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SURGICAL TREATMENT OF LOWER LUMBAR SPINE PATHOLOGY IN CHILDREN AND ADOLESCENTS

© *A.V. Krutko[1], A.J. Sanginov[1], M.B. Giers[2], A.A. Alshevskaya[3], A.V. Moskalev[3]*

[1] Novosibirsk Research Institute of Traumatology and Orthopedics n.a. Ya.L. Tsiv'yan, Novosibirsk, Russia;
[2] Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, USA;
[3] Biostatistics and Clinical Trials Center, Novosibirsk, Russia

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Introduction. Analysis of the modern literature shows that the number of children complaining of low back pain of varying intensity in the spine increases annually. Publications on the surgical treatment of juvenile osteochondrosis were scarce. Currently, there are no algorithms for choosing a surgical treatment for children and adolescents with lumbar spine pathology, particularly high-grade listhesis, methods and terms of surgical treatment, and the use of reduction maneuvers remain debatable. There are no high-quality evidence studies.
Aim. This study aimed to summarize the experience of treatment of children and adolescents with pathology of the lower lumbar spine.
Material and methods. We performed a retrospective analysis of the treatment outcomes in patients with lower lumbar spine pathology who were younger than 18 years and who underwent surgery in the Neurosurgical Department No. 2 of the Tsiv'yan Novosibirsk Research Institute of Traumatology and Orthopedics between 2008 and 2018. The mean age of the patients was 15.5 years. We structured pathologies and interventions in children and adolescents and evaluated the clinical and radiological outcomes of treatment and the rate of intraoperative and postoperative complications.
Results and discussion. From 2008 to 2018, 11,428 patients with degenerative spine disease and isthmic/dysplastic spondylolisthesis underwent surgery at the Neurosurgical Department No. 2. Of these, 55 (0.5%) patients were younger than 18 years. In all patients, surgical treatment led to pain relief and physical activity recovery. Decompression/stabilization surgery through the posterior approach enabled formation of an artificial block in 100% of cases. The rate of surgical treatment complications was 8.6% and 28.6% in children and adolescents with herniated lumbar intervertebral discs and spondylolisthesis, respectively.
Conclusion. Surgical treatment of children and adolescents with pathology of the lower lumbar spine demonstrated an excellent clinical outcome. Disc herniation did not recur 4.9 years after decompression surgery for herniated lumbar intervertebral discs. Decompression/stabilization surgery through the posterior approach in children and adolescents with spondylolisthesis facilitated abolition of pain, regression of neurological disorders, full recovery of physical activity, and formation of a reliable artificial block. Potential complications were resolved without consequences and did not downplay the importance of surgical techniques in the treatment of this group of patients.

Keywords: juvenile osteochondrosis; spondylolisthesis; protrusion; lumbar disc herniation; spondyloarthrosis; microdiscectomy; fusion.

ХИРУРГИЧЕСКОЕ ЛЕЧЕНИЕ ПАТОЛОГИИ НИЖНЕПОЯСНИЧНОГО ОТДЕЛА ПОЗВОНОЧНИКА У ДЕТЕЙ И ПОДРОСТКОВ

© *А.В. Крутько[1], А.Д. Сангинов[1], M.B. Giers[2], А.А. Альшевская[3], А.В. Москалев[3]*

[1] ФГБУ «Новосибирский научно-исследовательский институт травматологии и ортопедии им. Я.Л. Цивьяна» Минздрава России, Новосибирск;
[2] Неврологический институт Бэрроу, больница и медицинский центр Святого Иосифа, Финикс, США;
[3] Научно-исследовательский центр биостатистики и клинических исследований, Новосибирск

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Введение. Анализ современной литературы показывает, что количество детей, обращающихся с жалобами на боли в позвоночнике различной интенсивности, увеличивается с каждым годом. Публикаций, посвященных хирургическому лечению ювенильного остеохондроза, немного. В настоящее время нет алгоритмов выбора

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метода хирургического лечения детей и подростков с патологией поясничного отдела позвоночника, особенно листезов высокой степени, остаются дискуссионными способы и сроки хирургического лечения, использование редукционных маневров, отсутствуют исследования высокой степени достоверности.

