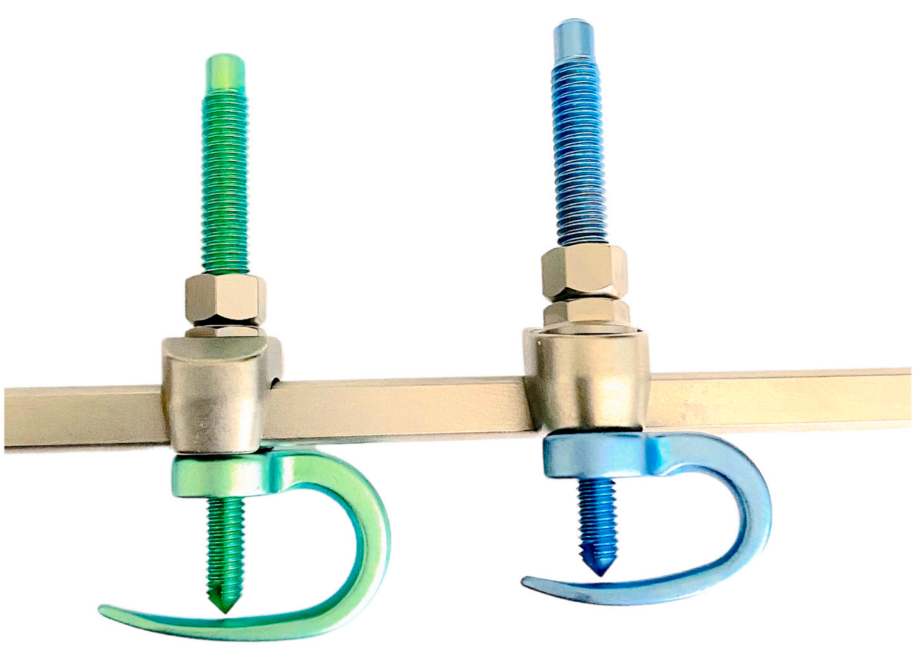

Fig. 3. Part of the LSZ growing system in assembled state. The blue hook is smaller than the green one because it is designed for the thoracic spine.

3.2. Intraoperatively

The LSZ growing system fixation length was 13.55 ± 1.29 vertebrae, while standard pedicle screw system length averaged 13.64 ± 0.81. The average blood loss during the 1st surgery was 145.45 ± 90.7 ml, and 209.1 ± 66.4 ml during the 2nd procedure. The average duration of the 1st surgery was 85 ± 16.88 min, and 152.72 ± 17.94 min for the 2nd procedure.

3.3. Radiographic data

The average initial preoperative angle of the main thoracic curve was 64.55 ± 3.21°, while the average lumbar curve was 46 ± 5.52°. After instrumentation using the LSZ system, the thoracic curve was corrected to 17.63 ± 5.14°, and the lumbar curve to 9.2 ± 5.45°. The percentage of correction for the thoracic and lumbar curves were 72.52 ± 8.35° and 80.59 ± 10.77°, respectively. Before replacement of the LSZ system with the pedicle screw system, the average angle of the thoracic curve was 21.1 ± 4.18°, and that of the lumbar curve was 14 ± 3.61°. After final instrumentation with the pedicle screw system, the angle of the thoracic curve was 11.45 ± 4.84°, and that of the lumbar curve was 6.4 ± 4.72°. Detailed data is presented in Table 1. As can be seen in Table 1, there was a slight loss of correction over time, which was compensated by performing the 2nd procedure. It is worth noting that one patient has demonstrated an increase in deformity correction by 12.1 % during the postoperative period after the LSZ surgery, which we associate with the patient's age at index LSZ instrumentation (10 years) and, as a consequence, an earlier LSZ replacement relative to the patient's age (at 14 years).

3.4. Spine growth

To assess the growth rate of the spine after LSZ instrumentation, the difference in the "LSZ growth coefficient" was estimated using the values taken immediately after LSZ procedure and immediately before the LSZ replacement. The average "LSZ growth coefficient" right after LSZ instrumentation was 0.9 ± 0.036, and 0.96 ± 0.05 right before its replacement. The difference in the coefficient was 0.063 ± 0.037, which indicates continued growth of the spine (Figs. 4 and 5).

3.5. Replacement of the LSZ growing system

None of the patients showed signs of spontaneous fusion at the time of the 2nd surgery, which made it possible to achieve additional correction during final pedicle screw instrumentation (Table 1). Also, all 11 patients had signs of metallosis of varying severity, mainly in the lumbar spine, which is associated with the high mobility of this region of the spine. The development of metallosis is perceived by us as an integral part of any growing system.

