

Evaluation of thoracic pedicle screw placement in adolescent idiopathic scoliosis

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Abstract Pedicle screw fixation is a challenging procedure in thoracic spine, as inadvertently misplaced screws have high risk of complications. The accuracy of pedicle screws is typically defined as the screws axis being fully contained within the cortices of the pedicle. One hundred and eighty-five thoracic pedicle screws in 19 patients that were drawn from a total of 1,797 screws in 148 scoliosis patients being suspicious of medial and lateral malpositioning were investigated, retrospectively. Screw containment and the rate of misplacement were determined by postoperative axial CT sections. Medial screw malposition was measured between medial pedicle wall and medial margin of the pedicle screw. The distance between lateral margin of the pedicle screw and lateral vertebral corpus was measured in lateral malpositions. A screw that violated medially greater than 2 mm, while lateral violation greater than 6 mm was rated as an “unacceptable screw”. The malpositions were medial in 20 (10.8%) and lateral in 34 (18.3%) screws. Medially, nine screws were rated as acceptable. Of the 29 acceptable lateral misplacement, 13 showed significant risk; five to aorta, six to pleura, one to azygos vein and one to trachea. The acceptability of medial

pedicle breach may change in each level with different canal width and a different amount of cord shift. In lateral acceptable malpositions, the aorta is always at a risk by concave-sided screws. This CT-based study demonstrated that T4–T9 concave segments have a smaller safe zone with respect to both cord-aorta injury in medial and lateral malpositions. In these segments, screws should be accurate and screw malposition is to be unacceptable.

Keywords Pedicle screws · Thoracic spine · Malposition · Adolescent idiopathic scoliosis

Introduction

The use of thoracic pedicle screw instrumentation has become increasingly widespread in the treatment of scoliosis owing to the consistently superior results achieved in terms of fixation and deformity correction [8, 12].

For thoracic pedicle screws used in the treatment of spinal deformities, the incidence of screw misplacement increases up to 43% when all the inserted screws are evaluated by computed tomography (CT) in the postoperative period. The technical difficulties posed by thoracic screws in scoliotic deformities have the potential for significant neurologic, vascular and visceral injury [2].

The term acceptable has been hypothesized mainly in thoracic spine due to the frequent and clinically benign nature of pedicle wall compromise in smaller thoracic pedicles [3]. In the present CT-based study; many of the acceptable thoracic pedicle screws were found to have the potential risk for significant injury.

The purpose of this paper is to analyze our malpositioned screws with respect to the criteria of acceptability and the potential complications.

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Materials and methods

In all, 1,797 transpedicular thoracic screws that were inserted over the past 10 years in 148 patients with adolescent idiopathic scoliosis using the free hand technique were analyzed, retrospectively. All screws were inserted by the same surgeon (A.Y.Ş). Clinical complaints as well as the radiological criteria of Kim on suspicious malpositions were recorded at early and late postoperative radiographs [9]. A thin-slice computed tomography was performed only in patients with suspicious malposition of the pedicle screw on postoperative plain radiographs.

The current study involves a total of 185 thoracic pedicle screws in 19 patients that were investigated with postoperative CT data. All of the measurements were done by an independent radiologist, who was experienced in musculoskeletal radiology. Medial screw malposition was measured between medial pedicle wall and medial margin of the pedicle screw. The distance between the lateral margin of the pedicle screw and lateral vertebral corpus was measured as lateral malposition. A screw that violated medially greater than 2 mm was rated as an “unacceptable screw” while a screw that violated laterally greater than 6 mm was rated as an “unacceptable screw”. On CT examination, direct screw contact with an angled orientation in contact with pleural lining was accepted to be putting the pleura at risk. Screws with parallel orientation to pleura without tip contact were considered to be acceptable (Fig. 1).

There were four males and 15 females with an average age of 14.8 years (range 9–27 years). Follow-up period ranged between 4 and 70 months (mean = 35.9 months). The curves were classified according to the Lenke classification system. Ten were type 1A, three type 1B, one type 3C, four type 5C and one type 6C.