Цель — обобщить опыт лечения детей и подростков с патологией нижнепоясничного отдела позвоночника.

Материал и методы. Проведен ретроспективный анализ результатов лечения пациентов с патологией нижнепоясничного отдела позвоночника в возрасте до 18 лет, прооперированных в нейрохирургическом отделении № 2 ФГБУ «ННИИТО им. Я.Л. Цивьяна» за 2008–2018 гг. Средний возраст пациентов составил 15,5 года. Проведена структуризация патологий и выполненных вмешательств детям и подросткам. Оценены клинико-рентгенологические результаты лечения, частота интра- и послеоперационных осложнений.

Результаты и их обсуждение. В период с 2008 по 2018 г. в нейрохирургическом отделении № 2 прооперированы 11 428 пациентов с дегенеративными заболеваниями позвоночника и спондилолистезами (истмическим, диспластическим), из них 55 были в возрасте до 18 лет (0,5 %). Хирургическое лечение во всех случаях привело к купированию болевого синдрома и восстановлению физической активности пациентов. Формирование артифициального блока после декомпрессивно-стабилизирующих вмешательств из заднего доступа достигнуто в 100 % случаев. Частота осложнений при хирургическом лечении детей и подростков с грыжами поясничных межпозвонковых дисков и спондилолистезом составила 8,6 и 28,6 % соответственно.

Заключение. Хирургическое лечение детей и подростков с патологией нижнепоясничного отдела позвоночника показывает отличный клинический результат. Через 4,9 года после декомпрессивных операций по поводу грыжи поясничных межпозвонковых дисков рецидив грыжи диска ни в одном случае не выявлен. Декомпрессивно-стабилизирующие вмешательства из заднего доступа у детей и подростков со спондилолистезом способствуют купированию болевого синдрома, неврологических расстройств, полному восстановлению физической активности и формированию надежного артифициального блока. Возникающие осложнения купируются без последствий и не умаляют достоинства хирургических методов лечения данной категории пациентов.

Ключевые слова: ювенильный остеохондроз; спондилолистез; протрузия; грыжа поясничных межпозвонковых дисков; спондилоартроз; микродискэктомия; межтеловой спондилодез.

Introduction

Analysis of has shown that the number of children who complain of pain of varying intensity in the spine increases yearly. The incidence of Perthes disease has recently increased. According to a panel of authors, the incidence of lumbodynia in children and adolescents ranges from 10% to 30% [1]. Back pain is fairly prevalent in adolescents aged 13–15 years [2].

Yang et al. analyzed the data of adolescents aged 10–19 years who sought back pain treatment from 2007 to 2010. In 80.3% of cases, the causes of lumbodynia have not been identified as of yet. In the remaining cases, distortion of the musculo-ligamentous apparatus (muscle spasm in 8.9%), scoliosis (4.7%), degenerative lesions of the lumbar spine (1.7%), and lumbar disk hernia (1.3%) were diagnosed. The frequency of other diseases, including spondylolysis, spondylolisthesis, infection, tumor, and fracture, was less than 1% [3]. Generally, spondylolisthesis (especially stages 1–2) does not manifest clinically in children [4, 5]. Nonetheless, studies have demonstrated that the frequency of symptomatic spondylolisthesis in children amounts to 5% [6]. According to other authors, scoliosis serves as the primary cause of pain syndrome in adolescents [7].

Various studies have indicated that herniated lumbar intervertebral disk occurs in 0.1%–0.4% of children and adolescents [8, 9]. Potential risk factors for disk herniation in children include injuries (most often sports, weight lifting, falling), genetic predisposition, and impaired development of the spine [10–12]. The principles of diagnostics and conservative therapy in children and adolescents do not differ from those in adults. However, the effectiveness of conservative therapy in children is relatively low [9]. Surgical treatment shows excellent results and minimal risk of complications [13–15].

In children and adolescents, spondylolisthesis is registered in 2.4%–6.0% of the cases [16]. In children under the age of 1, spondylolisthesis may not manifest. Between the ages of 5–7, the incidence of spondylolisthesis is about 5%, and this incidence rate can increase slightly, where it reaches 6% by the age of 18. A high degree of dysplastic spondylolisthesis, as described by Marchetti and Bartolozzi, is observed in 1% of spondylolisthesis cases [17]. It has been shown that spondylolisthesis is three times more common in boys than in girls [18]. The primary complaint of children and adolescents with spondylolisthesis is pain in the lumbar spine. In some cases, compression syndrome or neurological disorders are observed.

