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Results of surgical treatment of high-grade spondylolisthesis

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Spondylolisthesis of Grade III–IV according to the Meyerding classification, referred to in English literature as "high-grade spondylolisthesis," involves a significant degree of vertebral displacement and leads to substantial impairment of spinal function, gait disturbances, and early disability in patients. Despite the fact that clinical symptoms, classifications, and diagnostic methods have been known and established for quite some time, the issue of surgical treatment remains a subject of debate to this day. Objective. To evaluate the outcomes of surgical treatment in patients with high-grade spondylolisthesis. Methods. A retrospective analysis was conducted on the surgical outcomes of 24 patients with significant vertebral displacement who underwent intraoperative traction and transpedicular fixation using a "spine–pelvis" system. Pre- and postoperative radiographic measurements included the slip angle, pelvic incidence, lumbar lordosis, sacral slope, pelvic tilt, as well as evaluation of sagittal vertical axis alignment and pelvic tilt angle. Results. All patients demonstrated a reduction in slip angle and restoration of sagittal vertical axis alignment to within normal limits. Other parameters of spinopelvic balance were also moderately improved, thereby bringing sagittal spinal alignment closer to normal values and enhancing the biomechanical conditions for spinal function. Conclusions. The use of intraoperative traction via ligamentotaxis allowed for repositioning of the displaced vertebra and facilitated the placement of transpedicular screws. The combination of intraoperative spinal traction and pulling on transpedicular screws using reduction devices enabled correction of the displaced vertebra to Grade I–II according to Meyerding, thereby restoring the supportive function of the spine.

Спондилолістез III–IV ступеня за класифікацією Meyerding (в англомовній літературі «high-grade spondylolisthesis») — із високим ступенем зсуву, призводить до значних порушень функції хребта та ходи, ранньої інвалідизації пацієнтів. Незважаючи на той факт, що клінічні симптоми, класифікації та методи діагностики розроблені та відомі досить давно, питання вибору тактики лікування залишається дискутабельним і дотепер. Мета. Вивчити результати хірургічного лікування пацієнтів із істмічним спондилолістезом із великим ступенем зсуву. Методи. Проведено ретроспективний аналіз результатів операцій 24 осіб зі спондилолістезом зі значним ступенем зсуву, яким застосували інтраопераціну тракцію та транспедикулярну фіксацію за системою «хребет – таз». На рентгенограмах проводили до- та післяопераційні вимірювання кутів ковзання хребця, тазового нахилу, поперекового лордозу, крижового нахилу, скосу таза, а також оцінювали положення сагітальної вертикальної осі і кут нахилу таза. Результати. Усім пацієнтам вдалося зменшити кут ковзання хребця та повернути до норми положення сагітальної вертикальної осі. Інші показники хребетно-тазового балансу також були дещо зменшені, завдяки чому вдалося наблизити сагітальний баланс хребта до нормативних значень і покращити біомеханічні умови його функціонування. Висновки. Використання інтраопераційної тракції за рахунок лігментотаксису дозволило змінити положення зміщеного хребця та полегшити встановлення в нього транспедикулярних гвинтів. Поєднання інтраопераційної тракції хребта та тяги за умов використання транспедикулярних гвинтів із застосуванням вправляючих пристроїв уможливило досягти вправлення зміщеного хребця до I–II ступеня за Meyerding та відновлення опорної функції хребта. Ключові слова. Спондилолістез, інтраопераційна тракція, транспедикулярна фіксація, вправлення.

Key words. High-grade spondylolisthesis, intraoperative traction, pedicular fixation, reduction

Introduction

Spondylolisthesis is a condition characterized by the displacement of a vertebra forward. It most often occurs in children and adolescents, causes pain in the lumbar spine, and in some cases is accompanied by neurological symptoms. Its development is caused by a combination of factors that cause spondylolisthesis: dysplasia of the "bone hook" (intervertebral joints), increased lordosis, stress fractures of the interarticular part, leading to its elongation, disc degeneration and deformation of the sacrum. When these factors reach a certain level, the progression of the pathological process becomes inevitable. They occur either simultaneously or sequentially in a growing person. At the same time, in 11.3 % of cases, the displacement reaches a value of more than 50 % of the surface of the upper endplate of the vertebra below [1].

