COMPARATIVE ANALYSIS OF THE ACCURACY OF PEDICLE SCREW INSERTION IN SURGICAL TREATMENT OF CHILDREN WITH IDIOPATHIC SCOLIOSIS

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Objective. To perform comparative analysis of the accuracy of pedicle screw placement in spinal deformity correction in children with idiopathic scoliosis using 3D-CT navigation.
Material and Methods. Surgical treatment of 96 patients aged 14–18 years with Lenke type I and V idiopathic scoliosis was performed. In the study group (n = 66), pedicle screws were inserted using the navigation station, in the control group (n = 30) – by the freehand method. The accuracy of pedicle screw position was assessed using postoperative CT images of the spine based on the Gertzbein scale.
Results. The total number of pedicle screws inserted in the study group was 1166, in the control group – 546. In the study group, position of screws was correct in 96 % (1119 screws) of observations and incorrect in 4 % (47 screws). In the control group, the correct position was noted only in 78 % (426 screws) of cases, and the number of incorrectly inserted screws was significantly larger – 22 % (120 screws). In the study group, incorrectly inserted screws in the thoracic spine were detected in 4.8 % of cases, in the lumbar spine – in 2.5 %; in the control group, pedicle screws were incorrectly inserted in the thoracic spine in 35.1 % of cases, in the lumbar spine – in 10.1 %.
Conclusion. Using the navigation station during surgical intervention aimed at correcting the deformity of the spine in children with idiopathic scoliosis of various locations allows a significant increase in the number of correctly inserted pedicle screws used for instrumentation.
Key Words: idiopathic scoliosis, transpedicular fixation, navigation, children.

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Currently, Cotrel – Dubousset instrumentation is most commonly used for surgical correction of scoliotic deformity of the spine [3, 4, 9, 11, 13]. According to several authors [1, 2, 8, 10, 12], transpedicular fixation is superior to laminar one from the standpoint of biomechanics. However, it is associated with the risk of possible screw malposition, which is primarily due to structural changes in the vertebrae caused by scoliotic process. For this reason, the control and correct positioning of transpedicular supporting elements are important components in the surgical treatment of patients with idiopathic scoliosis.

Fluoroscopy is one of the basic and widely used methods to control insertion of pedicle screw systems. The accumulated experience of its application shows a number of significant limitations of inserting screws under the image intensifier control. First of all, it is high radiation dose to the patient and staff. Furthermore, screw insertion is controlled only in one planar projection, which greatly reduces the accuracy and safety of the procedure. In the case of 2D fluoroscopy, significant deviations in screw trajectory can reach 7–54 % and the incidence of associated neurological complications is 5–7 % [14, 15, 22]. Additional use of optical navigation systems is a promising way to improve the surgical technique of pedicle screws insertion. 2D fluoronavigation is one of the simplest navigation assistance methods. Its principal advantages include significant (10–12-fold) reduction of radiation exposure [16], which is especially important when performing surgical procedures in children and adolescents, as well as the possibility of simultaneous monitoring of screw insertion in several projections, providing conditions for improving the accuracy of surgical procedures. 2D fluoro-navigation provides two-dimensional information and cannot control screw insertion in the axial and coronal projections, which is the principal disadvantage of the method.

Recently, 3D navigation methods that provide more favorable conditions for the planning and insertion of the pedicle screws have become very popular in clinical practice. The use of navigation systems during surgical correction of idiopathic scoliosis in children is a novel and promising method, significantly improving the possibility of correct screw insertion into deformed vertebrae involved in the curvature and significantly reducing the risk of intraoperative complications [5–7]. According to the meta-analysis performed by Tian et al. [23] in 2011, 3D navigation methods have significant advantages in terms of accuracy of insertion of the transpedicular supporting elements before screw insertion under the 2D fluoroscopic control. Our retrospective literature review analyzes the results of screw insertion through the pedicles of 7533 lumbar and thoracic vertebrae. The accuracy of 3D-navigation-assisted screw insertion reached 96.7 % and significantly exceeded the capabilities of the conventional screw insertion methods under 2D – fluoroscopic control [23]. The advantages of 3D navigation are the most apparent in the case of thoracic spinal surgery. Amiot et al. [14] have clearly demonstrated higher accuracy 3D navigation compared to the operations performed under fluoroscopic control. Navigation assistance improved the accuracy of screw insertion in 95 % of cases, while in the case of fluoroscopic control, this value was significantly lower, 85 % [14]. Analysis of surgical outcomes in 100 patients with spinal cord injuries carried out by Laine et al. [20] showed that 3D navigation assistance reduced perforation of pedicles from 13.4 to 4.6 %, while according to Kotani et al. [19], it was reduced from 11.0 to 1.8 %.

