



CLASSIFICATION OF SCREW MALPOSITIONS IN INSTRUMENTAL FIXATION OF SPINAL DEFORMITIES

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Objective. To perform a non-systematic review of classifications of screw malpositions in transpedicular fixation of thoracic and lumbar spine deformities and to develop a tactical classification of screw malpositions in instrumental fixation of scoliotic deformities of the spine with a consensus assessment (kappa coefficient).

Material and Methods. A search of studies was conducted in the Pubmed, eLibrary, and Google databases that evaluated the location of screws using or justifying the classification. Given the narrow specificity of the topic, publications of any design were included in the sample. Based on the data obtained, the authors proposed a tactical classification of screw malpositions in instrumental fixation of scoliotic deformities of the spine with an assessment of expert agreement using the Cohen's kappa coefficient.

Results. A total of 139 articles were found in the databases, including 21 articles from references. Of them, 66 articles did not correspond to the topic of the study, 12 — did not have the open-text access, and 85 — had open-text access. Twenty articles met the inclusion criteria. The analysis showed that classifications used mainly determine the displacement of screws into the lumen of the spinal canal without taking into account clinical manifestations and treatment tactics. Five classifications have been proposed to assess the position of screws in scoliosis, while only one determines the tactics of patient management based on a score assessment.

Conclusion. An objectified method for assessing the accuracy of screw position is needed to provide additional evidence of the safety of malpositions and to determine the clinical significance of malpositions, risk factors associated with incorrect installation, and further actions of the surgeon.

Keywords: screw placement accuracy; screw position; scoliosis; screw position classification; screw malposition.

Please cite this paper as: Prudnikova OG, Strebkova MS, Matveev EA, Evsyukov AV. Classification of screw malpositions in instrumental fixation of spinal deformities. *Russian Journal of Spine Surgery (Khirurgiya Pozvonochnika)*. 2025;22(3):6–17. In Russian. DOI: <http://dx.doi.org/10.14531/ss2025.3.6-17>

Heterogeneous data on screw malpositions during instrumental fixation of the spine, particularly in cases of scoliosis, have been reported in the literature, with rates averaging 25%–41% of cases [1]. According to Ansorge et al. [2], the malposition rate in the surgical treatment of scoliosis ranges from 1.9% to 11.0% when using navigation and from 1.5% to 50.7% when using the freehand technique. Meanwhile, the rate of complications associated with implant malposition is similar across all methods, ranging from 0% to 1.4%. Researchers addressing this issue consider that the main problem in spinal deformity surgery is assessing screw position and determining further treatment strategy.

The objective is to conduct a non-systematic review of classifications of screw malpositions in transpedicular fixation of thoracic and lumbar spine deformities and to develop a tactical classification with an agreement assessment (the Kappa coefficient).

Material and Methods

Literature search and selection strategy.

A search of studies was conducted in the PubMed, eLibrary, and Google databases that evaluated the placement of screws in transpedicular fixation of the thoracic and lumbar spine deformities using or justifying classification. Three researchers performed the literature search. Given the highly specialized field of the topic, papers of any design were included in the sample (Table 1).

Inclusion criteria: open-access full-text articles in English and Russian, systematic reviews, meta-analyses (both randomized and non-randomized), retrospective, prospective studies, and clinical case series involving instrumental fixation of deformities of the thoracic and lumbar spine, where the pedicle screws placement was evaluated based on CT data after surgery using or justifying the classification of malpositions.

Exclusion criteria: case reports, articles unavailable in full-text, articles without evaluation of screw placement based on CT data after instrumental fixation of deformities of the thoracic and lumbar spine.

An initial search of the literature was conducted using the following keywords: “classifications for pedicle screw position” without filtering the search depth for the period up to February 2025. Thereafter, publications that did not meet the study criteria were excluded. In the third phase, the full texts of the selected articles were reviewed for compliance with the inclusion criteria and the references for relevant studies.

Based on the obtained data, the authors suggested a tactical classification of screw malpositions in instrumental fixation of scoliotic deformities of the spine. The expert agreement of the presented classification was assessed using the Cohen's Kappa coefficient that is used for quantitative evaluation of the level

of agreement between two experts and shows how reliably two experts measure the same thing, given that they may agree by chance.

An expert agreement, as discussed in the article, is divided into intra-expert and inter-expert agreement. The case of intra-expert agreement involves comparing evaluations made by the same expert at different times, which is the equivalent of reproducibility. In contrast, inter-expert agreement involves the evaluation of the same object by multiple experts.

Three surgeons (the first with over 20 years of experience, the second with 10 years of experience, and the third with one year of experience) were provided with 39 images of malpositions in axial and coronal planes, a lateral scout image of the spine, and comments on clinical manifestations. The images did not provide any information or markers associated with classification. The evaluation was conducted twice, with a two-week time gap. The Kappa coefficient was assigned for each type of malposition and for the classification as a whole in pairs for surgeons (the first and the second; the second and the third; the first and the third). Normally distributed data sets were expressed as mean values and standard deviations.

Results

Overall, 139 articles were found in the databases using keywords. Twenty-one articles were found from the references. Sixty-six articles were excluded for not aligning with the research topic, and 12 lacked full-text availability. Consequently, 85 articles with full text were available, and 20 met the inclusion criteria.