High-grade spondylolisthesis (HGS), grades III–IV according to the Meyerding classification causes significant impairment of the functions of the spinal column and gait, early disability of patients [2].

Even though clinical symptoms, classifications and diagnostic methods of spondylolisthesis have been developed quite a long time ago, the question of choosing treatment tactics remains debatable to this day. All surgical methods can be conditionally divided into three groups: operations with in situ fixation, complete or partial reduction of the displaced vertebra using implants of various designs, and vertebrectomy.

Each of these surgical techniques has its own indications, advantages and disadvantages. Like most other surgical interventions on the spine, any treatment method should restore its supporting and protective function, eliminate pain syndrome, as well as neurological symptoms, in combination with a minimum number of complications that may occur both during and after surgery [3, 4].

One of these treatment methods may be open reduction of the displaced vertebra using intraoperative traction of the spine and transpedicular construction according to the "spine-pelvis" system, the results of which are not yet sufficiently studied.

Purpose: to study the results of surgical treatment of patients with isthmic spondylolisthesis with a large degree of displacement.

Material and Methods

A retrospective analysis of the results of surgical treatment of 24 subjects (20 female and 4 male) with spondylolisthesis with a significant degree of displacement was conducted. The average age in the study group was 33.2 years (from 10 to 55 years).

The study materials were reviewed and approved by the Bioethics Committee at the CNPE Professor M. F. Rudnev City Multidisciplinary Clinical Hospital for Mothers and Children (protocol No. 1 dated 14.05.2025). All patients involved in the study were informed of the surgical intervention plan and signed informed consent.

The intervention technique was as follows: with the patient in the prone position, under general anesthesia and using multimodal spinal cord monitoring, transpedicular screws were inserted into the L_I vertebra, which were connected to each other by a fixing rod, and a temporary traction device with two fixation points was installed between the rod on the L_I vertebra and the wings of the pelvis. After that, stepwise traction of the spine was performed, radiologically controlling the process of reduction of the L_V vertebra. The screws were placed in the latter after achieving correction and improving its position [7]. Then, transpedicular screws were used in the L_{IV} and S_I and pelvic screws were inserted according to the S2AI method [5, 6]. The next step was to install the fixing rods that connected the screws. The final translational displacement of the L_V was eliminated using rod introducers installed on the heads of the L_V screws (Fig. 1, a). The reduction process was accompanied by verification of evoked sensory and motor potentials. If their values fell by more than 60 % compared to the baseline data obtained before surgical manipulation, the reduction was stopped, and the correction was reduced until normal spinal cord monitoring parameters were restored.

After the reduction was completed, the transpedicular fixation system was stabilized, the intraoperative traction device was dismantled, and the screws installed in the L_I vertebra were removed (Fig. 1, b). After preliminary decortication of the posterior parts of the fixed vertebrae, a bone autograft taken from local tissues was placed. The wound was sutured in layers. X-ray control was performed directly on the operating table.

Patients were verticalized the next day after surgery.

During the analysis of medical histories, clinical manifestations of spondylolisthesis with a significant degree of displacement were studied both before and after surgery. The degree of displacement was determined according to the Meyerding classification. Pre- and postoperative measurements of the angles of vertebral slip, pelvic tilt, lumbar lordosis, sacral tilt, pelvic obliquity were performed on the radiographs, and the position of the sagittal vertical axis and the angle of pelvic tilt were also assessed.