3D fluoro-navigation is one of the most attractive 3D navigation methods, which is based on the concomitant use of 3D image intensifier and a conventional optical navigation system. Capability of producing intraoperative 3D images followed by the control of screw insertion in the axial, coronal, and sagittal projections is the principal advantage of this technique. Significant drawbacks of 3D fluoro-navigation include low quality of intraoperative images, especially in patients with osteoporosis, high body weight and/or severe disorders of the spine anatomy [18]. Analysis of the literature shows that intraoperative 3D-CT navigation has the highest accuracy and can be regarded as an optimal method when inserting pedicle screws during surgery [23–25].

The study was aimed at the comparative analysis of the accuracy of insertion of the transpedicular supporting elements during spinal deformity correction in children with idiopathic scoliosis using 3D-CT navigation.

Material and Methods

The study is based on the analysis of the results of examination and surgical treatment of 96 patients aged 14–18 years with grade III and IV idiopathic scoliosis of the thoracic, thoracolumbar, and lumbar spine, including 18 (18.8 %) males and 78 (81.3 %) females. All patients were examined and treated at the department of spinal pathology and neurosurgery at the Turner Scientific Research Institute for Children's Orthopedics in 2011–2015.

The study group consisted of 66 patients with grade III–IV idiopathic scoliosis, where the accuracy and stability of pedicle screws inserted during surgery were evaluated using a navigation station. The control group consisted of 30 patients with idiopathic scoliosis with similar localization, who underwent insertion of transpedicular elements of the posterior spinal instrumentation system using the freehand method.

The type of deformity, localization, and structural characteristics of its constituting scoliotic curves were determined using idiopathic scoliosis classification developed by Lenke et al. [21].

The study group included 13 (19.7 %) male and 53 (80.3 %) female patients, whose mean age was 15.4 ± 0.6 years. The control group included 5 (16.7 %) male and 25 (83.3 %) female patients, whose mean age was 15.9 ± 0.8 years (Fig. 1).

In the study group, 11 (17 %) patients were diagnosed with grade III scoliotic deformity of the spine, and 55 (83 %) patients were diagnosed with grade IV. In the control group, 6 (20 %) patients had grade III scoliosis and 24 (80 %) patients had grade IV scoliosis.

According to classification proposed by Lenke et al, the type I deformity was observed in 40 (60.6 %) study group patients, type V – in 26 (39.4 %) study group patients; in the control group, the type I deformity was observed in 18 (60 %) patients, type V – in 12 (40 %) patients.

Orientation of scoliotic curves was typical for idiopathic scoliosis in all types of deformity. In both groups, all thoracic curves in patients with type I scoliosis were right-sided, all the thoracolumbar and lumbar curves in patients with type V scoliosis were left-sided.

The distribution of tactical options used for correction of scoliotic deformity was similar in the study and control groups (Table 1).

Therefore, there were no significant differences between the study and control groups in terms of the baseline data (sex, age, type and degree of deformity), orientation of the primary deformity curve, and options of surgical correction of scoliotic deformity. Follow-up time was 3 to 5 years (3.4 ± 0.5) in the study group and 3 to 5.5 years (3.9 ± 0.9) in the control group.

In both groups, patients underwent postoperative CT scan of the spine to assess the insertion accuracy of the pedicle screws. Accuracy of the position of inserted transpedicular elements was evaluated using the scale proposed by Gertzbein et al. [17], where Grade 0 (full correct) – transpedicular screw is completely within the pedicle of the vertebral arch and does not contact the adjacent soft tissues, Grade I – transpedicular screw is displaced with respect to the cortical layer of the pedicle by up to 2 mm, Grade II – screw displacement by 2 to 4 mm, Grade III – more than 4 mm (Fig. 2).