Surgical technique

After a standard posterior midline incision, a meticulous exposure of the posterior elements of the thoracic spine was made to the tip of the transverse processes bilaterally. Estimated pedicle entry points were decorticated with a rongeur and the pedicle was perforated with 2.7 or 3.2 mm drill. Drill hole was checked with a blunt ended probe. When the probe meets pedicle walls in all directions and cancellous bone at the tip, accuracy of the pilot hole was confirmed. Following the measurement of the depth, appropriate sized screw was inserted.

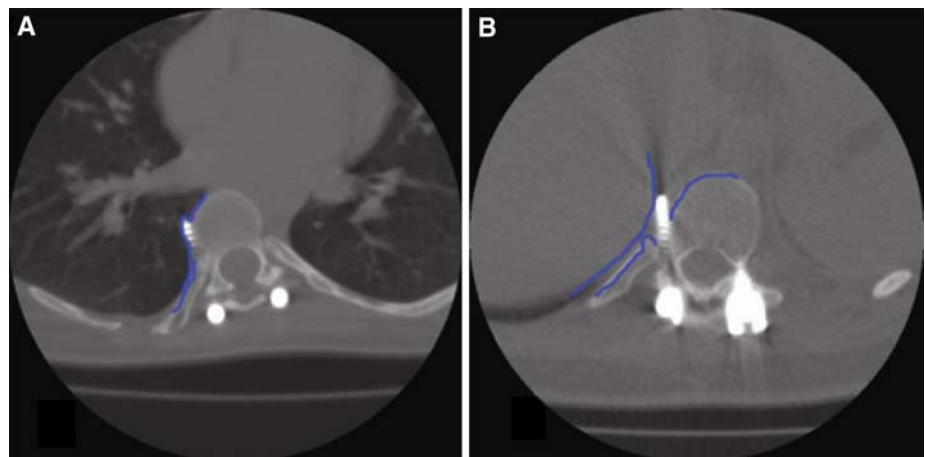
Screws were inserted on every segment on the concave side, and every third vertebra on the convex side. Intraoperative plain radiography was used. Deformity correction was achieved using a rod derotation maneuver alone. Following instrumentation, the fusion was carried out using autogenous iliac cancellous bone graft.

Results

A total of 185 thoracic pedicle screws in 19 patients were investigated. The diameters of screws were 4.5 or 5.5 mm. The number of inserted screws per each vertebral level was shown in Fig. 2. Screw containment and the rate of misplacement were determined by postoperative axial CT sections. In 185 thoracic pedicle screws inserted into scoliotic spine, 54 screw misplacements (29%) occurred. One hundred and thirty-one screws (70.8%) were placed accurately.

The malpositions were medial in 20 (10.8%) and lateral in 34 (18.3%) screws. Of the 20 medially misplaced screws, 9 were violated 0–2 mm, 6, 2–4 mm, 3, 4–6 mm and 2, >6 mm from the pedicle wall. Laterally misplaced 34 screws showed 0–2 mm violation in 8 screws, 2–4 mm

Fig. 1 **a** A screw with an angled orientation direct contact with pleural lining putting the pleura at risk. **b** An unacceptable screw with parallel orientation to pleura without tip contact which may be considered without risk



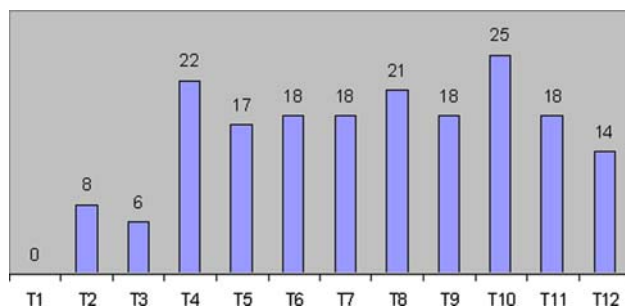


Fig. 2 The number of the thoracic pedicle screw ($n = 185$) per level

in 11, 4–6 mm in 10 and >6 mm in 5 from the pedicle wall. Anterior violation was never seen (Table 1).

Medial violation was on the concave side in 14 screws and convex side in 6 screws. Distribution of the medially violated screws among levels were 1 screw in T3, 4 in T4, 3 in T5, 4 in T6, 3 in T7, 1 in T10, 1 in T11 and 3 in T12. Medial violation was never seen at the level of T2, T8 and T9. There were one screw at the level of T3 and one screw at the level of T11 both having a 10-mm violation on the convex side. These screws were left in misplaced position owing to the absence of neurological symptoms (Table 1).