Still at the preliminary selection stage, we were attracted by the question of authors' preferences in using one or another classification when evaluating screws position. Accordingly, 85 full-text articles were analyzed for the choice of classification and etiology of the deformity for which fixation of the spine was performed. The most popular classification was that proposed by Gertzbein and Robbins [3]. The authors

Table 1

Inclusion/exclusion criteria and selection of publications

Components	Inclusion	Exclusion
Participants	Patients with instrumented spinal fixation. Pedicle screw placement was evaluated by CT scans after surgery using the classification	Patients with instrumented spinal fixation. Pedicle screw placement was not evaluated by CT scans after surgery
Intervention	Surgical treatment of deformities of the thoracic and lumbar spine using transpedicular fixation	
Comparison	Classification of screw malpositions	
Result	Development of a classification of malposition in instrumental fixation of scoliotic spinal deformities	
Study design	Systematic review, randomized and non-randomized, retrospective, prospective studies, case series	Clinical cases
Publications	In Russian, in English, full-text	In any other languages, without full-text access

sed various classification options when evaluating the position of screws in scoliosis (Table 2).

The articles that met the selection criteria were divided into two groups: 13 articles with proposed classifications; 7 review articles (Table 3).

All of the classifications of malpositions in pedicle screw placement were proposed by the authors during clinical studies while analyzing postoperative CT images. At the same time, only five studies evaluate the position of screws in instrumental fixation of the spine in scoliotic deformity. These publications describe the characteristics of vertebral fixation in scoliosis, both in terms of screw placement and postoperative evaluation of their position.

Since in full-text articles authors refer to classifications not adapted for scoliosis, these classifications are also analyzed in this study (Table 4).

The performed analysis of full-text articles showed that classifications determining the malposition of screws into the spinal canal lumen are mainly used to evaluate the position of screws. Even the classification by Neo et al. [6], which describes malpositions relative to the ver-

tebral artery channel, is used. The classification by Gertzbein and Robbins [3] is the most commonly used. There are different types of classifications used to evaluate the position of screws in scoliosis, determining the relevance of our study.

Most of the selected classifications determine the degree of medial/lateral malposition of the screw relative to the vertebral pedicle on axial CT scans (usually at 2 mm intervals): Neo et al. [6], Zdechavsky et al. [11], Rampersaud et al. [12], Wiesner et al. [9], and Rao et al. [13]. In the Russian-language article by A.V. Gubin et al. [14], the evaluation of screw malposition is also done based on the medial/lateral position relative to the vertebral pedicle without associating it to clinical manifestations and determining treatment strategy.

The classification by Oba et al. [15] combines five basic techniques for evaluating medial/lateral screw malposition and further distributes them according to the hazard rate of injury to adjacent anatomical structures.

Another type of classification option-ally considers the superior or inferior malposition of the screw relative to the pedicle: Laine et al. [5] and Gertzbein and

Table 2

Classifications used in full-text articles of the selection stage

Authors of classifications	Number of articles	Etiology of deformities (some authors used one classification for different pathologies in one article)
Gertzbein, Robbins [3]	38	Idiopathic scoliosis — 3; neuromuscular scoliosis — 2; post-traumatic deformities — 4; spondylolisthesis — 9; degenerative scoliosis — 7; deformities of unspecified etiology — 15; experiment — 1
Laine et al. [5]	2	Idiopathic scoliosis — 1; deformities of unspecified etiology — 1
Neo et al. [6]	4	Idiopathic scoliosis — 3; ankylosing spondylitis — 1
Rao et al. [13]	1	Idiopathic scoliosis — 1
Heary et al. [7]	8	Idiopathic scoliosis — 1; post-traumatic deformities — 3; degenerative scoliosis — 2; deformities of unspecified etiology — 4
Zdichavsky et al. [11]	6	Post-traumatic deformities — 3; spondylolisthesis — 1; degenerative scoliosis — 1; deformities of unspecified etiology — 2
Wiesner et al. [9]	2	Spondylolisthesis — 1; deformities of unspecified etiology — 1
Rampersaud et al. [12]	2	Idiopathic scoliosis — 1; post-traumatic deformities — 1; degenerative scoliosis — 1; spondylolisthesis — 1

Robbins [3], but without association with clinical manifestations.

While evaluating the position of the screws, Gertzbein and Robbins [3] determined that 1–3 mm penetration of the medial wall of the vertebral arch in the thoracic spine is possible without neurological deficit, and up to 4 mm penetration at the T8–L4 levels. The area from 0 to 4 mm is called the “epidural safe zone” (2 mm is the epidural space and 2 mm is the subarachnoid space).

One option for tactical classification is the classification of malpositions proposed by Aoude et al. [4] based on a survey of spine specialists. This classification has a scoring system for evaluating screw placement and clinical manifestations and determines treatment strategy.

The following classifications have been adapted for scoliosis: Heary et al. [7], Upendra et al. [1], Abul-Kasim et al. [8], and Sarwahi et al. [10]; these classi-

fications consider both the anatomical features of the vertebrae in deformities and variants of malpositions relative to the deformed structures in association with clinical manifestations but do not specify tactical issues after a diagnosed malposition.

One of the seven review articles presented is a systematic review; one more is a meta-analysis; and two of them are literature reviews on the topic under study. By agreement between the authors, two articles (the original article and a prospective study) have been included for analysis of the characteristics of spinal fixation in scoliosis and evaluation of screw placement in this pathology.