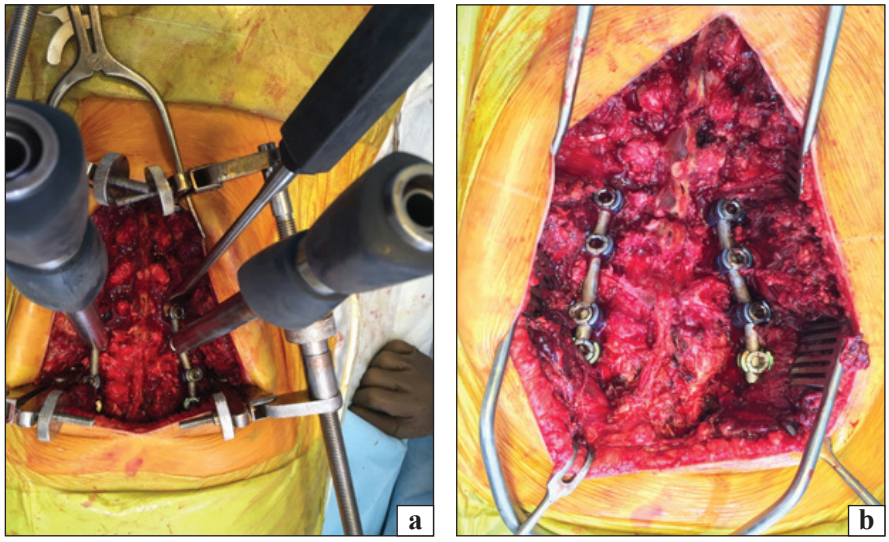

Fig. 1. View of the operating field: a) after installation of the intraoperative distance device, transpedicular structure and rod introducers on the heads of L_V screws; b) after reduction of the displaced vertebra and final stabilization of the transpedicular system according to the "spine-pelvis" scheme

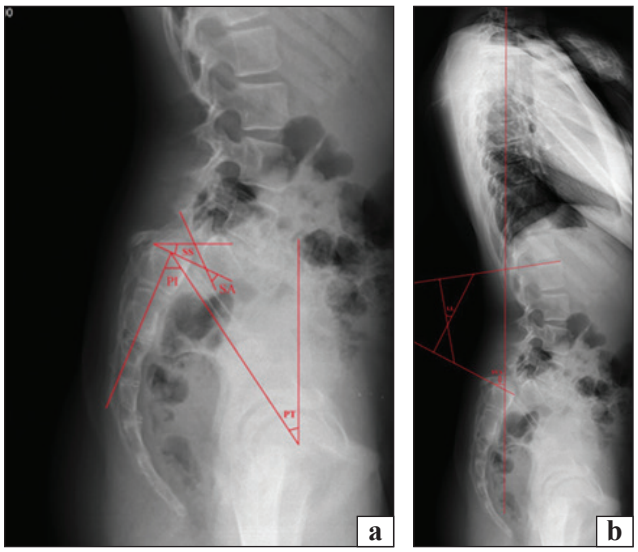

Fig. 2. Radiographic parameters determined in patients with spondylolisthesis with a high degree of displacement: a) vertebral slip angle (SA), pelvic inclination angle (PI); sacral tilt angle (SS), pelvic tilt (PT); b) lumbar lordosis (LL), sagittal vertical axis position (SVA)

The reference values for lumbar lordosis were an angle equal to PI ± 9°, the angle of sacral tilt was 20°–25°, and the distance from the sagittal vertical axis to the posterior-upper edge of the sacral platform was 0–4 cm. The normative value of pelvic tilt (PT) was an angle less than 20° [8].

The quality of the spinal fusion was assessed radiographically using a computed tomography (CT) scan of the lumbosacral spine, which was performed in the long term after surgery [9].

The inclusion criteria for the study were: patients with spondylolisthesis grades III and IV according to Meyerding and spondyloptosis, absence of previous surgical interventions on the spine, presence of results of clinical and instrumental examination methods within 3–5 years after surgery.

Results

All the patients in the study group mainly presented with pain in the lumbar spine, fatigue during prolonged walking. Six patients were found to have L_V and S_I radiculopathy. One patient had lower paraparesis. The other two were diagnosed with secondary thoracolumbar scoliosis (Fig. 3).

In the postoperative period, irritation of the L_V and S_I spinal roots was noted in 3 patients, and in 8 patients, gait disturbance was observed, which developed as a result of tension in the muscles of the lower extremities and regressed within 3–6 months after surgery and a course of rehabilitation treatment. In 3 patients, respectively, 1, 2 and 5 years after the operation, a fracture of the fixing rods occurred, which required revision surgery. At the same time, only in one of them, signs of pseudarthrosis in the lumbosacral junction area were detected during implant replacement. A study of computed tomography scans of all operated patients 3–5 years after treatment showed the presence of mature spondylofusion masses in the posterior spine (Fig. 4).