The accuracy of positioning of transpedicular supporting elements inserted into the vertebrae under the control of 3D-CT navigation and using freehand method was comparatively analyzed based on the Gertzbein et al. scale using a scheme determining the correctness of pedicle screw position with respect to the bone structures of the instrumented vertebra, where the data were labeled with the abbreviation SLIM + V. The first part of the abbreviation specifies screw position with respect to the outer walls of the pedicle, which is estimated in a

Table 1
Distribution of study and control group patients with respect to the type and extent of operations, n (%)

Extent of operations	Group	
	Study	Control
Spine deformity correction using third generation instrumentation, posterior local fusion	18 (27.3)	8 (26.7)
Anterior release, fusion; correction of spinal deformity using third generation instrumentation, posterior local fusion	18 (27.3)	8 (26.7)
Anterior release, fusion; the course of halo-femoral traction; correction of spinal deformity using third generation instrumentation, posterior local fusion	30 (45.4)	14 (46.6)

specific sequence: S – superior (cranial) wall of the pedicle, L – lateral (outer) wall of the pedicle, I – inferior (caudal) wall of the pedicle, and M – medial (inner) wall of the pedicle. The second part of the abbreviation (V – vertebral body) specifies pedicle screw position with respect to the anterolateral surface of the vertebral body.

Results and Discussion

The total number of transpedicular supporting elements was 1166 in the study group and 546 in the control group. In the study group, correct screw position with respect to the bone structures of the instrumented vertebrae was in general observed in 96 % of cases (1119 screws), incorrect – in 4 % of cases (47 screws).

In the control group, evaluation of screw position with respect to the pedicles and vertebral bodies showed that only 78 % (426) screws had correct position, the number of incorrectly inserted transpedicular supporting elements was significantly higher ($P < 0.05$) and accounted for 22 % (120 screws).

A comparative analysis of the accuracy of pedicle screw position showed higher number of screws with smaller displacements in the study group as compared to that in the control group. Thus, the number of screws with Grade I displacement was 60.0 % (28 screws) and 2.4 % of the total number of inserted screws. In 30 % of cases (14 screws), the position of the supporting elements was determined as Grade II, which accounted for 1.2 % of the total amount of screws inserted in the study group patients. Grade III displacement of the transpedicular supporting elements was observed only in 10.0 % of cases (5 screws) and accounted for 0.3 % of the total number of inserted screws.

In the control group, the number of cases of Grade I displacement was lower and accounted for 40.0 % (48 screws) of all incorrectly inserted supporting elements (120 screws) and 8.8 % of the total number of inserted screws. In 34.0 % of cases (41 screws), the analysis of postoperative CT scans of the spine showed Grade II displacement, which is 7.5 % of the total number of implanted transpedicular supporting elements. The control group demonstrated significantly higher ($P < 0.05$) number of screws, whose displacement with respect to the bone structures of instrumented vertebra involved in the primary scoliotic curve was characterized as Grade III, 26.0 % (31 screws) of cases. This type of supporting element displacement accounted for 5.7 % of the total number of inserted pedicle screws (Table 2).

Analysis of distribution of pedicle screw displacement types with respect to the bone structures of the instrumented vertebrae in the study group patients based on the SLIM + V scheme showed the following results. The number of incorrectly positioned screws inserted on the right and on the left with respect to the line of the spinous processes of thoracic and lumbar vertebrae was almost equal and amounted to 25 (53.2 %) and