Discussion

Currently, no standardized technique exists for evaluating screw placement after spine surgery [2, 4, 17]. The eval-

uation of the screw position based on radiological data is a preliminary examination; CT is used to accurately evaluate the screw position, including a series of CT scans with slice thicknesses of 2.5 mm, reconstructed at 2 mm intervals and with a visual field sufficient for the spine visualization, as well as to reconstruct sagittal and coronal images of the spine. The evaluation of the position of pedicle screws generally includes malposition relative to the vertebral pedicle (medial, lateral, and foraminal) and vertebral body (anterior).

In 2007, Kosmopoulos and Schizas [17] published a meta-analysis on the accuracy of pedicle screw placement and identified 35 different evaluation techniques in 130 articles.

In accordance with Adamski et al. [20], the precise clinical significance of incorrect screw placement remains unclear because of the rarity of clinical manifestations and complications, and the authors suggest conducting an evaluation using several classifications simultaneously.

In the systematic review by Aoude et al. [19], it was shown that out of 68 articles included in the review, 37 (54%) used comparable methodologies: evaluation of pedicle integrity with an increment of 2 mm (malposition up to 2 mm are considered to be safe or acceptable, and more than 2 mm are considered to be unsafe). This does not include fixation of bone structures (screw support) and the position of screws relative to important anatomical structures. The second more commonly used evaluation system (16 articles; 24%) classifies screws as being “within” or “outside” the pedicle (the screw is completely within the pedicle, or up to 25% of the screw diameter may extend beyond the pedicle), but without considering the direction of malposition or clinical manifestations [19].

In 2018, Aoude et al. [4] published a study in which they surveyed 35 Canadian spine surgeons to standardize the evaluation of pedicle screw malpositions. The questionnaire included questions about clinical techniques and imaging criteria. The study showed that the clinical findings are crucial for deciding on treatment strategy in cases of screw mal-

Table 3

Articles that met the selection criteria and were included in the review

Authors	Year of publication	Study design	Study direction
Gertzbein, Robbins [3]	1990	Clinical	The classification is presented
Aoude et al. [4]	2018	Clinical	The classification with intra-expert agreement is presented
Laine et al. [5]	2006	Clinical	The classification is presented
Neo et al. [6]	2005	Clinical	The classification is presented
Heary et al. [7]	2004	Clinical	The classification is presented
Abul-Kasim et al. [8]	2009	Retrospective	The classification is presented
Wiesner et al. [9]	2000	Clinical	The classification is presented
Sarwahi et al. [10]	2016	Retrospective analysis	The classification is presented
Zdichavsky et al. [11]	2004	Retrospective analysis	The classification is presented
Upendra et al. [1]	2008	Clinical	The classification is presented
Rampersaud et al. [12]	2005	Clinical	The classification is presented
Rao et al. [13]	2002	Retrospective analysis	The classification is presented
Gubin et al. [14]	2015	Clinical	Postoperative evaluation of pedicle screw position
Oba et al. [15]	2023	Systematic review Prisma (20 articles)	Characteristics of the five main classifications, their grouping into a single classification
Watanabe et al. [16]	2010	Prospective	Evaluation of vertebral pedicles in scoliosis fixation
Kosmopoulos, Schizas [17]	2007	Meta-analysis (130 articles)	Analysis of techniques for postoperative evaluation of pedicle screws
Ansorge et al. [2]	2023	Review (51 articles)	Comparative analysis of screw malposition classifications
Akazawa et al. [18]	2015	Original article	Evaluation of vertebral pedicles in scoliosis with reasoning for screw placement
Aoude et al. [19]	2015	Systematic review (68 articles)	Review of screw malposition classifications
Adamski et al. [20]	2023	Review (43 articles)	Description of systems of screw position evaluation

position. The authors suggested a preliminary rating system based on their analysis to standardize the classification of pedicle screws and assist surgeons in deciding which pedicle screws need to be repositioned.

Sarwahi et al. [10] have introduced a classification system considering a potential clinically significant malposition, the direction of malposition, and the remaining distance between the screw and the adjacent anatomical structures. They define screw placement as precise placement, minor malposition, uncertain malposition, and hazardous malposition. According to the authors, no neurological disorders are detected with medial screw malposition of less than 4 mm. The presented review gives a detailed description of the options and complications

associated with anterior malposition of screws behind the vertebral body, which occurs in 10 to 15% of cases. Anterior malpositions are hazardous to the aorta, iliac artery and vein, esophagus, trachea, bronchi, pleural cavity, and lungs. A retrospective analysis of screw malposition has determined that a distance of 1 mm between the screw point and the organ is safe. In the evaluation of screw malposition relative to the aorta, it is recommended to perform a CT scan with the patient in the supine or prone position. If no changes are detected, an intravenous contrast computed tomography scan, and assessment of morphological changes and aortic wall deformation should be performed.

