Accuracy of thoracic pedicle screw placement in scoliosis using the ideal pedicle entry point during the freehand technique

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Abstract Previously, we described the ideal pedicle entry point (IPEP) for the thoracic spine at the base of the superior facet at the junction of the lateral one third and medial two thirds with the freehand technique on cadavers. Here we measured the accuracy of thoracic pedicle screw placement (Chung et al. *Int Orthop* 2008) on post-operative computed tomography (CT) scans in 43 scoliosis patients who underwent operation with the freehand technique taking the same entry point. Of the 854 inserted screws, 268 (31.3%) were displaced; 88 (10.3%) and 180 (21.0%) screws were displaced medially and laterally, respectively. With regard to the safe zone, 795 screws were within the safe zone representing an accuracy rate of 93%; 448 and 406 thoracic screws inserted in adolescent idiopathic and neuromuscular scoliosis showed an accuracy of 89.9 and 94%, respectively ($p=0.6475$). The accuracy rate of screws inserted in the upper, middle and lower thoracic pedicles were 94.2, 91.6 and 93.7%, respectively ($p=0.2411$). The results indicate that IPEP should be considered by surgeons during thoracic pedicle screw instrumentation.

Résumé Le point d'entrée idéal des vis pédiculaires (IPEP) au niveau thoracique se situe au niveau de la facette articulaire supérieure à la jonction du tiers latéral, 2/3 médial. Nous avons mesuré l'efficacité de cette technique « à main levée » par des scanners post-opératoires sur 43 scolioses chez 43 patients opérés. 268 (31,3%) des 854 vis mises en place n'étaient pas à un niveau parfait. 88 (10,3%) et 180 (21,0%) étaient soit trop médianes soit trop latérales. Néanmoins, si l'on considère la zone de sécurité, 795 vis soit 93% étaient en zone de sécurité. 448 et 406 vis thoraciques insérées lors d'une scoliose idiopathique ou neuromusculaire de l'adolescent étaient en zone saine dans respectivement 89,9% et 94% ($p=0,6475$). Le taux de précision des vis insérées à la partie supérieure ou médiane ou inférieure du pédicule thoracique était respectivement de 94,2%, 91,6% et 93,7% ($p=0,2411$). Résultats : cette étude montre que la technique de mise en place des vis pédiculaires à « main levée » peut être considérée comme une technique efficace au niveau thoracique.

Introduction

Pedicle screw instrumentation is gaining popularity in thoracic spine surgery since Boucher [2] described it for the lumbar spine in the 1950s. Though pedicle screws offer various biomechanical advantages, there is always a risk of neural, vascular or visceral injury. Hence accuracy is essential while inserting pedicle screws which depend upon an accurate entry point. For thoracic pedicles, the margin of error is less and hence there are many studies describing the entry point. Most of them however describe different entry points at different levels as well as different insertion techniques [5, 16, 23, 24] using the transverse process and superior facet as landmarks. In a deformed spine the

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transverse process may be abnormal in shape and size due to rotation and wedging [3]. As compared to this the base of the superior facet is easy to identify and has a constant anatomical relationship to the pedicle. We therefore, in our previous paper [6], proposed an ideal pedicle entry point (IPEP) for the thoracic pedicle at the base of the superior facet at the junction of the lateral one third and medial two thirds using a cadaveric model. The advantages of this technique are an entry point which is easy to identify, free from transverse process and has a very low incidence of medial and inferior pedicle violation. Here, we present our study on the accuracy of thoracic pedicle screw placement in scoliosis surgery using this ideal pedicle entry point (IPEP) for the thoracic pedicle with the freehand technique.

Materials and methods

Between 2004 and 2006, 43 patients (18 male and 25 female) underwent correction and fusion for scoliosis with transpedicular screw fixation using the freehand technique in which IPEP [6] was taken as the entry point for thoracic pedicles. There were 22 idiopathic and 21 neuromuscular scoliosis patients. The mean age and average pre-operative Cobb's angle at the time of the operation was 17.6 ± 7.3 years (range: 9–41 years) and $60.4^\circ \pm 15.0^\circ$ (range: 30–85°), respectively.