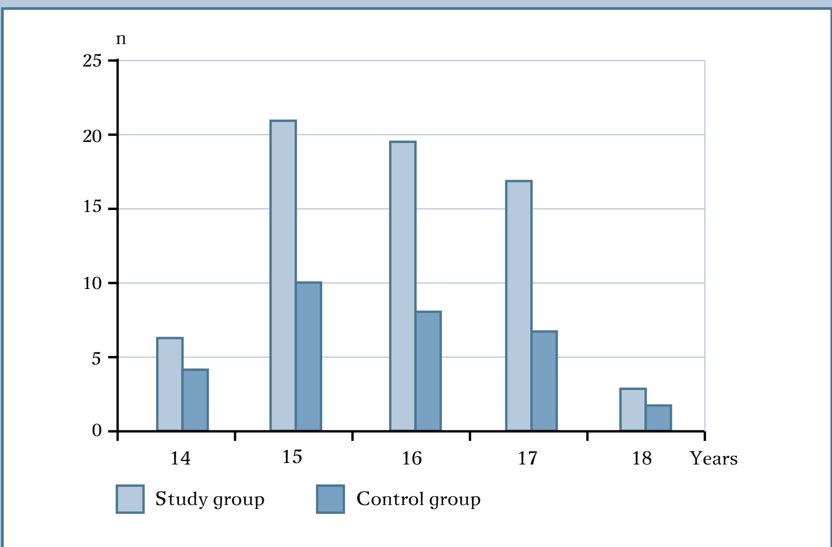

Fig. 1
Age distribution of patients in both groups

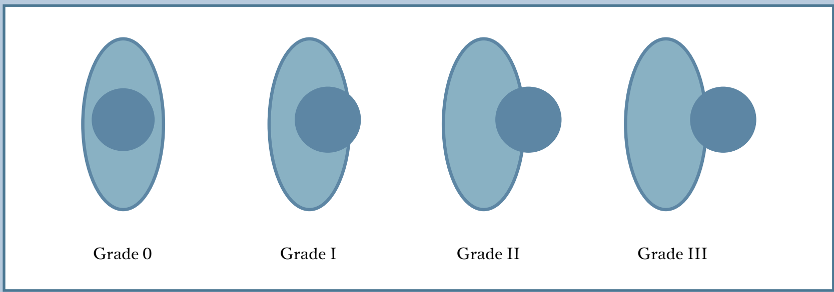

Fig. 2
Evaluation of the accuracy of pedicle screw position with respect to the pedicle of the vertebral arch (explanation in the text)

22 (46.8 %), respectively. Among all displacement types, the screws inserted in the vertebrae on the right with respect to the line of the spinous processes most often demonstrated displacement characterized by injury to the lateral wall of the pedicle, which accounted for 31.9 % (15 screws) of the total number of incorrectly inserted screws in the group where navigation was used. The occurrence of the other displacement types was approximately the same: 6.4 % (3 screws) – injury to the superior wall of the pedicle, 6.4 % (3 screws) – protrusion beyond the anterolateral surface of the vertebral body, 4.1% (2 screws) – injury to the inferior wall of the pedicle, and 4.1% (2 screws) – injury to the medial wall of the pedicle.

The distribution pattern of displacement types of the screws inserted into the vertebrae on the left with respect to the line of the spinous processes was similar to the aforementioned one. Displacement of the supporting elements characterized by injury of the lateral wall of the pedicle occurred in 23.4 % of cases (11 screws), injury to the superior wall of the pedicle occurred in 10.6 % of cases (5 screws), the inferior wall of the pedicle in 6.4 % of cases (3 screws), protrusion of the threaded portion of the transpedicular supporting element beyond the anterolateral surface of the vertebral body in 4.1 % of cases (2 screws), and injury to the medial wall of the pedicle in 2.1 % of cases (1 screw).

Distribution analysis of pedicle screw displacement types with respect to the spinal segments showed some regularities in the most common displacement type (injury to the lateral wall of the vertebral pedicle), which totaled 55.3 % of cases (26 screws). Thus, there was lateral malposition of the transpedicular supporting elements on the right side with respect to the line of the spinous processes at the level of T3–T5 vertebrae and at the thoracolumbar junction zone (T11–L2 vertebrae) in 14.9 % of cases (7 screws) for both levels. Incorrect position of screws inserted on the left side with respect to the line of the spinous processes was observed at the level of T6–T9 vertebra and accounted for 19.2 % of cases (9 screws).

It should be noted that this distribution is due to the fact that the pedicles of the vertebral arches at the levels of T6–T9 vertebrae and thoracolumbar junction zone, where the pedicle screws were inserted, were located on the concave side of the scoliotic curve and, in most cases, had small transverse size. Screw displacement was also due to anatomical anthropometric features of the pedicles of vertebral arches at the level of T3–T5 vertebrae in the form of reduced transverse size on the right. However, most cases with this type of screw position were characterized by Grade I displacement.

Thus, this type of screw malposition was due to the fact that, when forming the correct trajectory of the canal for the transpedicular supporting element under the control of 3D-CT navigation in the case of the small size of the pedicle, the surgeon to a certain degree lateralized its direction, when trying to preserve the medial wall of the pedicle, forming the spinal canal. It is another feature of the pedicle screw malposition in patients with spinal deformity due to idiopathic scoliosis, when forming bone canals and inserting screws during the operation (Table 3).