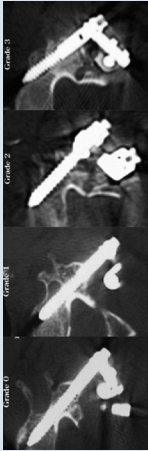
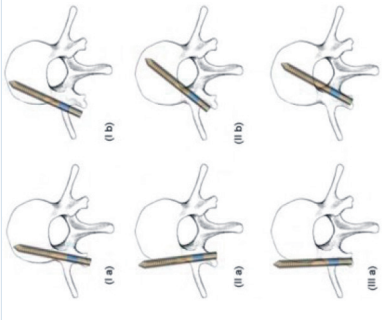
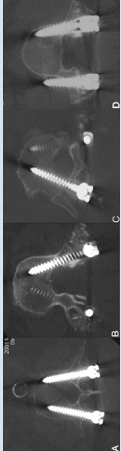
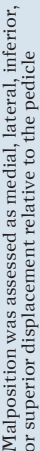
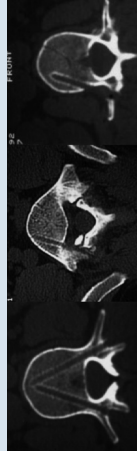
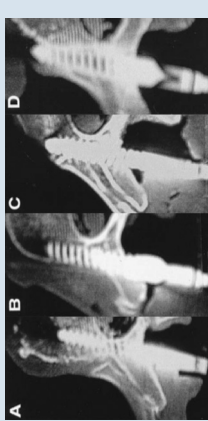
According to numerous researchers, most malpositions are asymptomatic and hence do not constitute an unfavor-

able outcome or complication. They may remain hidden for a long time, as their natural course is unknown [1, 10]. Moreover, the authors suggest that sometimes the screw proximity is overestimated on CT scans [10].

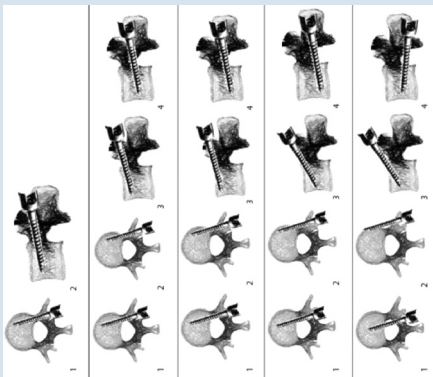
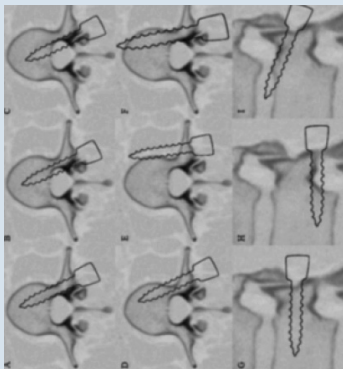
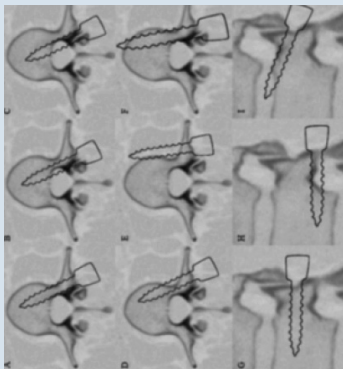
It is known that the shape and size of the pedicle in idiopathic scoliosis differ significantly from those of healthy vertebrae. Watanabe et al. [16] and Akazawa et al. [18] classified the dimensions of the pedicles and determined that malpositions of screws for the cortical canal with an internal diameter of the pedicle less than 1 mm accounted for 31.5%, and suggested not placing screws with such dimensions.

Other researchers have determined that the costotransverse joint is a three-dimensional support structure and that the “inside-outside-inside” screw place-

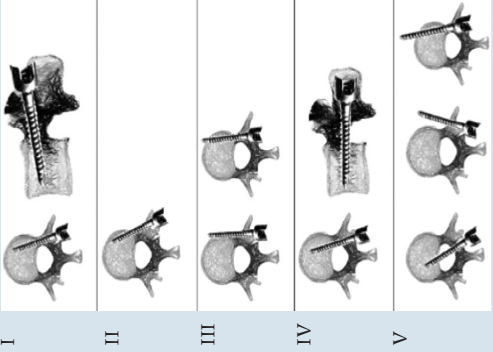
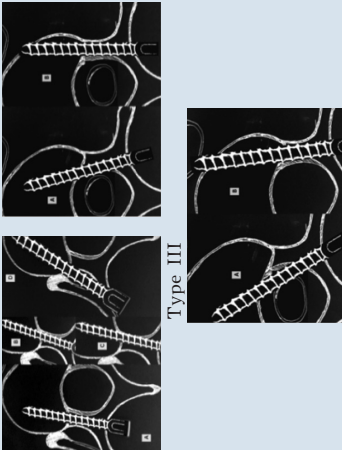
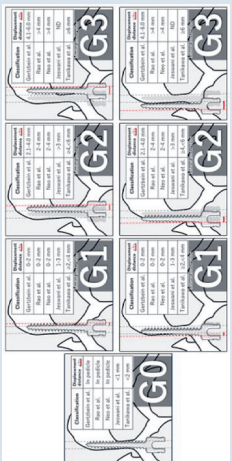
Table 4
Classifications of screw malpositions included in the review