Distribution of the laterally violated screws among levels was 1 screw in T2, 5 in T4, 4 in T5, 4 in T6, 5 in T7, 7 in T8, 5 in T9, 2 in T10 and 1 in T11 (Table 1). Lateral violation was seen on the concave side in 20 screws and convex side in 14 screws. Localizations of the unacceptable screws that misplaced laterally were T4 in 1, T5 in 1, T8 in 1 and T9 in two screws. Of the laterally misplaced 34 screws, 17 had no risk, while 17 had showed significant risk to aorta—visceral structures. In 34 lateral misplacements, 5 screws were

unacceptable. One unacceptable screw with 8.2-mm lateral misplacement showed to cause no risk. Of the 17 screws with significant risk, 7 were at risk to aorta, 6 to pleura, 2 to pleura and azygos vein, 1 to left atrium and aorta and 1 to the trachea. Of the 29 acceptable lateral misplacement 13 showed significant risk; 5 to aorta, 6 to pleura, 1 to azygos vein and 1 to trachea (Table 2). Of the seven patients with screw proximity to aorta; screws were revised in two patients with persistent pain. In two patients; all implants were removed after 1.5 year with the evidence of solid fusion. Three patients refused pedicle screw revision although they had been informed about the possible complications.

Overall, no clinically relevant misplacements were detected in terms of neurologic and pleural irritation symptoms.

Discussion

The accuracy of pedicle screws is typically defined as the screws axis being fully contained within the cortices of the pedicle [2, 9].

Despite the use of adjunctive techniques, accurate pedicle screw placement in thoracic spine remains to be challenging. New technology, such as stereotactic image guidance applied to screw placement has been associated with increased accuracy [20]. However, this technique requires CT scanning with preoperative irradiation and expensive equipment. The free hand pedicle screw insertion technique exhibits similar accuracy in experienced hands as compared to the image-guided techniques [14].

Table 1 Placement data of 185 pedicle screws in 19 patients

Level	Screws	None	Pedicle cortex perforation (mm)									
			Medial				Lateral					
			0–2	2–4	4–6	>6	0–2	2–4	4–6	>6		
T1	–	–	–	–	–	–	–	–	–	–	–	–
T2	8	7	–	–	–	–	–	–	–	–	1	–
T3	6	5	–	–	–	1	–	–	–	–	–	–
T4	22	13	1	3	–	–	1	2	1	1	–	
T5	17	10	3	–	–	–	2	–	1	1	–	
T6	18	10	2	1	1	–	–	2	2	–	–	
T7	18	10	2	–	1	–	1	2	2	–	–	
T8	21	14	–	–	–	–	2	3	1	1	–	
T9	18	13	–	–	–	–	1	1	1	2	–	
T10	25	22	–	1	–	–	1	1	–	–	–	
T11	18	16	–	–	–	1	–	–	1	–	–	
T12	14	11	1	1	1	–	–	–	–	–	–	
Total (%)	185	131 (70.81)	9 (4.86)	6 (3.24)	3 (1.62)	2 (1.08)	8 (4.32)	11 (5.94)	10 (5.4)	5 (2.7)	–	

Table 2 Risk analyze of the laterally malpositioned screws among to the levels

Level	Side	Malposition	Risk
T2	Convex	Acceptable	Pleura
T4	Convex	Acceptable	Pleura
T4	Convex	Acceptable	Pleura
T4	Convex	Acceptable	No risk
T4	Convex	Unacceptable	Azygos vein-Pleura
T4	Convex	Acceptable	No risk
T5	Convex	Acceptable	Trachea
T5	Convex	Acceptable	No risk
T5	Convex	Acceptable	Azygos vein-Pleura
T5	Concave	Unacceptable	Aorta
T6	Concave	Acceptable	Aorta
T6	Concave	Acceptable	No risk
T6	Concave	Acceptable	Aorta
T6	Concave	Acceptable	No risk
T7	Concave	Acceptable	Aorta
T7	Convex	Acceptable	Pleura
T7	Concave	Acceptable	No risk
T7	Concave	Acceptable	No risk
T7	Concave	Acceptable	No risk
T8	Concave	Acceptable	No risk
T8	Concave	Unacceptable	Left atrium-aorta
T8	Concave	Acceptable	No risk
T8	Concave	Acceptable	No risk
T8	Concave	Acceptable	No risk
T8	Concave	Acceptable	No risk
T8	Convex	Acceptable	Pleura
T9	Convex	Acceptable	Aorta
T9	Convex	Unacceptable	No risk
T9	Convex	Acceptable	Pleura
T9	Concave	Acceptable	No risk
T9	Concave	Unacceptable	Aorta
T10	Concave	Acceptable	Aorta
T10	Concave	Acceptable	No risk
T11	Convex	Acceptable	No risk