Literature data has indicated the advantage of surgical treatment methods for the progression of listhesis and the appearance of radicular syndrome and/or neurological disorders [17, 19–24]. With regard to the frequency and efficiency of the treatment of spondylolisthesis, including scoliosis in children and adolescents, M.V. Mikhailovsky et al. revealed that revealed that non-surgical treatment for spondylolisthesis of 1–2 degrees did not affect the quality of life of patients, and surgical treatment over long-term periods could provide a greater analgesic effect, with lesser risk of complications [25].

To date, the surgical treatment of high-grade spondylolisthesis is of utmost priority. The algorithm for choosing an effective method of surgical treatment has not been developed. In addition, the current methods of surgical treatment and the use of reduction maneuvers remain debatable, and there are no high-quality studies [22, 26, 27]. Several methods of surgical treatment for high-grade spondylolisthesis have been proposed, namely, posterior spondylosyndesis with an auto-bone *in situ* (Wiltse technique), instrumental *in situ* fixation of posterior spondylosyndesis with an auto-bone, corrective interbody fusion (according to Dubousset) [28], reduction of vertebra with interbody fusion, including an overlying segment with transpedicular fixation, and transsacral screw *in situ* fixation [29, 30]. A.P. Palejwala presents a case of transsacral transpedicular *in situ* fixation in a 12-year-old adolescent with degree 4 spondylolisthesis [31]. *In situ* fixations are recommended for maintaining the parameters of the sagittal balance [32]. In the case of surgical treatment of 12 adolescents with high degree of L_5 vertebra listhesis, posterior interbody fusion of the overlying segment and reduction of the L_5 vertebra were performed. Following the treatments, the pain syndrome regressed, and no complications were identified. Moreover, radiological studies show that the angular parameters and the spinal-pelvic relationships have improved [33].

The decompressive-stabilizing intervention with screw fixation and the use of reduction maneuvers can restore the segmental lordosis and spinal-pelvic relationships as well as improve the formation of the artifactual block [34, 35]. However, reduction methods may lead to neurological type of complications, [32, 36] where the frequency of persistent neurological complications amounts to 2.75% (0%–14%). Besides, complications occur in 0.47% (0%–4%) of *in situ* fixation cases 37]. Hence, the intraoperative use of neurophysiological monitoring has been recommended to prevent neurological complications. Nakamae et al. [38] performed a decompressive-stabilizing intervention with full reduction from the posterior approach under neurophysiological monitoring. There were no complications observed during the postoperative period. On the other hand, reducing maneuvers are associated with uneven and excessive distribution of biomechanical loads on the adjacent segment. Hence, the use of the reduction maneuvers should be combined with the extension of screw fixation into the pelvis [39].

There have been several studies published on the surgical treatment of Perthes disease; however, there is no study that investigates the efficiency of radiofrequency denervation of the zygapophysial joints and cold plasma coblation of the intervertebral disk in various manifestations of this condition. Given the alarming trend of degenerative diseases developing in adolescents, we suggest that radiofrequency denervation of the zygapophysial joints and coblation should be implemented in their treatment.

Given the above, the present study aimed to summarize the experience and study the efficiency of the surgical treatment for various pathologies of the lower lumbar spine in children and adolescents.

Material and methods

A retrospective analysis was performed on 11,428 patients with degenerative diseases and spondylolisthesis (isthmic, dysplastic). From 2008 to 2018, these patients were operated upon in the neurosurgical department No. 2 of the Tsivyan Novosibirsk Research Institute of Traumatology and Orthopedics. Patients under the age of 18 constituted 0.5% of the studied group (n = 55). Descriptive statistics were used to describe the indicators collected during the study period. The mean value (M) and the standard error of the mean (m) were calculated to indicate the age of patients. All calculations were made using Microsoft Excel 2016. The distribution of patients according to nosology is presented in Table 1.