Authors	Classifications	Comments to the classifications	Peculiarities
Neo et al. [6]		0 – no malposition; 1 – malposition less than 2 mm (i.e., less than half of the screw diameter); 2 – malposition more than 2 mm and less than 4 mm; 3 – malposition more than 4 mm (i.e., total malposition)	18 patients; evaluation of the screw relative to the vertebral artery canal
Zdichavsky et al. [11]		Ia – completely inserted into the pedicle and vertebral body; Ib – inserted into the vertebral body, but lateral to the pedicle; IIa – partial lateral malposition; IIb – partial medial malposition; IIIa – complete lateral malposition; IIIb – complete medial malposition	43 patients, 278 screws; described for thoracic trauma; no comparison with clinical manifestations
Rampersaud et al. [12]		A – completely in the pedicle; B – pedicle wall perforation less than 2 mm; C – pedicle wall perforation of 2–4 mm; D – pedicle wall perforation more than 4 mm	45 patients, 360 screws; thoracic spine, lumbar spine
Laine et al. [5]		0 – screw in the pedicle; 1 – malposition up to 2.0 mm; 2 – malposition of 2.1–4.0 mm; 3 – malposition of 4.1–6.0 mm; 4 – screw outside the pedicle	30 patients, 152 screws; lumbar spine
Wiesner et al. [9]		A – slight malposition (<3 mm); B – moderate malposition (3–6 mm); C – severe malposition (>6 mm)	51 patients, 408 screws; percutaneous screw placement, lumbar spine; canal after screw removal was evaluated; comparison with clinical data
Rao et al. [13]		0 (A) – no perforation; 1 (B) – perforation with one thread extending beyond the pedicle; 2 (C) – pedicle perforation from 2 to 4 mm; 3 (D) – pedicle perforation more than 4 mm	155 screws, thoracic vertebrae; perforation evaluation by CT scans and direct visualization in cadavers; axial images only; no comparison with clinical data

Continuation of the Table 4
Classifications of screw malpositions included in the review

Authors	Classifications	Comments to the classifications	Peculiarities																																		
Gertzbein, Robbins [3]		A – completely intrapedicular position without damage to the pedicle cortex; B – damage to the pedicle cortex less than 2 mm; C – damage to the pedicle cortex of 2–4 mm; D – damage to the pedicle cortex of 4–6 mm; E – damage to the pedicle cortex more than 6 mm or location outside the pedicle	40 patients, 167 screws; thoracolumbar spine; no comparison with clinical manifestations																																		
Aoude et al. [4]	<table><tr><th rowspan="2">Screw placement</th><th colspan="4">Data of axial images</th></tr><tr><th>malposition of > 6 mm</th><th>malposition of 4–6 mm</th><th>malposition of 2–4 mm</th><th>malposition of < 2 mm</th></tr><tr><td>medial</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td>inferior</td><td>2</td><td>2</td><td>1</td><td>0</td></tr><tr><td>lateral</td><td>2</td><td>2</td><td>1</td><td>0</td></tr><tr><td>superior</td><td>1</td><td>1</td><td>0</td><td>0</td></tr><tr><td>anterior</td><td>1</td><td>1</td><td>0</td><td>0</td></tr></table>	Screw placement	Data of axial images				malposition of > 6 mm	malposition of 4–6 mm	malposition of 2–4 mm	malposition of < 2 mm	medial	4	3	2	1	inferior	2	2	1	0	lateral	2	2	1	0	superior	1	1	0	0	anterior	1	1	0	0	Symptoms: radicular pain – 4; muscle weakness – 4; sensory disturbance – 1; no symptoms – 0. A score over 6 points requires screw replacement	A classification based on a systematic review was proposed
Screw placement	Data of axial images																																				
	malposition of > 6 mm	malposition of 4–6 mm	malposition of 2–4 mm	malposition of < 2 mm																																	
medial	4	3	2	1																																	
inferior	2	2	1	0																																	
lateral	2	2	1	0																																	
superior	1	1	0	0																																	
anterior	1	1	0	0																																	
Abul-Kasim et al. [8]		Medial perforation: grade 0, 1, 2; lateral perforation: grade 0, 1, 2; perforation of the anterior wall of the vertebral body: grade 0, 1; endplate perforation: grade 0, 1; foraminal perforation: grade 0, 1, 2 (the degree of perforation is indicated in mm)	46 subjects, 809 screws; scoliosis; significant inter-expert and intra-expert agreement (the Kappa-coefficient 0.69 and 0.76, respectively); comparison with clinical data																																		
Sarwahi et al. [10]		1) screws at risk (SAR): located more than 4 mm medially, located laterally or anteriorly and contacting anatomical structures that posed a risk (distance between the screw and the organ is less than 1 mm); 2) indeterminate misplacements (IMP): screws extending medially by 2–4 mm, or screws extending laterally or anteriorly (distance > 1–2 mm between the screw and the organ); 3) benign misplacements (BMP): screws partially passing through the pedicle, but not pose a risk to any structures; 4) accurately placed (AP) screw through the pedicle	127 patients, 2,724 screws; idiopathic scoliosis (94), neuromuscular (16), other types (17); 87.96% of screws were placed accurately, in 14.17% of cases the screws were dangerous, more than 40% of patients had screws that were of concern																																		

The end of the Table 4
Classifications of screw malpositions included in the review

