Review of currently used classifications for pedicle screw position grading in cervical, thoracic and lumbar spine

Przegląd współcześnie używanych klasyfikacji w ocenie położenia śrub przeznasadowych w odcinku szyjnym, piersiowym i lędźwiowym kręgosłupa

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Abstract

Pedicle screw fixation technique has been established as the safe standard for instrumentations in all spinal regions. However, the screw position is sometimes suboptimal. Cortical breaches may occur in different regions of the vertebrae. In addition to compromising bone purchase, pedicle perforations may endanger neural, vascular, and visceral structures. Moreover, a mispositioned screw can result in a greater risk of instrumentation failure. The accuracy of screw insertion has become a frequent topic of recent publications on spine surgery. Despite that, there is no unified way of reporting pedicle screws position. Several different scales are used. Given the multitude of used classifications and rarity of reported complications exact clinical relevance of pedicle screw misplacements remain unclear. In this article, the authors review types of scoring systems and propose a structured way for pedicle screw position grading based on a combination of the most used classifications.

Key words: classification, pedicle screws, pedicle screws positioning, safe zones.

Streszczenie

Stabilizacja z użyciem śrub przeznasadowych jest podstawową techniką w chirurgii wszystkich odcinków kręgosłupa. Pomimo powszechnie uznawanego bezpieczeństwa położenie śrub przeznasadowych nie zawsze jest optymalne. Do perforacji kręgu przez śrubę może dojść w różnych jego miejscach. Może skutkować to nie tylko osłabionym osadzeniem imlantu w kości, ale też grozić uszkodzeniem struktur nerwowych, naczyniowych oraz narządów wewnętrznych. Co więcej, nieoptmalnie położone śruby mogą powodować obniżoną wytrzmałość i większe ryzyko powikłań w postaci mechanicznego uszkodzenia instrumentarium. Precyzja położenia śrub przeznasadowych jest popularnym tematem w literaturze dotyczącej chirurgii kręgosłupa. Pomimo tego wciąż nie ustalono jednolitego sposobu opisu położenia śrub przeznasadowych. Używanych jest wiele skal. Z powodu ich mnogości i małego odsetka raportowanych powikłań stabilizacji przeznasadowej dokładne kliniczne znaczenie położenia śruby jest wciąż nieznane. W artykule proponują jednolity sposób oceny położenia śrub przeznasadowych w oparciu o poszechnie używane klasyfikacje.

Słowa kluczowe: klasyfikacja, śruby przeznasadowe, położenie śrub przeznasadowych, strefy bezpieczeńswa

Introduction

Since the pedicle screw fixation technique became widely used, spinal surgeons have paid increasing attention to the accuracy of screw placement [1,2]. However, the screw position is sometimes suboptimal. Cortical breaches may occur in different regions of the vertebrae. In addition to compromising bone purchase, pedicle perforations may endanger neural, vascular, and visceral structures [1,3,4]. Proximity to these structures can influence the decision to revise or remove misplaced screws. In most cases, minor cortical violations are considered clinically silent [1,3–6]. However, even the initially silent violations may be responsible for instrumentation failure, instability, reduced fusion rate and accelerated adjacent-level degeneration [3,7–9].

Another factor that causes the need for a structured assessment of pedicle screw positioning is the growing role of defensive medicine [10]. In this context, spine surgeons are especially at risk. In the USA, it takes about five years on average for a case to be adjudicated [5, 11, 12].

As a result, physicians spend an average of 27.2% of their careers in an open lawsuit.

Although clinically relevant complications related to screw misplacement are very rare and occur in less than 0.5%, neurological deficits attributed to misplaced screws and decreased stability leading to delayed complications represent the most frequent and highest payouts in spine malpractice claims. For that reason, meticulous documentation of pedicle screw position is a common area for avoiding malpractice claims and subsequent payouts involving misplaced pedicle screws [10]. Traditionally, pedicle screw insertion under the guidance of fluoroscopy techniques relies on clinical experience and anatomic landmarks. Development of intraoperative CT and neuronavigation improved accuracy in the placement of the pedicle screws, reduced complications, and allowed intraoperative inspection of pedicle screws in three dimensions [13, 14]. Furthermore, a growing number of surgeons acquire low-dose postoperative CT images to assess and ensure accurate pedicle screw placement. That opportunity created a need for pedicle screw position grading. To date, there are no established standards for grading screw malposition. Nevertheless, the accuracy of screw insertion has become a frequent topic of recent publications on spine surgery. The literature features many incomparable classifications, mostly introduced for single papers without intra-rater and inter-rater agreement assessment. This potential heterogeneity could produce biases in meta-analyses and systematic reviews that access accuracy [13, 15]. In this article, the authors review commonly used grading systems for pedicle screw placement and propose a structured way of screw position evaluation.