Table 1

The distribution of patients according to nosology

Nosology	Number of patients	Age, years ($M \pm m$)	Gender	
			Male, n (%)	Female, n (%)
IVD protrusion	8	16.3 ± 0.57	3 (37.8)	5 (62.2)
Disk herniation	23	15.8 ± 0.33	8 (34.8)	15 (65.2)
Spondylarthrosis	3	16.3 ± 1.1	1 (33.3)	2 (66.7)
Dysplastic spondylolisthesis	5	14.6 ± 0.8	2 (40)	3 (60)
Isthmic spondylolisthesis	16	14.8 ± 0.4	9 (56.3)	7 (43.7)
Total	55	15.5 ± 0.2	23 (41.8)	32 (58.2)

Note. IVD — intervertebral disk.

Twenty-three patients under the age of 18 (mean age 15.8 years) were operated on herniation of intervertebral disk (IVD). Upon admission to the clinic, all patients developed radicular pain syndrome. Among the patients, 4 patients (17.4%) had neurological disorders. In all cases, conservative treatment was ineffective.

Three patients were diagnosed with facet syndrome resistant to conservative treatment. Spondylarthrosis in the patients was verified by MRI. Subsequently, these patients were subjected to radiofrequency denervation of the zygapophysial joints. The average age of patients ranged from 14.6 years (in patients with dysplastic listhesis) to 16.3 years (in patients with protrusions and spondylarthrosis). In 8 patients, the protrusion of IVD was the cause of the pain syndrome. Twenty-one patients were operated on for isthmic (16) and dysplastic (5) spondylolisthesis.

The types of surgery are summarized in Table 2. MRI (as the primary diagnostic method) and radiography of the lumbar spine in two views with functional tests were conducted. Also, multislice spiral computed tomography (MSCT) of the lumbar spine and radiography of the spine with hip joints in step mode were performed on patients with spondylolisthesis.

Results and discussion

All patients with hernias of lumbar IVD had complete regression of radicular symptoms during the postoperative period. Neurological impairment was completely rectified within 1 year following

Table 2

Surgical interventions performed on children and adolescents in the clinic

Methods of surgical treatment	Nosology	Quantity, n	Age, years, $M \pm m$	Gender	
				Male, n (%)	Female, n (%)
Radiofrequency denervation	Spondyloarthrosis	3	16.3 ± 1.1	1 (33.3)	2 (66.7)
Cold plasma nucleoplasty	IVD protrusion	7	16.4 ± 0.6	3 (42.8)	4 (57.2)
Microdiscectomy	Disk herniation	6	16.3 ± 0.7	4 (66.7)	2 (33.3)
Posterior decompression, TPF, interbody fusion (posterior, transforaminal)	Spondylolisthesis, herniated disk in one case	22	14.8 ± 0.3	11 (50)	11 (50)
Endoscopic excision of a herniated disk	Disk herniation	3	14.3 ± 0.9	1 (33.3)	2 (66.7)
Medical dereception of IVD	IVD protrusion	1	15	–	1 (100)
Excision of a herniated disk, dynamic interspinal fixation (DIAM, Coflex)	Disk herniation	12	15.8 ± 0.5	3 (25)	9 (75)
Excision of a herniated disk, grafting of the defect of the fibrous ring with implant Barricaid	Disk herniation	1	17	–	1 (100)
Total	55	15.5 ± 0.2	23 (41.8)	32 (58.2)	

Note. IVD — intervertebral disk; TPF — transpedicular fixation.

the surgery. Recurrence of a herniated disk was not detected in any case within 4.9 years after the surgery (from 1 to 10 years). In one case, taking into account the median herniation of the disk along with the spinal stenosis, decompression, transforaminal interbody fusion, and transpedicular fixation were performed. The detailed results of this combination treatment were described in the multicenter work of A.A. Kuleshov et al. [40].

In the 3 patients who underwent radiofrequency denervation showed persistent clinical results, pain syndrome was relieved and physical activity restored. So far, there has been no study that has examined the efficacy of radiofrequency denervation in patients younger than 18 years old. Due to the high prevalence of degenerative diseases in adolescents, we surmised that radiofrequency denervation will be a popular choice of treatment.