The results of radiography before and after surgery are given in Table 1. The average vertebral slip angle was 62.1º, after surgery — 23.2º. The pelvic tilt index was 68.2º on average before surgery and 63.2º after, the sacral tilt — 42.5º and 36.2º, respectively. The lumbar lordosis value was 54.1º on average before surgery and 49.4º after. The position of the sagittal vertical axis before treatment changed from 7.7 cm before surgery and 3.3 cm after. The pelvic tilt — 23.8º and 24.2º, respectively (Table 1). According to the criteria given in [10], 20 patients were diagnosed

with grade I spondylosis, 3 with grade II, and 1 with grade IV. According to the Meyerding scale, before surgery, 13 patients had grade III displacement, 7 with grade IV, and 4 with spondyloptosis. After surgery, the distribution was as follows: grade III — 4, II — 14, and I — 6 subjects.

Discussion

Despite the general opinion that patients with spondylolisthesis with a significant degree of displacement require surgical treatment, the choice of adequate tactics is a debatable issue. Various surgical techniques are proposed in scientific literature, each with its own advantages and disadvantages. They can be conventionally divided into three main types: *in situ* fixation, reduction of the displaced vertebra, and vertebrectomy.

In situ fixation, both with and without a corset in the postoperative period, is a relatively safe and effective treatment that reduces pain and neurological symptoms.

A. Joelson et al. studied the results of *in situ* fusion in 35 patients aged 15 years with SIDS. They found that all patients had a good treatment outcome, which ensured the absence of pain, disability, and allowed most of them to work in their specialty for 29 years after treatment [11].

S. Noorian conducted a systematic analysis of 6 randomized clinical trials and 9 observational studies, where he evaluated the results of treatment in 1,538 patients with SIDS. Most of these studies showed that reduction and fusion lead to the same clinical outcome as *in situ* fixation [12].

At the same time, A. M. Lak et al. studied the results of treatment of 188 people with HGS who underwent *in situ* fusion or reduction [13]. *In situ* fixation was found to be accompanied by greater intraoperative blood loss, neurological complications, pseudarthrosis and infection.

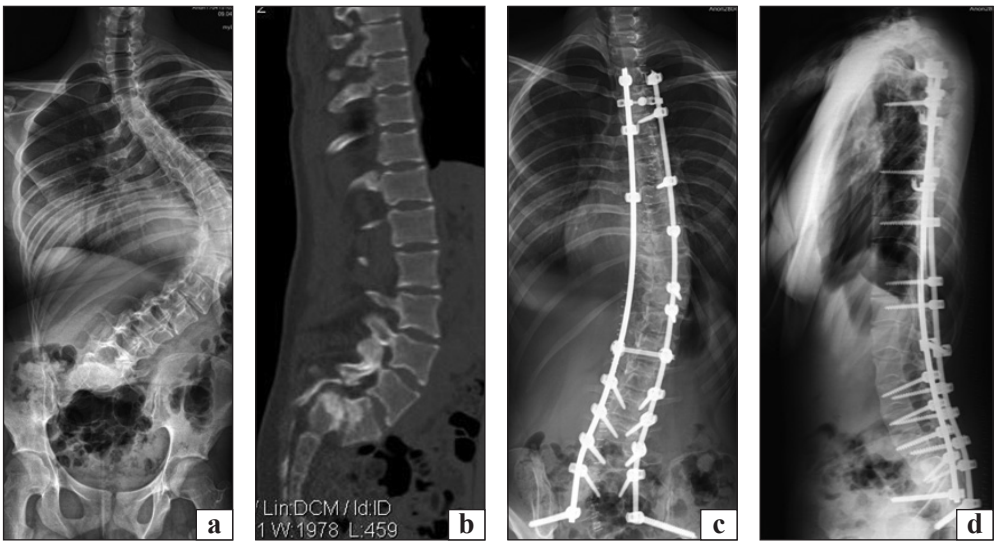

Fig. 3. Radiographic (a) and computed tomography images (b) of a 16-year-old patient with spondylolisthesis and left-sided thoracolumbar scoliosis before surgery and after polysegmental correction of scoliotic deformity and reduction of spondylolisthesis using intraoperative distraction. The extent of fusion Th_{II} is the pelvis. Spondylolisthesis was reduced to Meyerding grade I (c, d)