Pedicle screws accuracy grading systems

The most accurate way to access pedicle screw placement is to measure cortical breach out of vertebrae or pedicle on a CT scan [9]. Several scales are used. The most comprehensive systematic review, which analyzed 43.305 pedicle screws in a total of 3,442 patients, identified 68 articles, of which only 37 had comparable methodology [9].

The majority of these 37 papers use grades based on 2mm increments in intra or post-operative CT imaging [5,16–18].

These systems are more or less modifications of the first grading system proposed by Gertzbein and Robbins in 1990 [19]. The slight differences mostly considered the number and nomenclature of grading categories. Only 7 reported on the intra-rater and inter-rater reliability, which was substantial in 6 papers (k = 0.65-0.85) and (ICC = 0.62-0.69).

The second most used systems delineate only two grades (“in” or “out”), regardless of the region of cortical breakthrough.

In several articles, screw placement is described with respect to the location of the pedicle perforation (medial, lateral, superior, or inferior), whereas in others, malposition is expressed in relation to the percentage of screw diameter lying outside the osseous confines, but the region of violation is not indicated. Furthermore, in another meta-analysis, Kosmopoulos et. al report that only 50% of included studies even detailed how the evaluation was performed [20].

Only a few grading scales consider the remaining distance to the anatomical structures at risk. In other studies, the authors have merely reported the incidence of screw malposition without describing the features of the misplacements. Any classification includes the presence and absence of clinical symptoms corresponding to pedicle screw malposition [9].

Gertzbein–Robbins classification

The first structured evaluation system for the position of screws in the pedicle was introduced in 1990 by Gertzbein and Robbins [19]. GRS is the most common classification for assessing PS placement in the available literature, with substantial reported reliability [9].

The classification concerned the position of screws in the thoracic spine. The authors divided the position of the screws outside the pedicle: into lateral and medial and graded the position in 2 mm increments. While the screw’s ideal position, which lies entirely within the vertebral body and pedicle bone, is undisputed, the question remained as to how much of the position outside the epiphysis could be considered safe. The authors hypothesised that a medial lesion of the pedicle up to 4 mm remains within the anatomical safety zone, and a screw positioned in this way can be considered an acceptably positioned screw (Tab. 1).

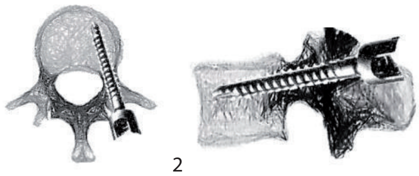
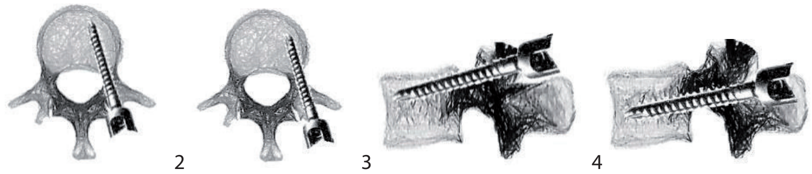
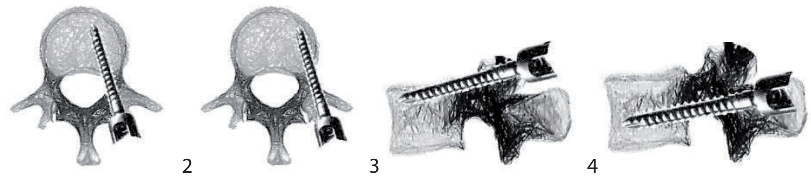
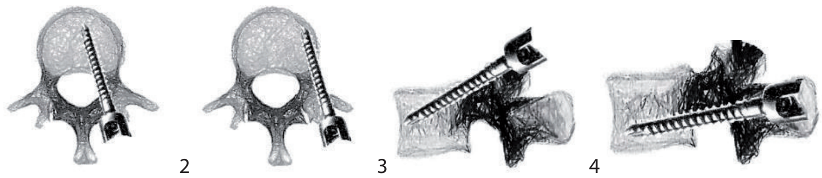
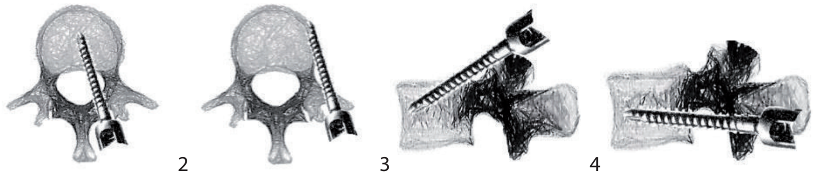
Screws located correctly in the safe (acceptable) zone are screws located medially outside the epiphysis up to 4 mm (grades A, B, C) and screws located lateral to the pedicle (regardless of grade).