Coblation was performed on 8 adolescents (average age 16.3 years). Pain syndrome was rectified only in 50% of the patients. In a patient persistent radicular symptoms manifested 8 months after the coblation; henceforth, the patient was subjected to further microdiscectomy In the remaining 3 patients, pain syndrome decreased slightly or persisted; therefore, conservative treatment was performed to alleviate it. In the literature, we have not found any studies that have assessed the efficiency of coblation in adolescents.

In the present paper, we aimed to analyze the results of surgical treatment of 21 adolescents with spondylolisthesis. In all cases, the indications for surgery were pain syndrome and/or neurological disorders and progression of dislocation according to radiological studies.

Patients mainly had isthmic (16) and dysplastic (5) spondylolisthesis. The average age of patients was 15.8 years; there were 11 boys and 10 girls (Table 3).

Spondylolisthesis, especially a high degree one, in children and adolescents requires complex surgical techniques. The main purpose of the surgery is to arrest pain and/or neurological disorders. The restoration of the vertebral-pelvic relationship and the formation of artifactual block are of great importance [41, 42, 19]. According to different authors, the frequency of fusion after surgery is 97.6% (81%–100%) [17, 36, 43]. In our series, after 2.5 years (from 12 to 40 months), formation of an artifactual bone block was revealed in all cases.

Reduction maneuvers were applied in all patients; in 14 cases, a full reduction was achieved, and in 7 cases, a partial reduction was achieved. In these patients, further reduction was not performed due to the high risk of neurological complications. S.V. Vissarionov et al. has reported on surgical treatment for L_5 spondylolisthesis in children (n = 48). In all cases, surgical treatment was performed with posterior approach and resulted in pain relief. With the degrees 1–3, complete reduction of the vertebra was achieved [1].

Clinical case

Patient B., 11 years old, was admitted to the clinic with a complaint about pain in the lumbar spine, with irradiation to the lower extremities along the outer surfaces of thighs and legs.

According to the radiological data of the lumbar spine, spondylolisthesis of degree 2 L_5 was

Table 3

Characteristics of patients with spondylolisthesis

Spondylolisthesis	Degree	Quantity, *n*	Age, years ($M \pm m$)	Gender	
				Male, *n* (%)	Female, *n* (%)
Isthmic	1	6	15.8 ± 0.7	4 (66.7)	2 (33.3)
	2	5	15.4 ± 0.8	3 (60)	2 (40)
	3	2	12 ± 1.6	1 (50)	1 (50)
	4	3	14 ± 0.7	1 (33.3)	2 (66.7)
Dysplastic	2	2	15 ± 1.3	–	2 (100)
	3	1	15	1 (100)	–
	4	1	15	1 (100)	–
	5	1	13	–	1 (100)

