J Orthop Sci (2015) 20:818–822
DOI 10.1007/s00776-015-0746-0

ORIGINAL ARTICLE

Evaluation of pedicle screw placement by pedicle channel grade in adolescent idiopathic scoliosis: should we challenge narrow pedicles?

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Received: 15 April 2015 / Accepted: 17 June 2015 / Published online: 30 June 2015

Abstract
Background Surgeons often have concerns about whether to place screws in narrow pedicles for correction of scoliosis. The aim of this study was to use pedicle channel grades based on preoperative CT to evaluate pedicle screw placement in posterior surgery for adolescent idiopathic scoliosis.
Methods The subjects comprised 55 patients who underwent posterior correction and fusion, and a total of 810 pedicles were examined in which screw placement had been planned and probing had been performed. Pedicle channel grades were determined by measuring inner pedicle diameter on preoperative CT scans. The grades were defined as grade 1 with an inner diameter of ≥ 4 mm, grade 2 with an inner diameter of ≥ 2 mm and < 4 mm, grade 3 with an inner diameter of ≥ 1 mm and < 2 mm, and grade 4 for a "cortical channel" with an inner diameter of < 1 mm.
Results The failure rate of screw placement was 0.5 % for pedicle channel grade 1, 2.9 % for grade 2, 12.0 % for grade 3, and 31.5 % for grade 4, showing significant differences ($p < 0.001$). For the laterality of curvature, the failure rate was 5.9 % for the convex side, 8.0 % for the neutral vertebra, and 9.0 % for the concave side, showing no significant difference. There was also no significant difference in failure rate between degrees of curvature of < 60° (8.2 %) and ≥ 60° (5.6 %). Logistic analysis showed that the pedicle channel grade was a significant risk factor for failure (odds ratio 4.0, $p < 0.001$).
Conclusions The failure rate of screw placement was 31.5 % for a cortical channel with a pedicle inner diameter of < 1 mm. Screw placement should be attempted in pedicles with an inner diameter of 1 mm or larger.

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Introduction

In recent years, pedicle screws have been widely used in surgery for adolescent idiopathic scoliosis (AIS). These screws act as powerful anchors for correction of scoliosis, and have contributed to good correction success rates. The pedicle diameters in patients with scoliosis are smaller than those of healthy individuals. Liljenqvist et al. noted that pedicles in scoliosis patients had left–right asymmetry and that they were small at the concave side of the apical vertebrae of the thoracic curve [1], recording a diameter of only 2.5 mm at the concave side of T8. Takeshita et al. reported that even screws 4 mm in diameter were inappropriate in 37 % of T3–T9 pedicles on the concave side [2], and also observed that the L1 and L2 pedicles were smaller than the T12 and L3.

Studies have shown rates of screw deviation of 12–28 % in AIS patients based on evaluations of postoperative CT images after placement of pedicle screws using a free-hand technique or intraoperative C-arm imaging [3–5]. The use of navigation has been reported to lower the deviation rates to 1.5–11.4 % [4, 6]. However, no study has reported a deviation rate of 0 %, even with innovative devices such as the O-arm imaging-based navigation system [7]. As the minimum pedicle diameter appropriate for screw placement in surgical treatment of scoliosis is not known, surgeons often have concerns about whether to place screws in narrow pedicles for scoliosis correction.

Watanabe et al. proposed a pedicle channel classification system to describe osseous anatomy [8], reporting cancellous channels in 90 % of pedicles and cortical channels in 7 % of pedicles in patients with scoliosis. However, it was not confirmed whether the pedicle channel classification could predict the success rate of actual screw placement.

In our study, we aimed to use pedicle channel grades based on preoperative CT to evaluate pedicle screw placement in posterior surgery for AIS. In addition, we sought to answer the following questions: 1) Is it difficult to place screws into cortical channels? 2) Screw placement failure occurs despite the use of O-arm-based navigation. In such cases, are the factors causing failure related to pedicle channels? 3) Should surgeons attempt pedicle screw placement in narrow pedicles in AIS patients?