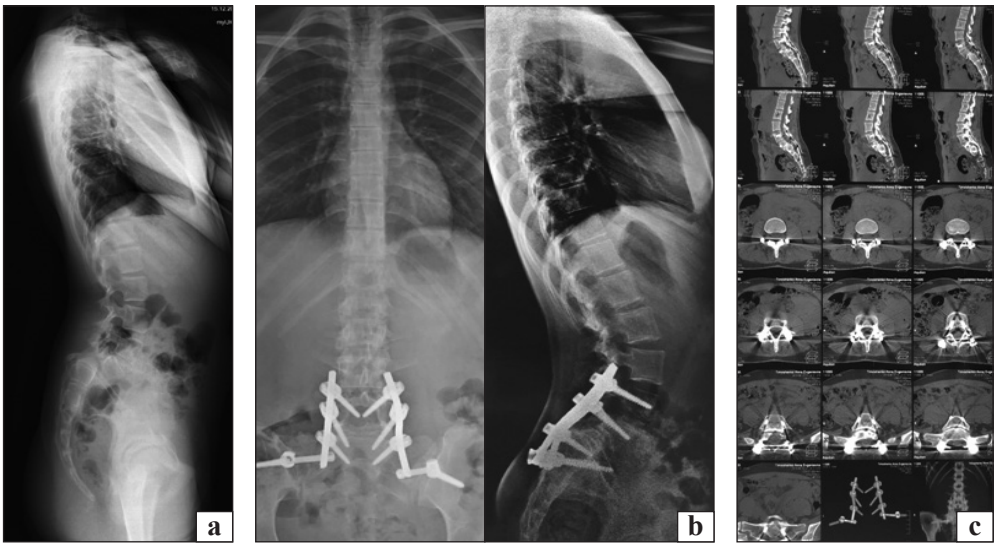

Fig. 4. Radiographic images of a 14-year-old patient with Meyerding grade IV spondylolisthesis before surgery (a) and after surgery (b). L_{IV} spondylodesis is extended to the pelvis. Spondylolisthesis was reduced to Meyerding grade II. A computed tomography 6 years after surgery showed the presence of a mature bone block in the fusion area (c)

Table 1

Radiographic parameters before and after surgery

Indicator	Surgical treatment	
	before	after
Slip angle (SA)	62.1º	23.2º
Pelvic inclination (PI)	68.2º	63.2º
Sacral tilt (SS)	42.5º	36.2º
Lumbar lordosis (LL)	54.1º	49.4º
Sagittal vertical axis (SVA)	7.7 sm	3.3 sm
Pelvic tilt (PT)	23.8º	24.2º

Thus, reduction, despite such complications as damage to the dural sac, reduces pain, the angle of displacement of the vertebra, changes the pelvic tilt, and also improves the Oswestry Disability Index. The authors of the study further note that both surgical techniques can be used in clinical practice, but reduction of the displaced vertebra provides a better treatment outcome.

Full or partial reduction of the vertebra in HGS has a large number of supporters. The main arguments indicating the advantage of its implementation are the ability to restore the disturbed biomechanics of the spine, improve the quality of fusion by more evenly distributing the load on the graft, change the shape of the spinal canal, and also obtain a positive cosmetic effect. But the main risk of complete reduction of a displaced vertebra by more than 50 % is the occurrence of neurological disorders [14, 15]. That is why most authors insist on partial elimination of the displacement, which allows to reduce the risk of developing radiculopathy of the L_{IV} and L_V roots [11]. The Spine Deformity Study Group has developed a classification of spondylolisthesis, which allows to determine the indications for performing a vertebral reduction. According to it, elimination of the displacement of the vertebra is not indicated in the case of a balanced pelvis, i.e. when the SS indicator is greater than the PT indicator, and in the opposite situation (PT greater than SS), the pelvis is considered unbalanced, and reduction is necessary [16].