Authors	Classifications	Comments to the classifications	Peculiarities
Heary et al. [7]	 I II III IV V	Class I – good placement, the screw is completely within the pedicle and the vertebral body; Class II – the screw extends beyond the lateral wall of the pedicle, but is located within the 'pedicle-rib' complex, and the screw tip is completely within the vertebral body; Class III – the screw tip penetrates the anterior or lateral wall of the vertebral body; Class IV – damage to the middle or inferior border of the pedicle; Class V – screws that pose a risk to the spinal cord, nerve roots, or major vessels require immediate removal and/or replacement	27 patients, 185 screws; scoliosis; thoracic spine; the 'pedicle-rib' complex is a supporting three-dimensional monoatomic structure; fixation through the costotransverse complex allows the safe use of screws of the appropriate size, the diameter of which is larger than the diameter of the pedicle
Upendra et al. [1]	 Type I Type II	Type I – acceptable placement; Type II – unacceptable placement without any clinically significant neurovascular complications; Type III – screw placement with clinical neurovascular complications and recorded damage to relevant vital structures	60 individuals, 341 screws; two groups: with scoliosis (24 individuals) and without scoliosis (36 individuals); malpositions – 49.28%; comparison with clinical data
Oba et al. [15]	 G0 G1 G2 G3	Medial, lateral malposition based on the combined assessment of the classifications by Rao, Neo, Gertzbein, Jeswani, Tanikawa: G0 – normal position; G1 and G2 – serious deviation; G3 – dangerous deviation	Systematic review, Prizma; children with scoliosis; pooled assessment of five classifications; no comparison with clinical data

ment is 70% stronger than intrapedicular fixation and does not result in clinical complications [1, 7].

Scoliotic deformities of the spine are characterized by changes in the shape of the vertebral body, the size and shape of the spinal canal, and the position of the dural sac within the deformed spine. All these morphological characteristics of the vertebrae determine the features of screw placement. In surgical treatment of scoliosis, support screws are placed for further correction of the deformity using surgical techniques. For this reason, the primary characteristic in this case will be a safe reference trajectory for placement.

The size and shape of the spinal canal and the topography of the dural sac in scoliosis are variable, associated with vertebral rotation, changes in the spinal axis, and changes in the shape of the vertebral pedicles. The change in the shape of the spinal canal is also associated with the etiology of the disease (narrow spinal canal in achondroplasia, etc.).

Traditionally, the pedicle has been defined as a safe zone for screw placement; however, only in certain cases (small size, vertebral deformity, rotation) it is just a reference point for selecting a safe trajectory.

Therefore, we believe that spinal deformity surgery is not a matter of pedicle screw placement but rather the safe placement of support points and posterior instrumentation for the improvement of curvature.

In the evaluation of screw placement in scoliosis, it is acceptable to perform extrapedicular placement with fixation of the vertebral body, placement of the screw through the costovertebral joint complex, intracanal placement on the convex side (with consideration of preoperative visualization of the dural sac), and intradiscal malposition in the extended fixation area.

The presented classifications of screw malpositions in scoliosis specify the options for extrapedicular screw placement. Meanwhile, clinical manifestations and the risk of injury or injury itself to organs will determine the treatment strategy and the necessity of recurrent surgery.

An objectivistic method for evaluating the accuracy of screw positioning is necessary to provide additional proof of the malposition safety. The optimal classification system should be reproducible and simple, define the clinical significance of malpositions, discuss risk factors associated with incorrect placement, and outline further actions to be implemented by the surgeon. Moreover, it should serve as a protective mechanism in the event of future judicial hearings.

The experience of surgical treatment of patients with scoliosis with postoperative CT control of screw position (247 patients (4,560 screws), including 81 patients (1,729 screws) with intraoperative CT navigation) and the eternal question of spinal surgeons, "to reinsert/not to reinsert" and "acceptable/unacceptable," served as a reason for systematizing malpositions.

Therefore, we have developed a tactical classification of screw placement for scoliosis deformities of the spine (Table 5).

Using the analysis of the literature and our own experience, we have determined the main criteria for evaluating the position of the screw in scoliotic deformities of the spine:

1) the position of the screw is evaluated in the axial and sagittal planes with an assessment of support and malposition beyond the safe zone;

2) the boundaries of the safe zone are the posterior-superior-external surface of the vertebral body, formed by the lateral wall of the spinal canal (pedicle or its cortical layer), the superior endplate, the lateral surface of the vertebral body (including the costovertebral complex), and the superior border of the intervertebral foramen;

3) a safe placement trajectory: the direction of placement is chosen based on the anatomical features of the vertebra and implies no injury to organs; the screw penetrates the vertebral body in the projection of the pedicle as an anatomically safe zone: extrapedicularly (discrepancy in pedicle dimensions, 'inside-outside-inside' trajectory, through the 'pedicle-rib' complex"), intracanal (visualized malposition of the dural sac on the

convex side of the deformity or its omission in cases of injury or disease);

4) in the evaluation of intracanal malpositions, it is essential to consider the diameter of the screw, the dimensions of the spinal canal at the given level (stenosis in systemic diseases), and the topography of the dural sac, including on the concave side of the deformity;

5) the most important anatomical structures requiring visualization in cases of malposition are the neural structures and their membranes, the aorta, iliac vessels, esophagus and gastrointestinal tract, trachea, bronchi, pleural cavity, and lungs;

6) clinical manifestations (intraoperatively): cerebrospinal fluid leakage from the screw canal, decreased TEPs amplitude during neuromonitoring, bleeding, air, etc.; in the postoperative period – symptoms corresponding to the topography of malposition;

7) additional examinations for malpositions to determine further treatment: MRI, CT myelography, CT of lungs, CT of abdomen, and CT angiography with the patient in supine/prone position;

8) the treatment strategy is defined by the results of intraoperative or postoperative CT scanning to check the position of the screws;

9) an intraoperative CT provides the opportunity to reinsert the screw during surgery. In some cases, the anatomical features of the vertebrae in scoliosis described above do not require a change in the screw placement trajectory. For this reason, we consider the first type of screw placement to be acceptable, while the second and third types of malposition are potentially hazardous and require intraoperative replacement.