Materials and methods

The subjects included 55 patients with AIS who underwent posterior correction and fusion, and a total of 810 pedicles were examined in which screw placement had been planned and probing had been performed. The institutional review board approved this retrospective study. The patient group comprised 46 women and 9 men, and their mean age was 16.1 ± 2.7 years at the time of surgery. There were 34 patients with Lenke type 1 curvature, 17 with type 2, one with type 4, and three with type 6. The mean degree of the main curve was 52.7° ± 9.6° preoperatively and 17.9° ± 6.3° postoperatively. The mean correction rate was 66.3 ± 10.1 %, and the mean number of fused vertebral bodies was 10.5 ± 1.6. The mean number of pedicle screws placed was 14.3 ± 3.9 per patient, and the screw density was 1.36 per level. Of the 55 patients, 29 received only screws for anchorage. The remaining 26 patients received primarily screws for anchorage and hooks only for proximal anchorage. The number of probed pedicles by vertebral body level was 10 pedicles at T1, 16 at T2, 16 at T3, 34 at T4, 49 at T5, 49 at T6, 66 at T7, 68 at T8, 92 at T9, 77 at T10, 83 at T11, 75 at T12, 76 at L1, 61 at L2, 36 at L3, 2 at L4, and 0 at L5.

CT imaging was performed preoperatively and postoperatively from the thoracic to lumbar vertebrae using a thin slice thickness of 1.25 mm. A picture archiving and communication system (PACS) was used to send CT data to a workstation, and measurements were made using 3D reconstruction software (Synapse Vincent version 3.3; FUJIFILM Medical Co., Ltd., Tokyo, Japan). Pedicle channel grades were determined based on the classification described by Watanabe et al. [8], which was calculated by measuring inner pedicle diameters (cancellous bone diameters) on preoperative CT scans, and the definitions of grades were revised. The inner pedicle diameters (cancellous bone diameters) were measured at narrowed areas of the pedicles using cross-sectional images taken parallel to each of the upper end plates.

The grades in this study were defined as follows: grade 1 for a “large cancellous channel” with an inner diameter of ≥ 4 mm; grade 2 for a “moderate cancellous channel” with an inner diameter of ≥ 2 mm and < 4 mm; grade 3 for a “small cancellous channel” with an inner diameter of ≥ 1 mm and < 2 mm; and grade 4 for a “cortical channel” with an inner diameter of < 1 mm (Fig. 1).

The following patients were included in the evaluation of screw placement: patients in whom probing was performed but screw placement was discontinued, and those in whom screws were removed intraoperatively. If probing had been performed but screw placement was discontinued due to perforation, the status of such pedicles was described as “cancel” (cancelled screw placement). If screws had been removed intraoperatively due to malposition confirmed by imaging after placement, the status was described as “removal” (removed screws). If screws had shown a deviation of 2 mm or more on postoperative CT scans, the status was described as “deviation” (deviated screws). If screws had been placed properly, the status was described as “success” (successful screw placement) (Fig. 2). If the pedicles had been probed but the status was classified as “cancel”, “removal”, or “deviation”, the pedicles were then assigned a status of “failure” (failed screw placement). The failure rate was calculated as the percentage of pedicles categorized as “failure”. The deviation rate was calculated as the percentage of pedicles categorized as “deviation” among pedicles in which screws were ultimately placed.

The O-arm imaging base system with StealthStation navigation (Medtronic Sofamor Danek, Memphis, TN, USA) was used to minimize technical factors, and factors associated with failure of pedicle screw placement were analyzed. After a reference clamp was applied to the spinous process of the vertebra, CT data were obtained with automatic registration by 3D fluoroscopy, and the entry points were determined using the navigation system. Gearshift probing was used to create screw holes. The pedicles were tapped using a tap device with a diameter 1 mm smaller than that of the screws, and the screws were then inserted. The independent variable was failure. The dependent variables were laterality of curvature (concave side, convex side, or neutral vertebra), left or right side, degree of curvature (< 60° or ≥ 60°), and pedicle channel grade. Univariate (Pearson’s Chi-square test) and multivariate (logistic) analysis were performed.