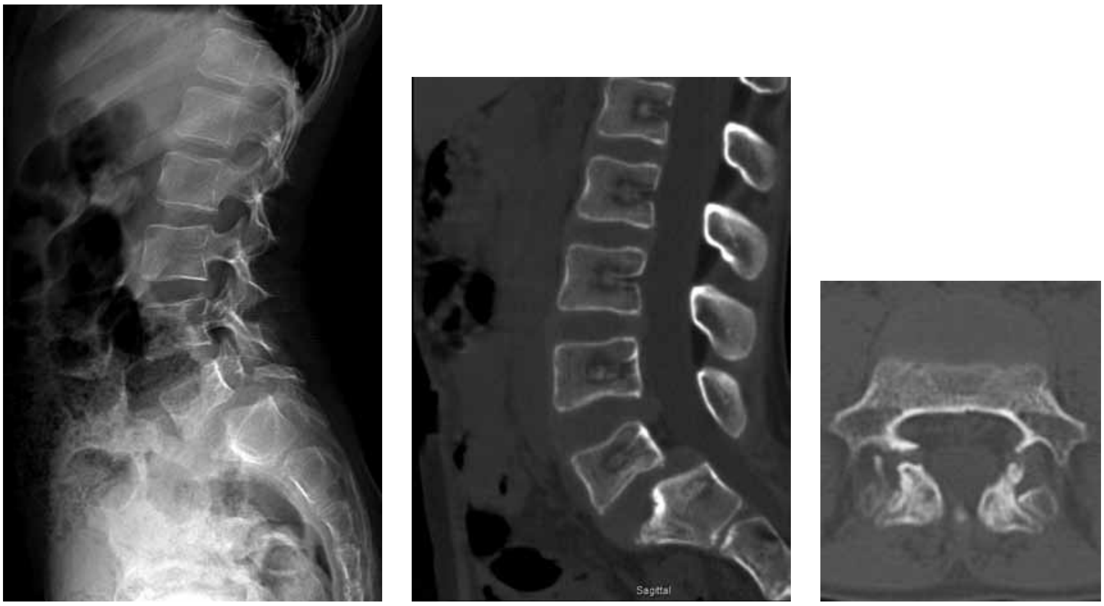

Fig. 1. MSCT of the lumbar spine before surgery

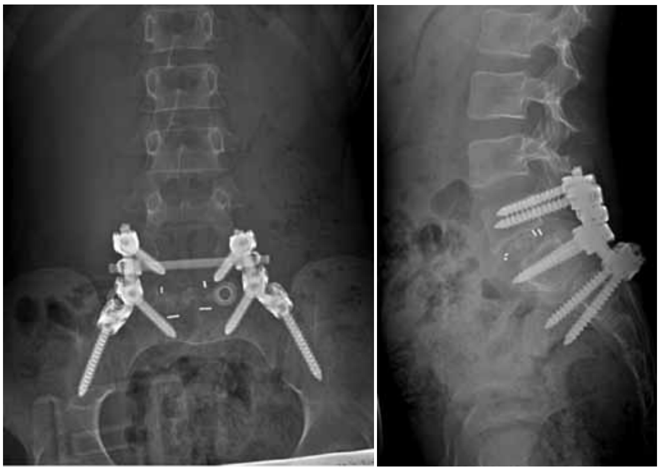

Fig. 2. Radiography of the lumbar spine in two views immediately after the surgery

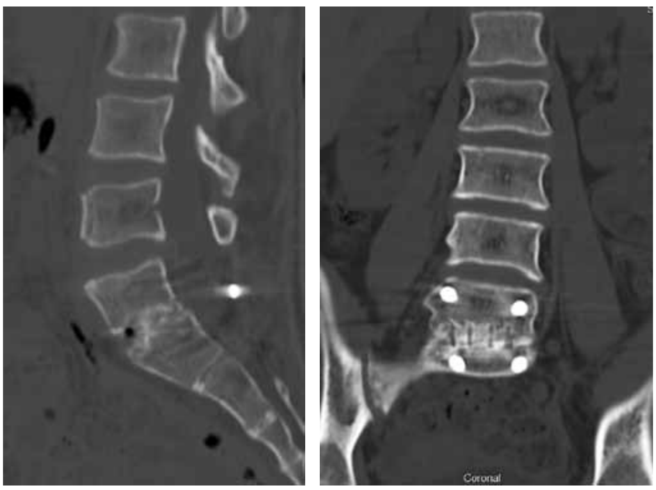

Fig. 3. MSCT of the lumbar spine 1.5 years after the surgery

detected (Fig. 1). As observed on the MSCT of the lumbar spine (see Fig. 1), there was a congenital malformation, a bilateral slit-like bone defect in the inter-articular part of the L_5 arch. *Spina bifida posterior* of L_5. True spondylolisthesis of L_5 of the degree 2. Deformity of the intervertebral disk L_5–S_1 and the cranial part of the body S_1.

After clinical, neurological, and instrumental examinations, diagnoses of dysplastic spondylolisthesis of L_5 of degree 2 (44%), bilateral foraminal stenosis of L_5–S_1, segmental instability of L_5–S_1, bilateral dynamic compression syndrome of L_5 roots, and lumbodynia syndrome were established.

Considering the persistent pain syndrome after the conservative treatment and progressive nature of spondylolisthesis of L_5, the following surgical intervention was performed: L_5 laminectomy, microsurgical decompression of the spinal cord roots, complete reduction of the L_5 vertebra, transpedicular fixation of the L_5–S_1 with additional fixation in the pelvic bone, and posterior interbody fusion of L_5–S_1. The duration of the surgery was 355 mins; the volume of blood lost was 800 ml. The patient was activated on the day 2 after surgery. During the postoperative period, the radicular pain syndrome had regressed completely, and no neurological disorders were detected. According to the control radiography, the restoration of the anatomical relationship of the vertebrae was noted. The position of the screws and implants was correct (Fig. 2). During the follow-up period, the patient had no complaints. After 1.5 years, MSCT revealed the formation of a reliable artifactual block, and the integrity of the surgical hardware was preserved (Fig. 3).