Analysis of the distribution of pedicle screws displacement types with respect to the bone structures of the instrumented vertebra in the control group according to the SLIM + V scheme showed the following results. The number of incorrectly positioned screws inserted on the concave and convex sides with respect to the line of the spinous processes of thoracic and lumbar vertebrae was almost equal and amounted to 64 (53.3 %) and 56 (46.7 %), respectively, similarly to the study group. However, in contrast to the prospective study group, screw displacement in the control group patients was predominantly characterized by injury to the medial wall of the pedicle. It was observed in 48.3 % (58 screws) of the total number of incorrectly inserted screws.

Thus, the type M displacement (injury to the medial wall of the pedicle) was the most common one among all displacement types of the screws inserted into the vertebrae on the convex side with respect to the line of the spinous processes and accounted for 22.5 % of cases (27 screws); the type V displacement (vertebral body) was the second most common one and accounted for 16.7 % of cases (20 screws). Other types of displacements occurred at approximately the same rate: injury to the superior wall of the pedicle – 5.8 % (7 screws), injury to the lateral wall of the pedicle – 5.0 % (6 screws), and injury to the inferior wall of the pedicle – 3.3 % (4 screws).

Distribution pattern of displacements of the screws inserted on the concave side of the vertebrae with respect to the line of the spinous processes was similar to the aforementioned one, except for the type V displacement. Displacement

Table 2

Distribution of vertebrae with respect to the accuracy of screw position

Vertebra	Study group (scT = 1166)			Control group (scT = 546)		
	Grade			Grade		
	I	II	III	I	II	III
T3	3	1	0	0	1	1
T4	2	3	0	2	4	4
T5	3	0	0	5	3	2
T6	2	2	0	3	1	1
T7	3	1	0	4	1	2
T8	2	2	1	4	2	4
T9	2	1	1	6	7	4
T10	1	1	0	2	4	2
T11	1	1	1	4	5	1
T12	2	1	1	6	2	4
L1	3	0	1	4	2	2
L2	2	0	0	3	2	1
L3	1	0	0	0	1	0
L4	1	1	0	1	3	1
L5	0	0	0	4	3	2
Total scIN, n	28	14	5	48	41	31
Total % of scIN	60	30	10	40	34	26
Total % of scT	2.4	1.2	0.3	8.8	7.5	5.7

scT — total number of inserted screws, scIN — the number of incorrectly inserted screws.

of the supporting structures characterized by injury to the medial wall of the pedicle accounted for 25.8 % of cases (31 screws); injury to the superior wall of the pedicle and protrusion of the threaded portion of the transpedicular supporting structure beyond the anterolateral surface of the vertebral body occurred in 8.3 % (10 screws) of cases, injury to the inferior wall of the pedicle – 2.5 % of cases (3 screws), injury to the lateral wall of the pedicle – 1.7 % of cases (2 screws).

Distribution analysis of pedicle screw displacement types with respect to the spinal segments in the control group also showed some features and patterns. The screws inserted on the convex side with respect to the line of the spinous processes demonstrated medialisation of the transpedicular supporting elements at the level of T3–T4 vertebrae with respect to the pedicle of the vertebral arch in 7.5 % of cases (9 screws) and at the level of T12–L2 vertebrae in 10.0 % of cases (12 screws). The type V displacement was identified at the level of T11–T12 vertebrae in 7.5 % of cases (9 screws) and at the level of L2–L5 vertebrae in 6.7 % of cases (8 screws). Injury to the medial wall of the pedicle caused by screws inserted on the concave side with respect to the line of the spinous processes was observed at the level of T6–T9 vertebrae and accounted for 20.8 % of cases (25 screws). Protrusion of the threaded portion of the screw beyond the anterolateral contour of the vertebral body occurred in 5.8 % of cases (7 screws).

It should be noted that this distribution of M-type displacement (medial) is also due to anatomical and anthropometric characteristics of the pedicles of the vertebral arches involved in the scoliotic curve. However, most screws characterized by this position in the retrospective study group corresponded to Grade II and III displacement. Type V displacement, which accounted for 25 % of cases (20 screws), is due to mismatch between the size of the transpedicular supporting element and the length of the screw path.