A total of 854 screws were inserted into thoracic pedicles. A spine fellow (HNM) reviewed digitised radiographs and computed tomography (CT) scans of all patients taken pre- and post-operatively using the picture archiving and communication system (PACS); hence all measurements were done with the help of software at a magnification of 300%. Any penetration of the bony cortex was measured in millimeters. We divided the penetration of the pedicle medially or laterally as grade 0 (fully contained within the pedicle, Fig. 1), grade 1 (penetration ≤ 2 mm), grade 2 (penetration 2.1–4.0 mm), grade 3 (penetration 4.1–6.0 mm) and grade 4 (penetration 6.1–8.0 mm). Screw penetration anterior to the vertebral body was measured in the same manner. Screws, displaced medially (Fig. 2) in grade 1 and laterally (Fig. 3) in grades 1–2, were considered within the safe zone while the rest of the displaced screws were considered potentially at risk. We analysed the placement of screws according to disease groups between group I (idiopathic scoliosis) and group II (neuromuscular scoliosis) using the chi-square test. In addition, we also analysed the thoracic pedicle screw placement amongst upper thoracic (T1–T4), middle thoracic (T5–T8) and lower thoracic (T9–T12) levels using the chi-square test.

Surgical technique The spine was exposed up to the tips of the transverse processes subperiosteally. In the thoracic

Fig. 1 Fully contained screws within the pedicle and body

spine, facet joints were thoroughly cleaned to ensure better visualisation of bony landmarks. The entry points in all of the thoracic vertebrae were at the junction of the outer third and inner two thirds of the superior facet joint [6], which was chosen as the ideal entry point for the thoracic pedicle. For the lumbar spine the junction of the mammillary process, inferior aspect of the transverse process and pars interarticularis was chosen as the entry point. First we made the entry with a probe into the pedicle for an initial 10–15 mm. Thereafter, further passage in the pedicle was made with a pathfinder. Before taking the pathfinder, a 2-mm curved ball-tipped probe was used to check the entry point which was created by the probe. The ball-tipped probe was again used to check the integrity of the pedicle when entry was made up to 20 mm with the pathfinder and then lastly used for the final creation of the pedicle passage. The pathfinder was removed and a ball-tipped probe was

Fig. 2 Medially displaced screw encroaching the canal by 3.7 mm, which is potentially at risk

Fig. 3 Laterally displaced screw out of the pedicle by 4.2 mm, which is also potentially at risk

introduced to feel the intact medial, lateral, superior, inferior and anterior cortices at each step. If we found any breach in either the medial or the lateral wall, again the entry was made in a different direction. We inserted screws at all levels to increase the rigidity of the instrumentation. Deformity correction was carried out using a rod derotation manoeuvre and, if necessary, in situ bending of the rod. Decortications of all laminae and facet joints were done and fusion was performed with autologous bone grafts mixed with allograft. Once the patient became stable, post-operative radiogram and CT scan were performed.

Results

The average age was 18.3 ± 7.6 years and 16.9 ± 7.1 years for adolescent idiopathic scoliosis (AIS) and neuromuscular scoliosis, respectively, and the average Cobb's angle was $60.6 \pm 13.8^\circ$ and $60.2 \pm 16.6^\circ$.

A total of 854 thoracic pedicle screws, 448 in adolescent idiopathic and 406 in neuromuscular scoliosis, were inserted. The diameters of inserted screws ranged from 5.5 to 6.5 mm, 5.0 to 5.5 mm, 4.0 to 5.0 mm and 3.5 to 4.5 mm in lumbar, lower thoracic (T9–T12), middle thoracic (T5–T8) and upper thoracic (T1–T4) pedicles, respectively. The lengths of screws were 40–45 mm, 35–40 mm, 30–35 mm and 25–30 mm in lumbar, lower thoracic, middle thoracic and upper thoracic areas, respectively, in both groups. Of the inserted screws, 31.3% (268/854) penetrated either the medial or lateral wall accounting for 10.3% (88/854) and 21.0% (180/854), respectively, while 31 screws (3.6%) penetrated the anterior wall on an average of 1.8 mm (range: 0.5–5.6 mm). With regard to the safe zone, 209 of 268 displaced screws (77.9%) were within the safe zone, which makes a total of 795 of 854 inserted screws, representing an accuracy rate of 93%.