The main limitation of this scale is the lack of determination of the presence and direction in which the screw breaks through the vertebral body.

Heary classification

Considering the limitations of Gertzbein and Robbins classification, as safe screw placement is not limited to the proper position in the pedicle, Heary et al. in 2004 presented a classification that assessed the position of screws in the thoracic spine in relation to the vertebral body and pedicle (Tab. 2) [21]. In the thoracic region, screws misplaced anteriorly can endanger visceral structures such as

Table 1. Gertzbein-Robbins classification

Gertzbein and Robbins classification		
A	Fully intrapedicular position without breach of pedicle cortex.	 1 2
B	Exceeding the pedicle cortex < 2 mm. 1. medially 2. laterally 3. superiorly 4. inferiorly	 1 2 3 4
C	Exceeding the pedicle cortex 2-4 mm. 1. medially 2. laterally 3. superiorly 4. inferiorly	 1 2 3 4
D	Exceeding the pedicle cortex 4-6 mm. 1. medially 2. laterally 3. superiorly 4. inferiorly	 1 2 3 4
E	Exceeding the pedicle cortex > 6 mm or is outside of the pedicle. 1. medially 2. laterally 3. superiorly 4. inferiorly	 1 2 3 4

the thoracic pleura, lungs, esophagus, and aorta. Additionally, this grading system clearly distinguished medial and lateral pedicle violations [3]. Moreover, the classification proposed by Heary considers the pedicle-rib complex or "effective pedicle" in the thoracic spine.

The pedicles in the thoracic region are smaller and exhibit a high degree of variability among patients [22–24]. Therefore, the placement of pedicle screws in this region is technically more challenging and at greater risk of malposition and biomechanical failure. In many cases, the pedicles are unacceptably narrow to place pedicle screws.

The pedicle-rib complex is a three-dimensional anatomic structure surrounded by the transverse process, pedicle, rib, costal transverse process joint, and rib head joint [25] (Fig. 1).

This relationship increases the effective width of cortical bone in which a screw can be safely placed since a perforation of the lateral pedicle wall can be effectively compensated by the adjacent rib.

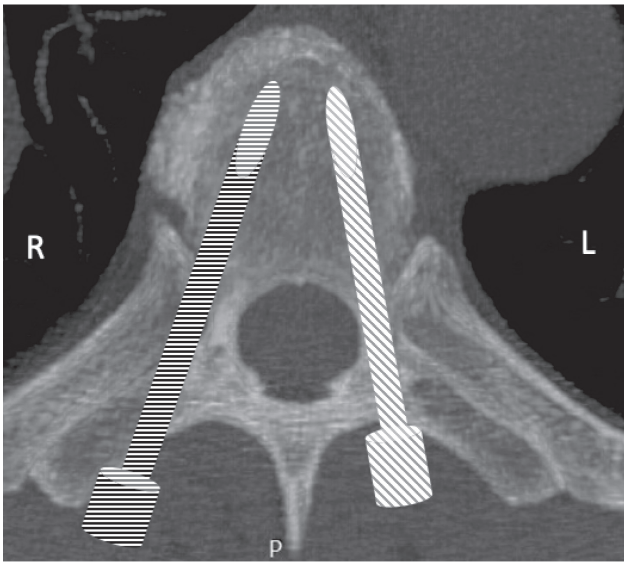
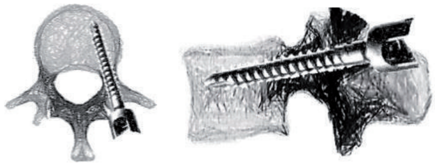
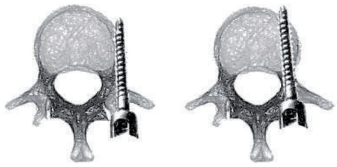
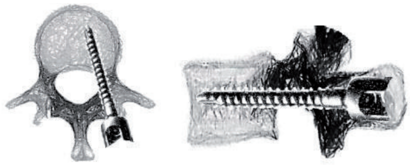


Fig. 1. Pedicle-rib complex. Left pedicle screw is placed in true pedicle. Right pedicle screw is placed in effective pedicle composed with pedicle-rib complex.