Considering the proposed classification of screw malpositions, it becomes clear that its particularity is to be applied both during intraoperative and postoperative CT control.

The inter-expert evaluation showed high consistency and high reproducibility. The inter-expert evaluation was conducted for all three types of malpositions and for the classification as a whole. The mean Kappa coefficient was 0.63 ± 0.065 for the first type of malposition; 0.66 ± 0.11 for type 2; 0.87 ± 0.09

for type 3; and 0.75 ± 0.14 for the classification as a whole, which shows a considerable agreement among researchers. The mean value of the Kappa coefficient

in the intra-expert evaluation was 0.86 ± 0.10 (high agreement).

Study limitation. Limited expert evaluation.

Conclusion

The technical options for placing screws in scoliosis are determined by the morphological characteristics of

Table 5

Tactical classification of screw malpositions in instrumental fixation of spinal deformities

Type	Topography	Intraoperative CT control: tactics	Postoperative CT control: tactics
1 – malpositions that do not require replacement; safe; M1	Malposition: – intracranally: thoracic spine up to 2 mm, lumbar spine up to 2 mm; – foraminally: up to 2 mm; – ventrally, paravertebrally: distance to adjacent important anatomical structures more than 1 mm. Support trajectory: large part of the screw (>75% of the length) is located within the vertebra. No symptoms of malposition. Exception: the trajectory is determined to be safe given the anatomical features	Does not require replacement	Does not require replacement
2 – potentially critical malpositions; conditionally safe; M2–/+	Malposition: – intracranally: thoracic spine up to 4 mm, lumbar spine more than 2 mm, but less than the screw diameter; – foraminally: more than 2 mm; – ventrally, paravertebrally: distance to adjacent important anatomical structures less than 1 mm, their deformation. Conditional support trajectory: screw partially passes through bone structures (75 to 50% of the length), bone canal not along the entire length of the screw, screw inside the structure (acceptable for several screws). Symptoms of malposition are absent (M2–), detected (M2+). Exception: the trajectory is determined to be safe given the anatomical features	Screw replacement	Commentary, additional examination, indications for replacement: clinical manifestations (M2+), high risk of organ damage according to examination data, asymptomatic damage to internal organs
3 – malpositions requiring replacement; dangerous or threatening; M3–/+	Malposition: – intracranally: thoracic spine more than 4 mm, lumbar spine more than screw diameter; – foraminally: more than 4 mm. – ventrally, paravertebrally: deformation or displacement of anatomical structures. Unsupport trajectory: – screw inserted through bone structures (less than 50%) but does not fixate the vertebral body; – screw partially penetrates bone structures (75 to 50% of the length), located at the distal or proximal fixation level. Symptoms of malposition are absent (M3–), detected (M3+).	Screw replacement	Screw replacement

the vertebrae and the spine as a whole and by the performance of corrective maneuvers. The main feature of their position is a safe support trajectory for placement.

The fact that a screw is misplaced does not imply that it is inadequate or poses a health hazard. When malposition is detected, the degree of malposition is the only factor that determines whether it is incorrect.

The presented classifications of screw malpositions in scoliosis define the options for extrapedicular screw placement. Meanwhile, clinical manifestations and the risk of injury or injury itself to organs will determine the treatment strategy and the need for repeat surgery.

We have created a tactical classification of screw placement in cases of scoliosis with high expert agreement, defining three types of malposition: type 1 – no repositioning required; type 2 – requires clarification and determination of indi-

cations for repositioning; type 3 – clearly requires repositioning. A specific feature of the classification is its applicability to both intraoperative and postoperative CT monitoring.

An objectivistic method for evaluating screw position accuracy is essential for providing additional evidence of malposition safety, determining the clinical significance of malpositions, risk factors associated with incorrect placement, and further steps to be taken by the surgeon. The optimal classification system needs to be reproducible and simple, define the clinical significance of malpositions, identify risk factors associated with incorrect placement, and further actions by the surgeon. The classification should be uniform and applicable for intraoperative and postoperative CT monitoring. Furthermore, it should be a protective mechanism in the event of future judicial hearings.

One of the primary points of discussion is the requirements for the time interval for decision-making and repositioning of screws in cases of M2+ and M3 malposition. During intraoperative CT monitoring, a single repositioning definitely sounds like the most reasonable solution. Numerous additional factors may influence decision-making in the postoperative period. In this connection, we consider it unreasonable to set any time limits at this stage of studying the problem. The issue requires further multicenter study, which is planned by the authors.

The study had no sponsors. The authors declare that they have no conflict of interest.

The study was approved by the local ethics committee of the institution.