Complication

In children and adolescents with degenerative diseases of the lower lumbar spine, operation by using minimally invasive methods did not result in complications. In the 2 patients with herniated lumbar intervertebral disks, one manifested epidural hematoma and another had dura mater (DM) damage (Table 4). Given the point nature of damage to the DM, grafting was not performed. During the postoperative period, no liquorrhea was observed. According to the literature, the incidence of intraoperative DM damage in children and adolescents ranges from 1% to 5% [44, 45].

In the early postoperative period after hernia excision of the L_4–L_5 disk, a patient manifested radicular symptoms in the form of pain on the outer surface of the thigh and lower leg and weakness of the flexors and extensors of the foot. MRI data revealed that epidural hematoma was causing a compression of the dural sac; therefore, the surgery was repeated, and hematoma was excised. During the postoperative period, the radicular symptoms had regressed and the neurologic impairment completely stopped within 3 months. Besides, there are studies that describe surgical site infections (SSI) after the excision of herniated disk in children. Cahill at al. revealed SSI in 1 out of 87 operated patients [44]. There are cases of aggravation of neurologic impairment in the early postoperative period, recurrent disk herniation, and reflex urinary retention [24, 46, 47]. However, recurrence of herniated disk in our series was not observed. According to some authors, the recurrence rate is about 3.3% [47].

In a retrospective work by Huynh et al., the results of surgical treatment of children and adolescents with spondylolisthesis and/or stenosis (group A) and hernias of lumbar intervertebral disks (group B)

Table 4

The frequency and structure of the complications

Nosology	Complications			Q-ty of cases	%	Treatment	Outcome
	Intra-operative	Postoperative					
		early	late				
Disk herniation	Damage to DM	–	–	1	4.3	Considering the small size of the defect, grafting was not performed	Favorable
	–	Epidural hematoma	–	1	4.3	Repeated surgery, excision of hematoma	Favorable
Total for hernias				2	8.6	Situational	Favorable
Spondylolisthesis	Injury of DM	–	–	1	4.8	Suturing the defect	Favorable
	Radiculopathy of L_5	–	–	2	9.5	Conservative treatment	In one case it was favorable, in another case there was a moderate neurologic impairment
	–	Post-hemorrhagic anemia of moderate severity	–	2	9.5	Blood transfusion in one case, and symptomatic therapy in another case	Favorable
	–	–	Transverse fracture of S_1–S_2	1	4.8	Bed rest for 2 months, then spinal support therapy for 4 months	Favorable, consolidation
Total with spondylolisthesis				6	28.6	Situational	Favorable

Note. IVD — intervertebral disk; DM — dura mater.

were compared. It was found that the frequency of complications in group A was significantly higher (18.1% and 5.3%, $p < 0.0001$) than that of group B. In patients with spondylolisthesis and/or stenosis, more bed-days, complications, and costs were noted [48].

The present study shows that the incidence rate of complication in the treated patients was 28.6% (Table 4). Jalanko et al. reported 21% of complications in the surgical treatment of spondylolisthesis in children and adolescents. The main complications are infectious and neurological [49, 50]. Intraoperative complications were observed in 3 cases. In one patient, the DM injury was recorded, due to which the defect was sutured. Neurological impairment associated with tension of the nerve roots occurred in 2 patients. Neurological complications occur during reduction maneuvers, and their frequency can reach up to 30% [20, 51–53]. In the early postoperative period, moderate post-hemorrhagic anemia was diagnosed in 2 patients.

Late complications occurred in one case. Two weeks after the surgery, severe sacrum pain occurred in the patient. According to radiological studies, the patient was diagnosed with a lateral S_1–S_2 fracture. Symptomatic treatment was performed. Bed rest for 2 months, and subsequent spinal assistant therapy for 4 months have shown a favorable outcome. Fracture area was consolidated. In high-grade spondylolisthesis, it is advisable to combine the reduction maneuvers with the extension of lumbosacral fixation more caudally than S_1 [39]. In our series of infectious complications, there are no cases of pseudoarthrosis, migration, or violation of the integrity of the surgical hardware.