The average time from the moment of LSZ instrumentation to its replacement was 40 ± 10.55 months.

3.6. Complications

There was no neurological deficit observed in any of the patients during or after either surgery. There were also no infectious complications. In two patients, revision surgeries were performed. In one patient, the adding-on phenomenon was observed, as the deformity progressed below the level of fixation due to initial selective correction of the thoracic spine by the LSZ system. This patient underwent an extension of the LSZ system to the L4 vertebra. In another patient, at a 22-months follow-up, a plate fracture occurred in the lumbar spine with migration of the fragment. The fractured plate was replaced.

We do not consider the "slippage" of laminar hook clips past the proximal or distal poles of the plates as a complication in itself, because it is a predictable event that can potentially occur within 3–4 or more years of observation from the moment of the initial instrumentation using the LSZ system due to the growth of the spine. This type of "slippage" occurred in five patients. We did not perform revision surgeries in those patients, because there were no signs of instability of the entire system and the patients had no complaints. These patients completed the 2nd stage of treatment within the planned period.

4. Discussion

In this retrospective study, we demonstrate the safety and results of using the LSZ growing system in adolescent idiopathic scoliosis in skeletally immature patients. In this cohort, there was significant improvement in the deformity angles after the initial instrumentation using the LSZ system with a slight loss of the achieved correction by the 4th year of follow-up, which was compensated by subsequent definitive pedicle screw instrumentation. Also, due to absence of spontaneous fusion and continued growth of the spine, final pedicle screw instrumentation allowed to achieve a greater correction in comparison to the initial correction. None of the patients showed significant deterioration of the deformity during the period leading up to the 2nd stage of surgical treatment, and no neurological or infectious complications arose.

The concept of spinal growth management using growing spinal rods is based on the use of the growth potential of the child's spinal column and originated with the Luque Trolley sliding technique. The "trolley" concept implied a non-fusion approach, with bilateral sublaminar wires connected to smooth longitudinal rods positioned along the vertebral laminas. The results of using this approach were contradictory, mostly related to the high frequency of spontaneous fusion due to subperiosteal wire conduction; high frequency of revision interventions approaching 100 %; and frequent infectious and neurological complications. That is why this method has gradually fallen out of use, with the exception of several centers.[10–12]

The previously widely used SHILLA technique comprises the correction of the apical region of the deformity using bilaterally placed monoaxial pedicle screws leading to fusion at this level. In the proximal and distal poles, polyaxial screws are placed without subperiosteal exposure and spinal fusion. In these screws, the setscrew does not fix the rod, but is attached to the top of the pedicle screw, thereby allowing the screws to slide longitudinally relative to the rods without hindering the

Table 1
Dynamics changes in radiographic deformity parameters throughout treatment.

	Before LSZ surgery, degrees ±SD	After LSZ surgery, degrees ±SD	% correction after LSZ surgery ±SD	Before pedicle screw surgery, degrees ±SD	% correction loss before LSZ replacement ±SD	After pedicle screw surgery, degrees ±SD	Final correction, % ± SD	4 years after final pedicle screw surgery, degrees ±SD
The main thoracic curve	64,55 ± 3,21	17,63 ± 5,14	72,52 ± 8,35	21,1 ± 4,18	5,43 ± 8,51	11,45 ± 4,84	82,1 ± 7,91	12,3 ± 5,16
Lumbar curve	46 ± 5,52	9,2 ± 5,45	80,59 ± 10,77	14 ± 3,61	10,89 ± 6,01	6,4 ± 4,72	85,64 ± 5,47	6,6 ± 2,32

SD – standard deviation.