There have been only a few papers concerning the evaluation of screw position after pedicle instrumentation in deformed pediatric spine using CT, by the free hand technique [3, 8, 9, 11, 14].

In our CT-based study, group of idiopathic deformed spine, the percentage of malpositioned thoracic pedicle screws using the free hand method is 29.1% (54/185). This percentage comparable to most series [3, 14, 18] is significantly higher than that of the previously reported series of Kim and Lehman [8, 11]. In this study, 19 patients were preselected from a series of 148 patients with adolescent idiopathic curves with the help of plain radiographs due to Kim's criteria on screw malposition which may cause an

underestimation of the overall rate of screw misplacement. Like the previously reported of all series, we have seen greater incidence of laterally malpositioned thoracic pedicle screws. It is unclear whether these screws achieved the breach position due to the transverse plane derotation maneuver associated with spinal deformity correction [17].

Lehman found decreased incidence of fully contained screws between T1 and T8 as compared to T9–T12 [11]. In our study, we have found decreased incidence of full containment in concave T4–T8 segments. T9–T12 segments had the greatest incidence of pedicle screw accuracy.

Acceptable limits of screw penetration remain controversial in patients with spinal curvatures having small pedicles and the cord shifted toward the concavity. Even the method of the measure of misplacement has not been defined to our knowledge which may cause determination errors in acceptability (Fig. 3). It has been suggested that slightly medial ≤ 2 mm or lateral ≤ 6 mm violations have little clinical or anatomic consequence and, therefore, have been deemed as acceptably placed screws [5, 15]. Our acceptable screw rate of 20.54% (38/185) is comparable to the most series [3, 14, 19], while it is far less than that of Lehman and Kim [8, 11].

Although many studies reported medial wall violation of the thoracic pedicle between 1, 4 and 14% from 1 to 8 mm, there were no permanent neurologic, cardiovascular or pulmonary complications associated in any cases [1, 2, 6, 7, 10, 12, 16, 20]. Belmont reported 35 screws with medial perforation of up to 4 mm without neurologic deficits [2]. Kim has reported 10 screws (1.7%) with medial cortical violation (between 2.5–5.0 mm) out of 577 thoracic

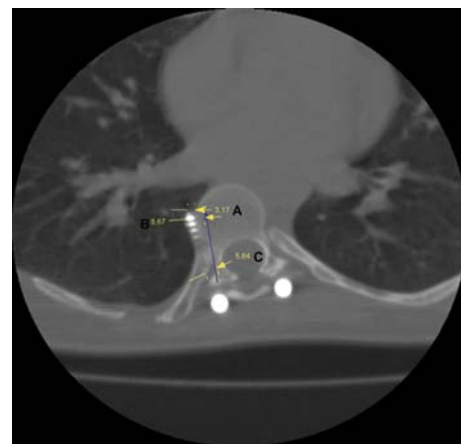


Fig. 3 Different types of measurement for a laterally misplaced screw. Yellow arrows indicate the value of the distance. Blue arrow indicates an imagination of the most laterally placed screw in the pedicle wall that can be deemed as an accurate screw. A Distance between lateral tip of the screw and lateral vertebral cortex (3.17 mm). B Distance between lateral tip of the screw and blue arrow (8.67 mm). C Distance between lateral edge of pedicle wall and lateral border of the screw (5.84 mm)

Fig. 4 Medial malposition at the convex side of T3 level. Extreme violation within the canal is notable on the CT section