It should be noted that all complications were recorded in listhesis of grade 3 or more. In 4 cases, we used neurophysiological monitoring. In these patients, the degree of reduction is dependent on the neurophysiological monitoring results. With a decrease in induced potentials, the reduction was stopped and fixed in the reached position. None of these patients had neurological disorders in the postoperative period.

Conclusion

Surgical treatment of children and adolescents with herniated lumbar intervertebral disks leads to a complete regression of radicular symptoms and neurological disorders as well as functional recovery.

Facet syndrome due to spondyloarthrosis of the lower lumbar segments of the spine can occur in adolescents. Radiofrequency denervation is a preferred treatment method in case of failure of conservative therapy. The effect of coblation of the intervertebral disk is comparable to that of conservative treatment methods; therefore, preference should be given to the latter.

The frequency of complications with surgical treatment of spondylolisthesis in children and adolescents directly depends on the reduction maneuvers. This procedure should be performed under neurophysiological monitoring. Regardless of the frequency of complications (28.6%), the outcome of surgical treatment of children and adolescents with spondylolisthesis is favorable.

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Contribution of the authors

A.V. Krutko performed surgical treatment of the patients, formulated the aim, design, and conclusions.

A.D. Sanginov was engaged in literature review, data collection and analysis, article design.

M.B. Giers was involved in design consultancy, literature review.

A.A. Alshevskaya performed data analysis, verification of formal aspects.

A.V. Moskalev performed data analysis, verification of formal aspects.

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Information about the authors

Aleksandr V. Krutko — MD, PhD, Professor, Head of Department of Neurovertebrology Novosibirsk SRITO named after Ya.L. Tsivyan, Novosibirsk, Russia. ORCID: 0000-0002-2570-3066. E-mail: ortho-ped@mail.ru.

Abdugafur J. Sanginov — MD, Neurosurgeon Department of Neurosurgery No. 2 Novosibirsk SRITO named after Ya.L.Tsivyan, Novosibirsk, Russia. ORCID: 0000-0002-4744-4077. E-mail: dr.sanginov@gmail.com.

Morgan B. Giers — Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, USA. ORCID: 0000-0002-2247-1167. E-mail: giersmorgan@gmail.com.

Alina A. Alshevskaya — MD, PhD, Head of Biomedical Departament of Biostatistics and Clinical Trials Center, Novosibirsk, Russia. ORCID: 0000-0002-7307-4524. E-mail: alkkina@yandex.ru.

Andrei V. Moskalev — Head of Biostatistics and Clinical Trials Center, Novosibirsk, Russia. ORCID: 0000-0002-6711-3822. E-mail: andrei.v.moskalev@gmail.com.

Александр Владимирович Крутько — д-р мед. наук, начальник отделения нейровертебрологии ФГБУ «Новосибирский НИИТО имени Я.Л. Цивьяна», Новосибирск. ORCID: 0000-0002-2570-3066. E-mail: ortho-ped@mail.ru.

Абдугафур Джабборович Сангинов — врач-нейрохирург нейрохирургического отделения № 2 ФГБУ «Новосибирский НИИТО имени Я.Л. Цивьяна», Новосибирск. ORCID: 0000-0002-4744-4077. E-mail: dr.sanginov@gmail.com

Морган Гиерс — отделение нейрохирургии, Неврологический институт Бэрроу, больница и медицинский центр Святого Иосифа, Финикс, США. ORCID: 0000-0002-2247-1167. E-mail: giersmorgan@gmail.com.

Алина Анатольевна Альшевская — канд. мед. наук, начальник биомедицинского департамента, Научно-исследовательского центра биостатистики и клинических исследований, Новосибирск. ORCID: 0000-0002-7307-4524. E-mail: alkkina@yandex.ru.

Андрей Владимирович Москалев — директор Научно-исследовательского центра биостатистики и клинических исследований, Новосибирск. ORCID: 0000-0002-6711-3822. E-mail: andrei.v.moskalev@gmail.com.