Results

Of the 810 probed pedicles, the status was “cancel” in 18 pedicles, “removal” in 7, “deviation” in 36, and “success”

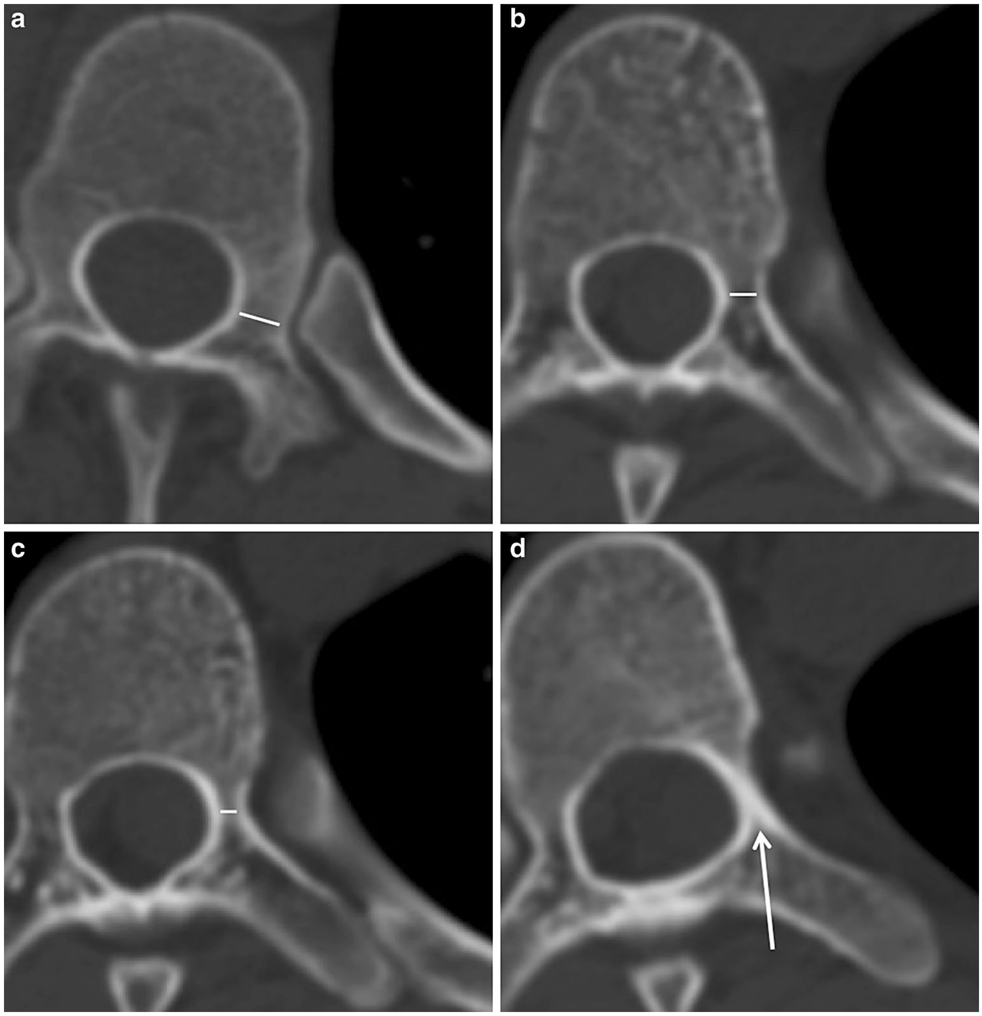

Fig. 1 Pedicle channel grade classification: **a** grade 1, "large cancellous channel" with an inner diameter of ≥ 4 mm; **b** grade 2, "moderate cancellous channel" with an inner diameter of ≥ 2 mm and < 4 mm; **c** grade 3, "small cancellous channel" with an inner diameter of ≥ 1 mm and < 2 mm; **d** grade 4, "cortical channel" with an inner diameter of < 1 mm

in 749. The failure rate was 7.5 %, and the deviation rate was 4.6 %. The pedicle channel grades were as follows: grade 1 in 196 channels, grade 2 in 342, grade 3 in 183, and grade 4 in 89. The failure and deviation rates were 0.5 and 0 %, respectively, for grade 1, 2.9 and 2.1 % for grade 2, 12.0 and 9.0 % for grade 3, and 31.5 and 17.6 % for grade 4 (Table 1).