In summary, this type of screw malposition is due to the lack of the possibility of visual control during formation of canals for the pedicle screws when using freehand method, and it is potentially dangerous due to possible injury to the spinal canal structures associated with damage to the medial wall of the pedicle and the risk of injury to the prevertebral structures in the case of type V displacement (Table 4).

The comparative analysis of the distribution of incorrect positions of pedicle screws with respect to the thoracic and lumbar spine in the study and control groups showed the following results. In the study group, incorrectly inserted transpedicular supporting elements in the thoracic spine were detected in 4.8 % of cases (38 screws). The distribution of incorrectly inserted screws in the segments of the thoracic spine is as follows: upper thoracic spine – 12.9 % (9 screws), medial thoracic spine – 5.1 % (16 screws), lower thoracic spine – 3.1 % (13 screws). In the lumbar spine, the number of incorrectly inserted screws was lower and amounted to 2.5 % (9 screws).

In the control group, incorrectly inserted transpedicular supporting elements in the thoracic spine were detected in 35.1 % of cases (91 screws). The following distribution with respect to the thoracic spine segments was observed: upper thoracic spine – 92.3 % (12 screws), medial thoracic spine – 37.7 % (32 screws), lower thoracic spine – 29.2 % (47 screws). There were 10.1 % (n = 29) incorrectly inserted screws in the lumbar spine.

Therefore, the number of incorrectly inserted screws in the thoracic spine was significantly higher ($P < 0.05$) in the control group. The percentage of incorrectly inserted screws increased in the cranial direction and reached maximum value in the upper thoracic spine, amounting to 4.8 % in the thoracic spine and 2.5 % in the lumbar spine in the study group; 35.1 % and 10.1 %, respectively, in the control group (Table 5).

Table 3

Distribution of thepedicle screw displacement types with respect to the bone structures of the instrumented vertebra in the study group, n

Vertebra	Dexter					Sinister				
	S	L	I	M	V	S	L	I	M	V
T3	–	2	–	1	–	–	–	–	–	1
T4	–	3	–	–	–	2	–	–	–	–
T5	–	2	–	–	–	1	–	–	–	–
T6	–	–	1	–	–	1	2	–	–	–
T7	–	–	1	–	–	1	2	–	–	–
T8	–	–	–	1	–	–	4	–	–	–
T9	1	–	–	–	–	–	1	1	1	–
T10	1	–	–	–	–	–	–	1	–	–
T11	1	1	–	–	1	–	–	–	–	–
T12	–	2	–	–	2	–	–	–	–	–
L1	–	3	–	–	–	–	1	–	–	–
L2	–	1	–	–	–	–	–	–	–	1
L3	–	–	–	–	–	–	1	–	–	–
L4	–	1	–	–	–	–	–	1	-	–
Total, n (%)	3 (6.4)	15 (31.9)	2 (4.1)	2 (4.1)	3 (6.1)	5 (10.6)	11 (23.4)	3 (6.4)	1 (2.1)	2 (4.1)

Dexter — screws installed on the right; Sinister — screws installed on the left; S — the superior wall of the pedicle of the vertebral arch; L — lateral wall of the pedicle; I — inferior wall of the pedicle; M — medial wall of the pedicle; V — vertebral body.

Conclusion

The comparative analysis showed that incorrectly inserted transpedicular supporting elements in the thoracic and lumbar spine accounted for 4 % in the study group, which was significantly ($P < 0.05$) less common than in the control group (22 %). Application of the navigation station during corrective surgery for spinal deformities in children with idiopathic scoliosis characterized by various localization can significantly increase the number of correctly inserted transpedicular screws.

The study was not sponsored. The authors declare no conflict of interest.