Of the 448 thoracic screws placed in idiopathic scoliosis (Table 1), a total of 152 screws (33.9%) were displaced either medially or laterally; 48 screws (10.7%) had perforated the medial wall or were placed medial to the pedicle; 98 screws (21.8%) had perforated the lateral wall or were placed lateral to the pedicle. Another 11 screws (2.4%) had perforated the anterior wall. Of these 152 misplaced screws, 117 screws (76.9%) were within the safe margin, and therefore a total of 413 screws were within the safe zone in the idiopathic scoliosis group, which showed an accuracy of 89.9%. Of the 408 thoracic screws placed in neuromuscular scoliosis patients (Table 2), a total of 116 screws (28.5%) were displaced either medially or laterally; 40 screws (9.8%) perforated the medial wall or were placed medial to the pedicle; 76 screws (18.7%) perforated the lateral wall or were placed lateral to the pedicle. There were 20 screws (4.9%) that perforated the anterior wall. Of the 116 misplaced screws, 92 screws (79.3%) were within the safe margin, making a total of 382 screws within the safe zone in the neuromuscular scoliosis group, which showed an accuracy of 94%. Comparing the displaced screws within the safe zone and screws at risk between adolescent idiopathic (group 1) and neuromuscular (group 2) scoliosis did not reveal any statistically significant difference ($p=0.6475$, chi-square test).

Of the 268 misplaced screws, 29.1% (87/268), 39.9% (107/268) and 30.9% (83/268) screws were displaced in the upper (T1–T4), middle (T5–T8) and lower thoracic (T9–T12) spine, respectively. With regard to the safe zone, the accuracy was 94.2% (196/208), 91.6% (286/312) and 93.7% (313/334) in the upper, middle and lower thoracic spine, respectively. (Table 1). Comparing the displaced screws within the safe zone and screws at risk among upper, middle and lower thoracic regions did not show any statistically significant difference ($p=0.2411$, chi-square test).

Table 3 shows the pre-operative and post-operative Cobb's angle, pelvic obliquity, thoracic kyphosis and lumbar lordosis. The average flexibility on pre-operative bending radiogram was $23.1 \pm 7.8^\circ$ (range: 8° – 36°). The average pre-operative and post-operative Cobb's angles measured were $60.4 \pm 15.0^\circ$ and $19.4 \pm 12.1^\circ$, respectively, with a correction rate of 67.8%. The same in group 1 was $60.6 \pm 13.8^\circ$ and $17.8 \pm 9.9^\circ$ with a correction rate of 70.7% and in group 2 was $60.2 \pm 16.6^\circ$ and $21.1 \pm 14.2^\circ$ with a correction rate of 65%. Similarly the pre-operative and post-operative pelvic obliquity exhibited overall a correction rate of 53.8 and 62.5% in group 1 and 52.8% in group 2. All changes are statistically significant ($p<0.0001$, paired *t*-test).

Discussion

Pedicle screw fixation is a challenging procedure because inadvertently misplaced screws have a high risk of complications [4, 7, 9, 10]. Misplaced screws also diminish

Table 1 Number of medially, laterally and anteriorly displaced screws according to their grades in AIS patients with their accuracy

Level	Length of screw (mm)	Medially displaced screws				Laterally displaced screws				Anteriorly displaced screws				Med. + lat. displaced mm	Total inserted	Within safe zone	Accuracy (%)		
		2.1–4.0 mm		4.1–6.0 mm		>6 mm		< 2 mm		2.1–4.0 mm		4.1–6.0 mm						>6 mm	
		< 2 mm	2.1–4.0 mm	4.1–6.0 mm	>6 mm	< 2 mm	2.1–4.0 mm	4.1–6.0 mm	>6 mm	< 2 mm	2.1–4.0 mm	4.1–6.0 mm	>6 mm						
T1	20–25	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	97.9		
T2	20–25	2	1	0	0	7	3	1	0	0	4	0	0	14	30	12			
T3	20–25	3	0	0	0	7	3	2	0	2	0	0	0	15	36	13			
T4	20–25	2	2	0	0	4	4	3	1	3	0	0	0	16	40	10			
A	20–25	7	3	0	0	18	10	6	1	5	4	0	0	45	110	35			
T5	25–30	3	2	0	0	3	2	2	0	0	0	0	0	12	40	8			
T6	25–30	5	1	0	0	6	2	2	0	0	0	0	0	16	42	13			
T7	25–30	5	2	0	0	6	5	2	0	0	0	0	0	20	42	16			
T8	25–30	5	2	0	0	4	3	2	0	0	0	0	0	16	42	12			
B	25–30	18	7	0	0	19	12	8	0	0	0	0	0	64	166	49			
T9	30–40	3	1	0	0	0	4	1	0	0	0	0	0	9	42	7			
T10	30–40	2	0	0	0	5	2	2	1	0	0	0	0	12	42	9			
T11	30–40	4	1	0	0	2	4	2	0	0	0	1	0	13	44	10			
T12	30–40	2	0	0	0	1	4	2	0	0	1	0	0	9	44	7			
C	30–40	11	2	0	0	8	14	7	1	0	1	1	0	43	172	33			
Thoracic	36	12	0	0	45	36	21	2	5	5	1	0	152	448	117	89.9			