In [17], a method for eliminating SIDS is presented by temporarily installing screws in vertebrae L_{II}–L_{III} with the use of further intraoperative distraction until partial L_V reduction is achieved. To decompress the spinal canal, a wide L_V laminectomy is performed and a cage is installed in the L_V–S_I intervertebral space, due to which a better fusion is achieved and thus the lumbar lordosis is restored.

K. Min suggested that, in addition, to facilitate reduction, the deformed upper locking plate of the S_I should be resected, which, in his opinion, is an obstacle to eliminating ventral displacement in the case of spondylolisthesis [18]. Similar results were reached in their work by M. A. Anjhazzallah et al. [19].

M. Kumar et al. proposed a method for correcting HGS using minimally invasive interbody fusion with a cage in 18 patients. The results of the study showed an improvement in spine-pelvic balance and Oswestry and VAS scores [20].

Another alternative for surgical treatment of spondylolisthesis with a significant degree of displacement is L_V vertebrectomy, proposed by R. Gaines, who presented the results of using this operation in 30 patients [21]. Over 25 years, according to the author, only two patients had complications in the form of screw fracture and pseudarthrosis. Also, in the period from 6 weeks to 3 years, L_V root radiculopathy and retrograde ejaculation were recorded as complications of anterior access to the ventral spine. At the same time, the clinical symptoms accompanying spondylolisthesis were eliminated in all patients.

K. Kalra presented the results of a modified Gaines operation, which consists in partial resection of the L_V vertebra in its lower part. According to the author, the advantages of this technique are as follows: the possibility of additional insertion of screws into the displaced vertebra, which facilitates its reduction; prevention of L_V root radiculopathy; prevention of spinal cord shortening, which occurs as a result of a decrease in the number of vertebrae and can lead to impaired function [22]. We conducted a retrospective analysis of the results of treatment of patients with isthmic HGS using intraoperative traction and transpedicular fixation of the L_{IV}-pelvis. According to the results of the operations, all patients managed to reduce vertebral slip angle (SA), as well as return the position of the sagittal vertical axis (SVA) to normal. Other indicators of spine-pelvic balance [23] were also slightly reduced, which made it possible to bring the sagittal balance of the spine closer to the normative indicators and improve the biomechanical conditions of its functioning.

At the same time, the reduction of the displaced vertebrae contributed to the regression of clinical symptoms, improvement of gait, as well as the maturation of a high-quality spinal fusion block, which was confirmed by postoperative CT scan. Fractures of the fixation rods in 3 patients occurred in the area of the lumbosacral junction, which is traditionally the least favorable for the formation of a bone block, but the replacement of the implant allowed to obtain a satisfactory result in the future.

The radicular-irritative syndrome and gait disorders that developed in patients in the postoperative period are explained by the fact that they managed to achieve significant reduction of the displaced vertebra and significantly change the pathological patterns of muscle function that arose as a result of anterior displacement of the vertebra during spondylolisthesis. Perhaps in patients of the older age group due to the greater rigidity of the spine, the number of potential neurological complications could be greater, but the use of intraoperative spinal cord monitoring allowed for controlled correction of the deformity (Fig. 5). The use of pelvic fixation made it possible to achieve stable fixation of the spine without the installation of interbody cages, for the introduction of which it is necessary to perform laminectomy [24] and manipulation of the dural sac, which increases the risk of its damage. Refusal of laminectomy in favor of indirect decompression of the spinal canal by eliminating the displacement of the vertebra allowed to preserve the supporting function of the posterior supporting column of the spine and increased the area of the bone graft zone, which also had a positive effect on the formation of a high-quality bone block. Table 2 presents the results of other studies on the surgical treatment of HGS for comparison. These studies show that our proposed technology provides approximately the same number of neurological complications and pseudarthrosis as compared to the methods of correction of vertebral displacement