Table 4

Distribution of the pedicle screw displacement types with respect to the bone structures of the instrumented vertebra in the control group, n

Vertebra	Dexter					Sinister				
	S	L	I	M	V	S	L	I	M	V
T3	–	–	–	2	–	–	–	–	–	–
T4	–	–	1	7	–	2	–	–	–	–
T5	–	1	2	–	3	1	–	–	–	3
T6	–	–	1	–	–	1	–	–	3	–
T7	–	–	–	–	–	–	–	–	7	–
T8	–	1	–	–	–	–	–	–	9	–
T9	3	1	–	2	–	3	–	2	6	–
T10	2	–	–	3	–	2	–	1	–	–
T11	1	1	–	–	4	1	2	–	1	–
T12	1	2	–	3	5	–	–	–	1	–
L1	–	–	–	5	–	–	–	–	3	–
L2	–	–	–	4	1	–	–	–	–	1
L3	–	–	–	–	1	–	–	–	–	–
L4	–	–	–	–	3	–	–	–	–	2
L5	–	–	–	1	3	–	–	–	1	4
Total, n (%)	7 (5.8)	6 (5)	4 (3.3)	27 (22.5)	20 (16.7)	10 (8.3)	2 (1.7)	3 (2.5)	31 (25.8)	10 (8.3)

Dexter — screws installed on the right; Sinister — screws installed on the left; S — the superior wall of the pedicle of the vertebral arch; L — lateral wall of the pedicle; I — inferior wall of the pedicle; M — medial wall of the pedicle; V — vertebral body.

Table 5

Distribution of incorrect positions of pedicle screws with respect to the thoracic and lumbar spine in the study and control groups, n

Vertebra	Study group (n = 66)		Control group (n = 30)	
	scT	scIN	scT	scIN
T3	25	4	2	2
T4	45	5	11	10
T5	75	3	20	10
T6	82	4	23	5
T7	74	4	22	7
T8	74	5	20	10
T9	91	4	24	17
T10	112	2	32	8
T11	117	3	45	10
T12	108	4	60	12
L1	119	4	67	8
L2	118	2	70	6
L3	76	1	71	1
L4	50	2	51	5
L5	0	0	28	9
Total	1166	47 (4 %)	546	120 (22 %)

scT— total number of inserted screws; scIN— the number of incorrectly inserted screws.

References

1. **Vasyura AS, Novikov VV, Mikhayilovskiy MV, Dolotin DN, Suzdalov VA, Sorokin AN, Udalova IG.** Surgical treatment of scoliosis using transpedicular fixation. Hir. Pozvonoc. 2011;(2):27–34. In Russian. DOI: http://dx.doi.org/10.14531/ss2011.2.27-34.
2. **VasyuraAS, Novikov VV, Belosyorov VV, Udalova IG.** Efficacy of laminar and transpedicular fixation in surgical treatment of thoracolumbar and lumbar idiopathic scoliosis. Hir. Pozvonoc. 2012;(1):48–53. In Russian. DOI: http://dx.doi.org/10.14531/ss2012.1.48-53.
3. **Vetrile ST, Kisel' AA, Kuleshov AA.** Efficacy assessment of one-step surgical correction of scoliotic spine deformity using Cotrel-Dubousset instrumentation. Journal of Traumatology and Orthopedics. Priorov. 2004;(4):58–68. In Russian.
4. **Vetrile ST, Kuleshov AA, Shvets VV, Kisel AA, Vetrile MS, Guseinov VG.** The concept of surgical treatment of various forms of scoliosis using modern technologies. Hir. Pozvonoc. 2009;(4):21–30. In Russian. DOI: http://dx.doi.org/10.14531/ss2009.4.21-30.
5. **Vissarionov SV, Drozdetsky AP, Kokushin DN, Belyanchikov SM.** Correction of idiopathic scoliosis under 3D-CT navigation in children. Hir. Pozvonoc. 2012;(2):30–36. In Russian. DOI: http://dx.doi.org/10.14531/ss2012.2.30-36.
6. **Vissarionov SV.** Approaches to spinal deformity correction using transpedicular systems in children with idiopathic scoliosis. Hir. Pozvonoc. 2013;(1):21–27. In Russian. DOI: http://dx.doi.org/10.14531/ss2013.1.21-27.
7. **Vissarionov SV, Kokushin DN, Drozdetsky AP, Belyanchikov SM.** Variants of spine deformity correction in children with idiopathic scoliosis of thoracic localization. Journal of Traumatology and Orthopedics. Priorov. 2012;(3):9–13. In Russian.
8. **Gubin AV, Riabykh SO, Burtsev AV.** Retrospective analysis of screw malposition following instrumented correction of thoracic and lumbar spine deformities. Hir. Pozvonoc. 2015;(1):8–13. In Russian. DOI: http://dx.doi.org/10.14531/ss2015.1.8-13.
9. **Kuleshov AA.** Surgery of severe scoliosis and functional features of some organs and systems: DMSc Thesis. Moscow, 2007. In Russian.
10. **Kuleshov AA, Lisyansky IN, Vetrile MS, Gavryushenko NS, Fomin L.V.** Comparative experimental study of hook and pedicle fixation systems used at surgical treatment of spine deformities. Journal of Traumatology and Orthopedics. Priorov. 2012;(3):20–24. In Russian.
11. **Mikhailovsky MV, Fomichev NG.** Surgery of Spinal Deformities. Novosibirsk, 2011. In Russian.
12. **Rubashkin SA.** Anatomico-morphometric justification for surgical correction of scoliotic deformity: Abstract of MD/PhD Thesis. Saratov, 2008. In Russian.
13. **Sobolev A.**V. Surgical treatment of children with thoracolumbar and lumbar idiopathic scoliosis: Abstract of MD/PhD Thesis. St.Petersburg, 2015. In Russian.
14. **Amiot LP, Lang K, Putzier M, Zippel H, Labelle H.** Comparative results between conventional and computer-assisted pedicle screw installation in the thoracic, lumbar, and sacral spine. Spine. 2000;25:606–614. DOI: 10.1097/00007632-200003010-00012.
15. **Belmont PJ Jr, Klemme WR, Dhawan A, Polly DW Jr.** In vivo accuracy of thoracic pedicle screws. Spine.2001;26:2340–2346. DOI: 10.1097/00007632-200111010-00010.