Table 2 Number of medially, laterally and anteriorly displaced screws according to their grades in neuromuscular scoliosis patients with their accuracy

Level	Length of screw (mm)	Medially displaced screws				Laterally displaced screws				Anteriorly displaced screws				Med. + lat. displaced	Total inserted	Within safe zone	Accuracy (%)				
		< 2 mm		2.1–4.0 mm		4.1–6.0 mm		> 6 mm		< 2 mm		2.1–4.0 mm						4.1–6.0 mm		> 6 mm	
T1	20–25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
T2	20–25	1	0	0	0	5	5	0	0	2	1	0	0	11	28	28					
T3	20–25	1	0	1	0	4	1	0	0	0	0	0	0	7	34	33					
T4	20–25	7	1	0	0	4	3	0	0	4	0	0	0	15	36	35					
A	20–25	9	1	1	0	13	9	0	0	6	1	0	0	33	98	96	97.9				
T5	25–30	4	2	0	0	3	3	1	0	4	0	0	0	13	37	34					
T6	25–30	1	0	0	0	3	1	2	0	1	0	0	0	7	36	34					
T7	25–30	1	1	0	0	3	2	3	0	1	0	0	0	10	36	32					
T8	25–30	3	0	0	0	7	1	2	0	2	0	0	0	13	37	35					
B	25–30	9	3	0	0	16	7	8	0	8	0	0	0	43	146	135	92.4				
T9	30–40	4	1	0	0	0	1	1	0	0	0	0	0	7	40	38					
T10	30–40	2	1	0	0	2	2	2	0	1	0	0	0	9	42	39					
T11	30–40	5	1	0	0	4	2	0	0	0	1	0	0	12	42	41					
T12	30–40	2	0	0	1	0	5	4	0	2	1	0	0	12	38	33					
C	30–40	13	3	0	1	6	10	7	0	3	2	0	0	40	162	151	93.2				
Thoracic		31	7	1	1	35	26	15	0	17	3	0	0	116	406	382		94			

Table 3 Disease groups with their age and pre-operative and post-operative Cobb's angle, pelvic obliquity, thoracic kyphosis and lumbar lordosis