All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

References

1. Upendra BN, Meena D, Chowdhury B, Ahmad A, Jayaswal A. Outcome-based classification for assessment of thoracic pedicular screw placement. *Spine*. 2008;33:384–390. DOI: 10.1097/BRS.0b013e3181646ba1
2. Ansorge A, Sarwahi V, Bazin L, Vazquez O, De Marco G, Dayer R. Accuracy and safety of pedicle screw placement for treating adolescent idiopathic scoliosis: a narrative review comparing available techniques. *Diagnostics (Basel)*. 2023;13:2402. DOI: 10.3390/diagnostics13142402
3. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement *in vivo*. *Spine*. 1990;15:11–14. DOI: 10.1097/00007632-199001000-00004
4. Aoude A, Ghadakzadeh S, Alhamzah H, Fortin M, Jarzem P, Ouellet JA, Weber MH. Postoperative assessment of pedicle screws and management of breaches: A survey among Canadian spine surgeons and a new scoring system. *Asian Spine J*. 2018;12:37–46. DOI: 10.4184/asj.2018.12.1.37
5. Laine T, Makitalo K, Schlenzka D, Tallroth K, Poussa M, Alho A. Accuracy of pedicle screw insertion: A prospective CT study in 30 low back patients. *Eur Spine J*. 1997;6:402–405. DOI: 10.1007/BF01834068
6. Neo M, Sakamoto T, Fujibayashi S, Nakamura T. The clinical risk of vertebral artery injury from cervical pedicle screws inserted in degenerative vertebrae. *Spine*. 2005;30:2800–2805. DOI: 10.1097/01.brs.00000192297.07709.5d
7. Heary RF, Bono CM, Black M. Thoracic pedicle screws: postoperative computerized tomography scanning assessment. *J Neurosurg*. 2004;100(4 Suppl Spine):325–331. DOI: 10.3171/spi.2004.100.4.0325
8. Abul-Kasim K, Str mbeck A, Ohlin A, Maly P, Sundgren PC. Reliability of low-radiation dose CT in the assessment of screw placement after posterior scoliosis surgery, evaluated with a new grading system. *Spine*. 2009;34:941–948. DOI: 10.1097/BRS.0b013e31819b22a4
9. Wiesner L, Kothe R, Schulitz KP, Rüther W. Clinical evaluation and computed tomography scan analysis of screw tracts after percutaneous insertion of pedicle screws in the lumbar spine. *Spine*. 2000;25:615–621. DOI: 10.1097/00007632-200003010-00013
10. Sarwahi V, Wendolowski SF, Gecelter RC, Amaral T, Lo Y, Wollowick AL, Thornhill B. Are we underestimating the significance of pedicle screw misplacement? *Spine*. 2016;41:E548–E555. DOI: 10.1097/BRS.0000000000001318
11. Zdichavsky M, Blauth M, Knop C, Lotz J, Krettek C, Bastian L. Accuracy of pedicle screw placement in thoracic spine fractures. Part II: A retrospective analysis of 278 pedicle screws using computed tomographic scans. *Eur J Trauma*. 2004;30:241–247. DOI: 10.1007/s00068-004-1423-8
12. Rampersaud YR, Pik JH, Salonen D, Farooq S. Clinical accuracy of fluoroscopic computer-assisted pedicle screw fixation: a CT analysis. *Spine*. 2005;30:E183–E190. DOI: 10.1097/01.brs.00000157490.65706.38
13. Rao G, Brodke DS, Rondina M, Dailey AT. Comparison of computerized tomography and direct visualization in thoracic pedicle screw placement. *J Neurosurg*. 2002;97(2 Suppl):223–226. DOI: 10.3171/spi.2002.97.2.0223
14. Gubin AV, Ryabykh SO, Burtsev AV. Retrospective analysis of screw malposition following instrumented correction of thoracic and lumbar spine deformities. *Russian Journal of Spine Surgery (Khirurgiya Pozvonocznika)*. 2015;12(1):8–13. DOI: 10.14531/ss2015.1.8-13 EDN: TODHKV
15. Oba H, Uehara M, Ikegami S, Hatakenaka T, Kamanaka T, Miyaoka Y, Kurogouchi D, Fukuzawa T, Mimura T, Tanikawa Y, Koseki M, Ohba T, Takahashi J. Tips and pitfalls to improve accuracy and reduce radiation exposure in intraoperative CT navigation for pediatric scoliosis: a systematic review. *Spine J*. 2023;23:183–196. DOI: 10.1016/j.spinee.2022.09.004

16. **Watanabe K, Lenke LG, Matsumoto M, Harimaya K, Kim YJ, Hensley M, Stobbs G, Toyama Y, Chiba K.** A novel pedicle channel classification describing osseous anatomy: how many thoracic scoliotic pedicles have cancellous channels? *Spine*. 2010;35:1836–1842. DOI: 10.1097/BRS.0b013e3181d3cfde
17. **Kosmopoulos V, Schizas C.** Pedicle screw placement accuracy: a meta-analysis. *Spine*. 2007;32:111–120. DOI: 10.1097/01.brs.0000254048.79024.8b
18. **Akazawa T, Kotani T, Sakuma T, Minami S, Tsukamoto S, Ishige M.** Evaluation of pedicle screw placement by pedicle channel grade in adolescent idiopathic scoliosis: should we challenge narrow pedicles? *J Orthop Sci*. 2015;20:818–822. DOI: 10.1007/s00776-015-0746-0
19. **Aoude AA, Fortin M, Figueiredo R, Jarzem P, Ouellet J, Weber MH.** Methods to determine pedicle screw placement accuracy in spine surgery: a systematic review. *Eur Spine J*. 2015;24:990–1004. DOI: 10.1007/s00586-015-3853-x
20. **Adamski S, Stogowski P, Roc awski M, Pankowski R, Kloc W.** Review of currently used classifications for pedicle screw position grading in cervical, thoracic and lumbar spine. *Chirurgia Narz d w Ruchu i Ortopedia Polska*. 2023;88:165–171. DOI: 10.31139/chnriop.2023.88.4.2

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Received 10.06.2025

Review completed 17.07.2025

Passed for printing 08.08.2025

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