16. **Gebhard FT, Kraus MD, Schneider E, Liener UC, Kinzl L, Arand M.** Does computer-assisted spine surgery reduce intraoperative radiation doses? Spine. 2006;31:2024–2028. DOI: 10.1097/01.brs.0000229250.69369.ac.
17. **Gertzbein SD, Robbins SE.** Accuracy of pedicular screw placement in vivo. Spine. 1990;15:11–14. DOI: 10.1097/00007632-199001000-00004.
18. **Jarvers JS, Katscher S, Franck A, Glasmacher S, Schmidt C, Blattert T, Josten C.** 3D-based navigation in posterior stabilisations of the cervical and thoracic spine: problems and benefits. Results of 451 screws. Eur J Trauma Emerg Surg. 2011;37:109–119. DOI: 10.1007/s00068-011-0098-1.
19. **Kotani Y, Abumi K, Oto M, Minami A.** Improved accuracy of computer-assisted cervical pedicle screw insertion. J Neurosurg. 2003;99(3 Suppl):257–263.
20. **Laine T, Lund T, Ylikoski M, Lohikoski J, Schlenzka D.** Accuracy of pedicle screw insertion with and without computer assistance: a randomised controlled clinical study in 100 consecutive patients. Eur Spine J. 2000;9:235–240. DOI: 10.1007/s005860000146.
21. **Lenke LG, Betz RR, Harms J, Bridwell KH, Clements DH, Lowe TG, Blanke K.** Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am. 2001;83:1169–1181. DOI: 10.2106/00004623-200108000-00006.
22. **Nottmeier EW, Seemer W, Young PM.** Placement of thoracolumbar pedicle screws using three-dimensional image guidance: experience in a large patient cohort. J Neurosurg Spine. 2009;10:33–39. DOI: 10.3171/2008.10.SPI08383.
23. **Tian NF, Huang QS, Zhou P, Zhou Y, Wu RK, Lou Y, Xu HZ.** Pedicle screw insertion accuracy with different assisted methods: a systematic review and meta-analysis of comparative studies. Eur Spine J. 2011;20:846–859. DOI: 10.1007/s00586-010-1577-5.
24. **Tian NF, Xu HZ.** Image-guided pedicle screw insertion accuracy: a meta-analysis. Int Orthop. 2009;33:895–903. DOI: 10.1007/s00264-009-0792-3.
25. **Tormenti MJ, Kostov DB, Gardner PA, Kanter AS, Spiro RM, Okonkwo DO.** Intraoperative computed tomography image-guided navigation for posterior thoracolumbar spinal instrumentation in spinal deformity surgery. Neurosurg Focus. 2010;28:E11. DOI: 10.3171/2010.1.FOCUS09275.

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