A surgery-related complication of intraoperative cerebrospinal fluid leakage was observed in one grade 4 patient. No patient had nerve injury or great vessel injury.

The failure rate of screw placement was 0.5 % for pedicle channel grade 1, 2.9 % for grade 2, 12.0 % for grade 3, and 31.5 % for grade 4, showing significant differences ($p < 0.001$). With regard to the laterality of curvature, the failure rate was 5.9 % for the convex side, 8.0 % for the neutral vertebra, and 9.0 % for the concave side, showing no significant difference. There was also no significant difference in the failure rate between the left side (7.9 %) and the right side (7.1 %) or between degrees of curvature of < 60° (8.2 %) and ≥ 60° (5.6 %) (Table 2). Logistic analysis showed that the pedicle channel grade was a significant risk factor [odds ratio 4.0, 95 % confidence interval (CI) 2.9–5.6, $p < 0.001$] (Table 3).

In probed pedicles, 11 %. were classified as grade 4. A high percentage of grade 4 was observed from T3 to T8 (T3 18.8 %, T4 35.3 %, T5 22.4 %, T6 26.5 %, T7 19.7 %, and T8 23.5 %). The highest number of such pedicles was found for T8 on the concave side, at 15 pedicles.

Inter- and intra-observer reliability of pedicle channel grade

A total of 192 pedicles from six cases (T1 to L4, bilateral pedicles) were randomly selected and used for reliability

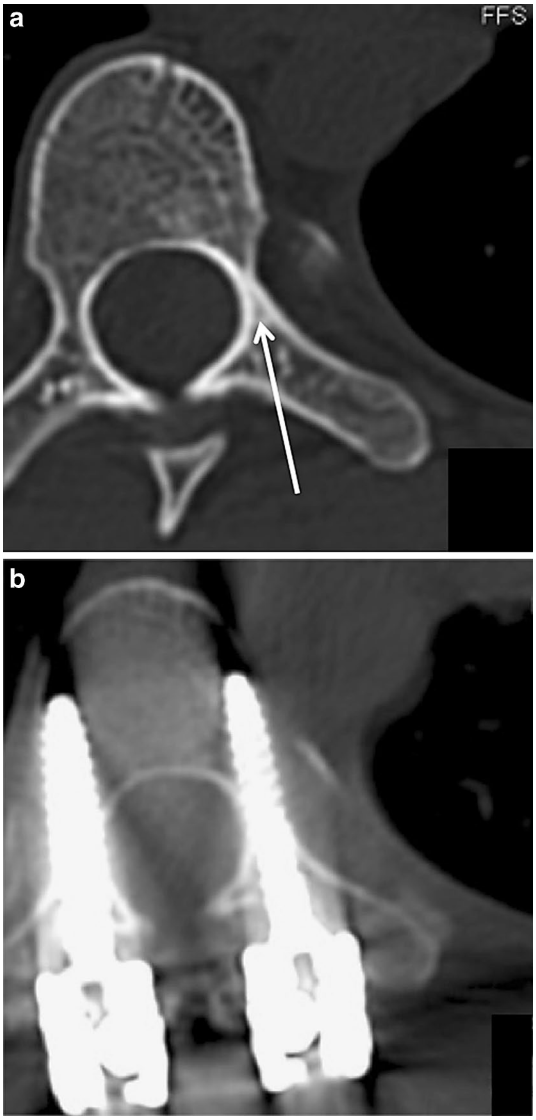

Fig. 2 Status was described as "success" if screws had been properly placed. **a** Pedicle channel grade 4. **b** Successful screw placement