Table 2. Heary classification

Heary classification		
Grade I	Well-placed screw entirely contained within the pedicle and VB	
Grade II	Screws violated the lateral pedicle wall but were still contained within the pedicle–rib complex, and the tip of the screw was entirely contained within the VB	
Grade III	Implants were those in which the screw tip penetrated the anterior or lateral VB	
Grade IV	Screws breached the medial or inferior pedicle borders	
Grade V	Positioning was reserved for screws that endangered the spinal cord, nerve root, or great vessels by violating the VB or pedicle cortices, and that required immediate removal and/or revision of the construct	

The trajectory of extrapedicular screw is farther away from the spinal canal than that of intrapedicular screws. The concept of an effective pedicle in the pedicle rib complex allows for safe use of adequate-size screws that exceed the diameter of the pedicle. This is particularly useful in the middle thoracic spine (T3-T6), where pedicles are extremely small. In this region, Heary Grade II placement is suggested rather than Grade I [21].

However, caution must be taken in the upper (T1-T2) thoracic region because of the proximity of spinal nerves critical for the upper limbs motor function. The major limitation of Heary classification is the lack of reliability assessment.

Gertzbein–Robbins classification – Breadow modification for cervical spine

Anatomically, the cervical pedicle diameter is narrow, and the pedicle axis is more convergent [26–30]. Complex neural anatomy and proximity of vertebral artery results in a higher risk of complications [8]. Consequently, in 2015, Breadow et al. modified the Gertzbein and Robbins classification adapting it to the cervical spine (Tab. 3) [27].

Pedicle screws safety zones

Although simple to use, most pedicle screw accuracy grading systems fail to point out the clinical relevance of the breaches, which should be the major objective. Various definitions of the position of the screw beyond the pedicle have been encountered in the literature, and the discussion of an acceptable position remains open [5,9,10,21,31–38]. Medial breaches of up to 2 mm are generally accepted as safe. Transient or permanent neurologic deficit occurrence has been exclusively reported for medial breaches of at least 4 mm. Based on these findings, Kim et al., proposed more clinically oriented concepts of "safe zones" as follows [42]:

1. "definite safe zone" position of the screw beyond the pedicle margin up to 2 mm;
2. "probably safe zone" position of the screw beyond the pedicle margin from 2 mm to 4 mm;

Table 3. Gertzbein–Robbins classification – Breadow modification for cervical spine

Gertzbein and Robbins classification – Breadow modification		
A	Fully intrapedicular position without breach of pedicle cortex Exceeding the pedicle cortex > 1 mm	 1  2
B	Exceeding the pedicle cortex 1 mm to ≤ 2 mm	
C	Exceeding the pedicle cortex > 2 mm to ≤ 3 mm	
D	Exceeding the pedicle cortex 3 mm to ≤ 4 mm	
E	Exceeding the pedicle cortex 4 mm or is outside of the pedicle. 1. medially 2. medially 3. narrowing of the lumen of the vertebral artery opening by more than half the diameter of the screw	 1  2  3

3. "questionable safe zone" with a screw position beyond the pedicle margin of 4 mm to 8 mm on the medial side, but without conflict with neural structures as assessed by intraoperative neurophysiological examination.

This concept was further developed by Sarwahi et al., who reported a novel classification system aimed at recognizing potentially clinically significant pedicle screw misplacements and considering the location of the breach and the remaining distance between the screw and the anatomical structures at risk [3].

1. Screws at risk (SAR): screws breaching medially by more than 4mm or screws breaching laterally or anteriorly that impinge (< 1 mm distance between screw tip and organ) on anatomic structures of concern such as the aorta, trachea, and esophagus (Fig. 1).
2. Indeterminate misplacements (IMP): screws breaching medially 2 to 4 mm or screws breaching laterally or anteriorly that are adjacent (> 1–2 mm distance between the screw tip and organ) to anatomic structures of concern.
3. Benign misplacements (BMP): screws breaching the cortical wall, but not placing any structures at risk.
4. Accurately placed (AP): screw completely contained by the pedicle.

However, it is unknown if the chosen cut-off of < 1 mm between the screw tip and the organ at risk for defining screw at risk due to anterolateral breaching is optimal [25, 43].

Conclusions

A standardized method to access pedicle screw placement is needed. Currently, the most widely used and accepted grading system for pedicle screw accuracy is the 2 mm increment grading system based on CT imaging. However, an, ideal grading system should include imaging and clinical data. The numerous classifications employed impede conducting unbiased meta-analyses. This combined with the rarity of reported complications means that the exact clinical relevance of pedicle screws misplacements remains unclear. When intra or postoperative CT imaging is performed in the absence of more clinically oriented classifications, the authors suggest performing assessment using two classifications simultaneously: Gertzbein–Robbins and Heary in the thoracic and lumbar segments and the Gertzbein–Robbins classification as modified by Bradlow in cervical spine. The pedicle screw grading system should be regarded as a tool, not an outcome measure. The evaluation of a successful fusion surgery should always include a clinical assessment and an appraisal of the screw position.

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