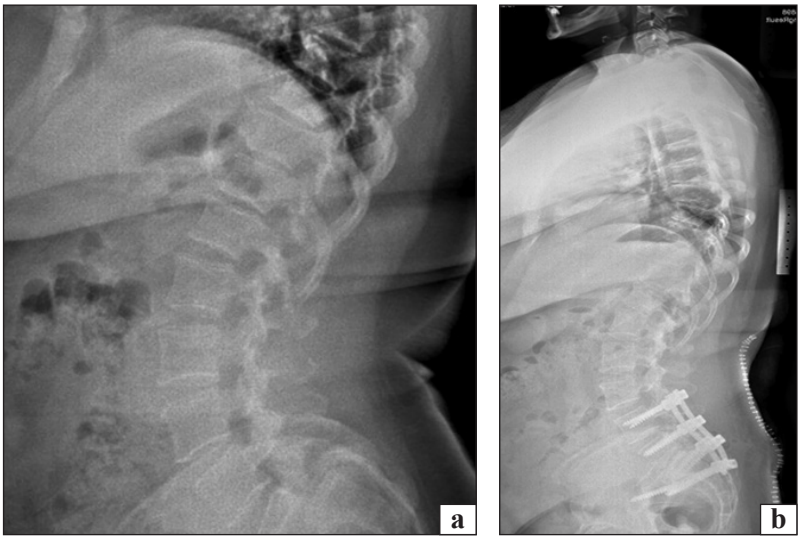

Fig. 5. Radiographic images of a 55-year-old patient with Meyerding grade IV spondylolisthesis in lateral projection before surgery (a) and after surgery (b) using intraoperative traction. L_{IV} spondylodesis is extended to the pelvis.

Table 2

Comparison of research results regarding surgical treatment of HGS

Author	Number of patients	Surgical technique	Complication (abs. / %)	Neurologic complications (abs. / %)	Pseudoarthrosis (abs. / %)
J. A. Smith et al. [25]	9	*In situ* fixation	10/111	2/22	2/22
O. Boachie-Adjei et al. [26]	6	Transpedicular fixation, decompression	3/50	3/50	0
I. Helenius et al. [27]	21 23 26	Posterolateral *in situ* spondylodesis Anterior *in situ* spondylodesis Anterior-posterior *in situ* spondylodesis	3/14 2/22 3/12	4/19 0 0	3/13 1/4 4/12
J-M. Mac-Thiong et al. [28]	61	*In situ* spondylodesis, transpedicular fixation and interbody spondylodesis, *in situ* screw and cage fixation	14/23	7/11	0
K. Min et al. [18]	15	Transpedicular fixation, S_I locking plate resection, interbody cage spondylodesis	4/26	4/26	0
M. K. Ashan et al. [29]	20	Intraoperative traction, decompression, transpedicular fixation	4/20	0	0
Our study	24	Intraoperative traction, spine – pelvis fixation	4/16	3/12	1/4

and a lower number of pseudarthrosis compared to in situ fixation. One of the complications reported in the observation [29], where spinal canal decompression was performed, resulted in a rupture of the dura mater in 2 cases.

Conclusions

The use of intraoperative traction due to ligamentotaxis allowed to change the position of the displaced vertebra and facilitate the installation of transpedicular screws in it.

The combination of intraoperative spinal traction and traction under the conditions of using transpedicular screws with the use of adjusting devices allowed to achieve reduction of the displaced vertebra to Meyerding grade I–II and restore the supporting function of the spine.

Increasing the area of the fusion zone by preserving the arch of the displaced vertebra in combination with decortication of the posterior spine contributed to the formation of a mature bone block.

Postoperative complications did not affect the final outcome of the treatment of patients in the study group.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Conducting prospective comparative studies of different methods of treating spondylolisthesis.

Information on funding. This study is not commercial and does not have external funding.

Authors' contribution. Mezentsev A. O. — operated on some of the patients, analysis of the obtained research results, drawing of conclusions, editing the text; Petrenko D. Ye. — operated on some of the patients, analysis of the obtained results, drafting the article; Demchenko D. O. — operated on some of the patients, analysis of literary sources, formation of the reference list and preparation of clinical cases.

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RESULTS OF SURGICAL TREATMENT OF HIGH-GRADE SPONDYLOLISTHESIS

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