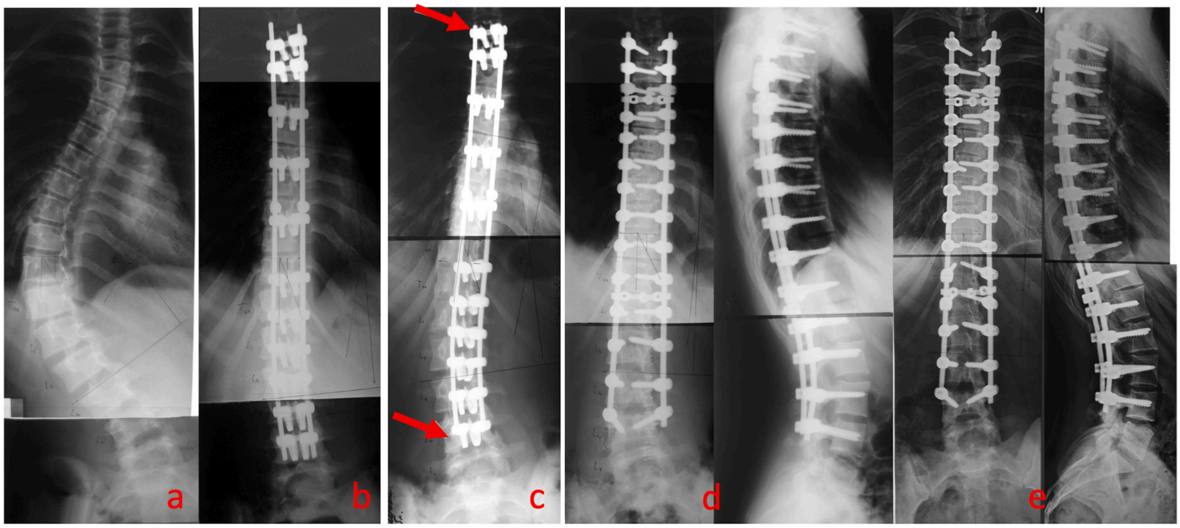

Fig. 4. The result of surgical treatment of a 12-year-old patient with AIS (Lenke IBN) with a deformity angle of 69°. a - X-ray of the spine in AP view before surgery. b - X-ray of the spine after instrumentation using the LSZ. The angle of residual deformity is 13°. c - Examination a 3-year follow-up, shortening of the proximal and distal free ends of the plate is noted due to an increase in the distance between the proximal and distal points of attachment of hooks to the plate, which indicates continued growth of the spine (red arrows). The angle of residual deformity is 18°. d - X-rays of the spine in AP and lateral views after replacing the LSZ with a pedicle screw system. Cobb angle of the residual deformity is 5°. e – X-rays of the spine in AP and lateral views at a 4-year follow-up to the final surgery. Deformity angle 4°.

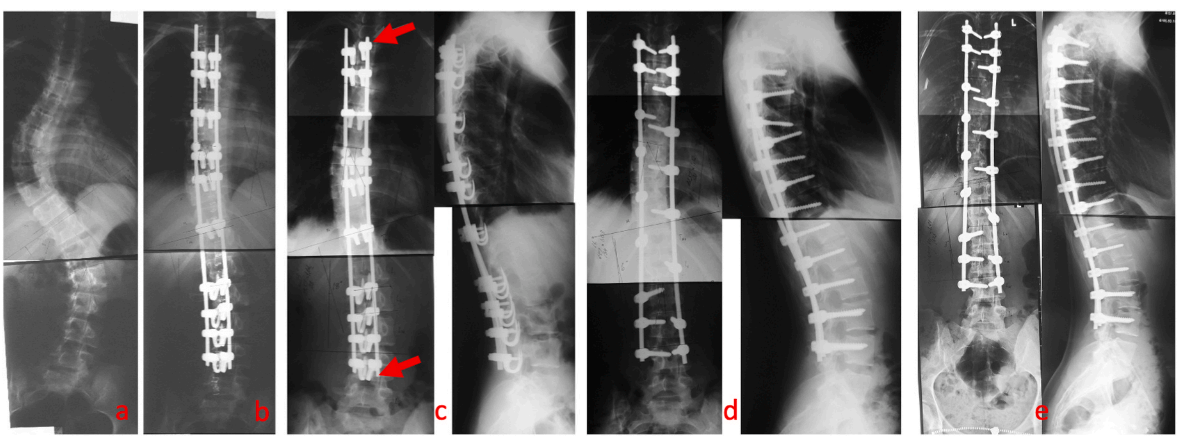

Fig. 5. The result of surgical treatment of a 13-year-old patient with AIS (Lenke IIICN). a - X-ray of the spine in AP view before surgery: the angle of the main curve is 63°, the lumbar curve is 52°. b - X-ray of the spine in AP view after instrumentation using the LSZ. The angle of the thoracic curve is 23°, the lumbar curve is 14°. c - X-rays of the spine in AP and lateral view at a 3-year follow-up to the initial LSZ instrumentation. There is a shortening of the proximal and distal free ends of the plate (red arrows). The angle of the thoracic curve is 28°, the lumbar curve is 18°. d - X-rays of the spine in AP and lateral views after replacement of the LSZ with a pedicle screw system. The angle of the thoracic curve is 18°, the lumbar curve is 6°. e – X-rays of the spine in AP and lateral views at a 4-year follow-up after the final surgery. The angle of the thoracic curve is 16°, the lumbar curve is 3°.