Table 1 Rates of pedicle failure and deviation

Pedicle channel grade	Grade 1	Grade 2	Grade 3	Grade 4	Total
N	196	342	183	89	810
Failure rate (%)	0.5	2.9	12.0	31.5	7.5
Deviation rate (%)	0	2.1	9.0	17.6	4.6

analysis of pedicle channel grade. Two independent observers who were blinded to the clinical data examined the pedicle channel grades of the 192 pedicles and re-examined them 2 weeks later. Inter- and intra-observer reliability was calculated using kappa values. Overall interobserver variability was 0.74, indicating good agreement, and overall intra-observer variability was 0.92, indicating excellent agreement.

Table 2 Univariate analysis of factors for failure of pedicle screw placement

Pedicle channel grade	Grade 1	Grade 2	Grade 3	Grade 4	*p* value
Failure rate	0.5 %	2.9 %	12.0 %	31.5 %	<0.001
Curve laterality	Convex	Neutral	Concave		
Failure rate	5.9 %	8.0 %	9.0 %		0.319
Right or left side	Left side	Right side			
Failure rate	7.9 %	7.1 %			0.675
Degree of scoliosis	<60	≥60			
Failure rate	8.2 %	5.6 %			0.214

Table 3 Multivariate analysis of factors for failure of pedicle screw placement

	Odds ratio	95 % CI	*p* value
Pedicle channel grade	4.0	2.9–5.6	<0.001

Discussion

There has been a trend toward an increasing use of pedicle screws in the surgical treatment of AIS. This increased use reflects efforts to improve anchorage through placement of as many screws per patient as possible, and thus to increase scoliosis correction rates. In addition, as surgeons gain experience with the use of screws, they will more likely attempt to use screws for narrow pedicles. Our study, however, showed that the use of screws in very narrow pedicles does not necessarily result in good correction rates.

There is still no consensus on the optimal number of screws to use. Some studies have shown no difference in correction rates between low and high screw density [9]. In general, screws are often used in the most cephalad and caudad vertebrae of the fusion construct. Screws are necessary in the juxta-apical vertebrae to perform direct vertebral rotation, as proposed by Suk et al. [10]. However, the specific sites that are important for anchorage in the correction of scoliosis have not been elucidated.

Cadaver studies have shown the occurrence of pedicle expansion with the placement of screws larger than the pedicle diameter. Yazici et al. conducted a study using fresh frozen cadavers of immature pigs [11], in which the inner pedicle diameter was enlarged by 34.4 % and the outer pedicle diameter by 15.0 %. Rinella et al. examined the cadaver of a 9-year-old boy, and enlarged the outer and inner diameters by 74 and 24 %, respectively [12]. Cho et al. reported enlargement of pedicle circumference by 3.8 % in adult human cadavers, but noted that there was eventually an osseous breach [13]. When screws are inserted in small pedicles in clinical cases, the question remains as to whether the resulting condition is pedicle expansion or pedicle fracture. In postoperative CT scans, it is difficult to clearly distinguish between these because of metal artifacts.

Our study has some limitations. There were three surgeons who performed the surgical procedures, but we did not examine whether there were technical differences among them. However, all three surgeons were spine surgery instructors with experience in screw placement without the use of navigation. In addition, our study used O-arm-based navigation and minimized surgeon technical factors. Since some narrow pedicles could have been excluded at the preoperative planning stage, there may have been a bias toward larger pedicles. In addition, screws had been removed intraoperatively due to malposition in some patients, but the criteria for removal had not been established, and removal was left to the discretion of each surgeon.

The failure rate of screw placement was 31.5 % for a cortical channel with a pedicle inner diameter of < 1 mm, indicating a high likelihood of failure. The main cause of screw placement failure was the narrowness of the pedicle channel, despite the use of O-arm-based navigation. The odds ratio for screw placement failure increased fourfold with an increase of one pedicle channel grade (narrower pedicle channel). Thus, screw placement should be avoided in this type of pedicle, and should be attempted only in pedicles with an inner diameter of 1 mm or larger.

Acknowledgments No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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