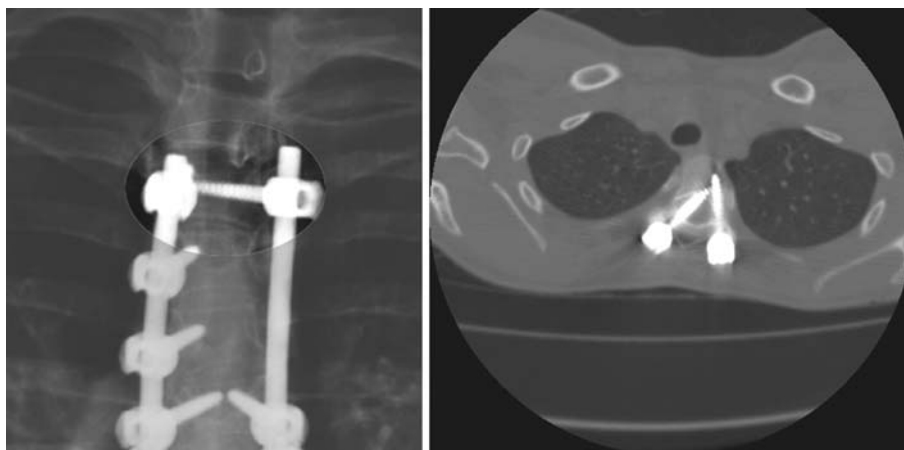


Fig. 5 Bilaterally medial violation in the same segment and narrowing of the spinal canal



Fig. 6 A lateral unacceptable screw at the convex side that has no risk to the visceral structures

pedicle screws evaluated by computed axial tomography (CAT) scanning [8]. Our study showed 11 screws (5.94%) with more than 2 mm medial violation. Concave T6 and T7 screws with 4–6 mm medial violation did not cause any neurologic deficit. T3 and T11 convex screws with 10-mm medial violation without causing neurologic deficit shows the extreme variability of medial safe zone for the convex–concave-sided thoracic pedicle screws. We think that the acceptability of medial pedicle breach may change in each level with different canal width and a different amount of cord shift (Fig. 4).

The shift of the dural sac toward the concavity in the apical region of the concavity of the thoracic curves is to be considered especially in bilateral thoracic pedicle screws on the same segments [13]. By an initial concave screw with medial perforation causing cord shift, the safe zone for a convex screw may be narrower (Fig. 5).

On the lateral side, the incidence, degree and acceptability of lateral positioned screws are even more controversial. Of the laterally malpositioned 34 screws 5 were

found to be unacceptable, while 29 found to be acceptable. One of the 5 unacceptable screw did not seem to have a potential risk (Fig. 6). In one unacceptable T4 convex screw with 9 mm misplacement azygos vein and pleura was at risk. All three other unacceptable screws were concave sided with significant risk to aorta injury on T5–T8–T9 levels. Of the laterally malpositioned 29 acceptable screws, 13 had a significant potential for risk to visceral injury. Of the acceptable lateral malpositions aorta was always at risk by concave-sided screws. Aorta at risk on T9 level and azygos-pleura at risk on T5 level with a slight misplaced screw <2 mm is of mention (Fig. 7). Bullmann defined the critical distance between screw tip and aorta as 1 mm bearing in mind the expansions of the aorta and the potential movement error [4]. Other authors have defined an impingement of the aorta by the screw tip to be critical [17]. We have not seen a vascular complication in 148 patients with 1.797 thoracic pedicle screws with a medium of 6-year follow-up, although seven screws showed risk with respect to aorta injury.



Fig. 7 An acceptable screw with a close proximity to the aorta at the level of T9

The presented results indicate that T4–T9 concave segments seem to have a smaller safe zone with respect to both cord-aorta injury in medial and lateral malpositions. In these segments, screws should be accurate and screw malposition is to be unacceptable. Of the 34 laterally malpositioned thoracic pedicle screws in these series, 13 of the 29 acceptable screws showed significant risk to visceral structures; while of the five unacceptable screws, one of them showed no risk to visceral structures which may indeed show the unreliability of the criteria of acceptability.

In thoracic pedicle screw instrumentation, a more strict criteria of acceptability is needed based on the potential risks in the specific segments of idiopathic curves.

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