growth of the spine.[13]

McCarthy et al.[14] in a preliminary report showed promising results of the SHILLA technique during a two-year follow-up period. But with a longer follow-up, these results were not confirmed as Andras et al.[15] conducted a retrospective comparative study of the use of the SHILLA technique versus growing rods in the treatment of EOS. After performing the primary surgery, the SHILLA group demonstrated greater deformity correction with an average Cobb angle of 26°, compared with the growing rod group, in which the average Cobb angle was 38°. However, over time, the Cobb angles in the SHILLA group increased compared to the values achieved initially. At the final follow-up, the average Cobb angle in SHILLA patients amounted to 45° compared to 35° in the growing rods group.

It is worth noting that the Luque Trolley and the SHILLA techniques, as well as other growth-friendly spine implants, are mainly used in patients with EOS. This group of patients is considered the most complicated in terms of treatment and outcomes, which does not allow us to compare our data with that available in literature.

Kwan et al.,[16] conducted a retrospective study of the results of surgical treatment of 1057 patients with AIS, using posterior pedicle screw instrumentation. The average age of the patients was 15.6 ± 3.7. The majority of patients had Lenke type 1 (46.9 %) deformities. For thoracic deformities, the average preoperative and postoperative values of the main curve angles were 67.9 ± 17.8° and 24.0 ± 12.1° respectively, with an average correction percentage of 65.3 ± 11.7 %. The average preoperative angle of the main curve for thoracolumbar/lumbar deformities was 62.3 ± 13.9°, while the average postoperative angle of the main curve was 20.8 ± 11.0°, with an average correction percentage of 67.4 ± 13.4 %. The average duration of the surgery was 146.8 ± 49.4 min. The average intraoperative blood loss was 952.9 ± 530.4 ml, while 53 patients (5 %) required allogeneic blood transfusion.

Assessing the reliability of spine fixation using the LSZ laminar hooks, Wilke et al.[17] in an in vitro experiment compared the primary and long-term stability of fixation of the thoracolumbar spine with LSZ laminar hooks in comparison with pedicle screws. Twelve bisegmental freshly frozen human thoracolumbar (T11–L1) spine samples with an average age of 74.5 years (range 47–86 years) were used. The samples were divided into two groups of 6 with comparable values of age and bone mineral density (BMD). The performed tests showed similar primary and long-term stability during flexion/extension and a tendency for greater flexibility during lateral bending and axial rotation in LSZ instrumentation. The differences were not significant for either primary stability or the risk of implant loosening between both stabilization systems.

The development and practical implementation of the LSZ system at our center allowed to perform primary spinal deformity correction and stabilization in skeletally immature patients with AIS, minimizing the risks of deformity progression and not interfering with the normal growth of the spine. The primary surgical intervention can be performed relatively quickly, with minimal blood loss, considering the severity of the disease and without disturbing the bone anatomy of the spine. Due to these factors, planned or revision replacement of the LSZ system is associated with lower risks, compared to alternative surgical approaches in this group of patients.

The main limitations of this study are the limited sample size, the lack of a comparison group, limited statistical analysis, which we will take into account and correct in subsequent studies.

5. Conclusion

Comparing our own data with literature data, we can hypothesize that the approach proposed by us in this article is a viable alternative allowing for better correction and continued spinal growth during the period before the final fusion. Subsequent studies with a larger sample of patients and a full statistical analysis may confirm or refute this hypothesis.

Currently, the use of the LSZ growing system at our center is limited to severe spinal deformities in skeletally immature patients with AIS. Subsequent publications will be aimed at evaluating the effectiveness of the presented approach in this group of patients.

CRediT authorship contribution statement

Mukhammad Tablikhanovich Sampiev: Methodology, Conceptualization. **Nikolai Vasilevich Zagorodniy:** Supervision, Methodology. **Shamil Khambalovich Gizatullin:** Writing – review & editing. **Ilya Petrovich Dubinin:** Resources. **KHava Magomedovna Chemurzieva:** Visualization, Project administration. **Ivan Stanislavovich Lysenko:** Writing – original draft, Investigation.

Declaration of Competing Interest

none.

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