No.	Age	Sex	Disease	Cobb's pre-op.	Cobb's post-op.	Flexibility	Screws	Pelvis pre-op.	Pelvis post-op.	Thoracic pre-op.	Lumbar pre-op.	Thoracic post-op.	Lumbar post-op.
1	13	F	AIS	46	15	14	28	4	3	24	61	32	55
2	14	M	AIS	62	17	32	26	1	0	22	46	12	45
3	14	F	AIS	73	16	21	26	2	1	12	63	20	35
4	15	F	AIS	80	35	25	28	4	1	52	63	30	31
5	13	M	AIS	48	8	30	30	2	2	46	39	25	25
6	14	F	AIS	57	15	27	26	2	0	10	56	9	47
7	16	F	AIS	54	14	17	28	2	0	23	42	13	40
8	16	F	AIS	42	4	34	26	2	0	38	35	28	40
9	18	F	AIS	78	34	10	26	3	1	27	54	20	36
10	13	M	AIS	70	8	22	30	5	1	53	40	16	34
11	13	F	AIS	50	9	36	26	1	1	44	16	11	42
12	25	F	AIS	45	26	8	18	3	1	33	44	20	44
13	14	F	AIS	67	15	32	26	0	0	22	48	14	37
14	17	F	AIS	68	18	14	24	3	0	34	52	33	49
15	15	M	AIS	40	4	28	14	2	0	46	41	32	33
16	14	F	AIS	59	25	15	24	1	1	20	41	14	35
17	19	F	AIS	50	11	22	28	2	0	68	20	15	27
18	17	F	AIS	45	10	20	22	1	1	25	65	24	51
19	35	F	AIS	70	20	10	24	2	2	26	59	27	41
20	41	F	AIS	65	22	16	26	0	0	23	45	26	32
21	30	F	AIS	85	40	30	26	6	4	31	39	24	31
22	17	F	AIS	80	26	22	28	5	1	23	49	3	41
23	19	M	CP	52	6	13	30	2	2	44	-16	21	20
24	23	M	CP	65	8	32	28	9	3	38	46	18	45
25	16	F	CP	55	19	21	31	20	4	32	4	16	39
26	22	M	CP	40	17	23	16	4	3	25	57	18	43
27	37	F	CP	40	11	18	28	7	2	17	51	15	25
28	12	M	DMD	66	28	33	31	30	17	15	-60	9	16
29	16	M	DMD	83	26	20	30	17	13	22	20	5	5
30	14	M	DMD	40	9	33	32	12	4	-29	24	3	30
31	18	M	DMD	30	17	11	28	12	8	2	-4	12	2
32	17	M	DMD	81	59	28	32	22	8	11	25	15	20
33	10	M	DMD	46	13	31	30	10	6	50	39	33	41
34	11	M	DMD	41	3	17	32	7	1	38	-37	15	1
35	12	M	DMD	55	15	22	32	22		7	54	11	1
36	12	M	DMD	82	18	26	32	17	6	45	-19	30	34
37	14	M	DMD	63	19	27	30	8	5	15	-3	15	11
38	13	F	SMA	82	41	36	32	13	7	5	25	8	15
39	9	F	SMA	71	5	19	32	5	2	40	13	25	13
40	30	F	SMA	63	33	31	28	25	18	53	-70	25	-18
41	11	F	NF	59	21	26	16	2	1	22	30	27	35
42	14	M	NF	68	39	30	10	1	1	46	24	26	26
43	26	F	Fract.	84	38	15	24	26	15	25	31	20	27

AIS adolescent idiopathic scoliosis, *CP* cerebral palsy, *DMD* Duchenne muscular dystrophy, *SMA* spinal muscular atrophy, *NF* neurofibromatosis, *Fract.* spinal fracture

the pull-out strength of implants and increase the chance of implant failure. In order to improve the accuracy of the thoracic pedicle screws various insertion techniques like the freehand technique, fluoroscopy and computer-assisted surgery [1, 15, 18], intra-operative electromyography (EMG), somatosensory evoked potential (SSEP) and motor

evoked potential (MEP) monitoring have been described. Image-guided techniques are expensive and time consuming. The freehand pedicle screw insertion technique on the other hand is simple and cheap and exhibits similar accuracy in experienced hands as compared to image-guided techniques [16, 23]. The freehand technique relies

on an accurate entry point, correct screw trajectories in transverse and sagittal planes and palpation of all walls of thoracic pedicles during each step of insertion. Hence it is imperative that there should be a constant entry point which is easy to identify. In our previous paper on cadavers [6], we introduced the concept of an ideal pedicle entry point (IPEP) for a thoracic pedicle with the freehand technique which is situated at the base of the superior facet at the junction of the lateral one third and medial two thirds. We have used this IPEP for our clinical study and achieved 93% accuracy in scoliosis. The advantages of our IPEP are that it is easy to identify the entry point which is constant, it does not depend on identification of the transverse process which is usually deformed in scoliosis, and it is very convenient to acquire the skill.

Many morphometric cadaver studies have been performed to analyse the anatomical variability of the thoracic and lumbar spine [5, 8]. In this study, we have determined the diameter of the pedicle screw to be used pre-operatively on CT scan: screws sized 5.5–6.5 mm in lumbar, 5–5.5 mm in lower thoracic (T9–T12), 4–5 mm in middle thoracic (T5–T8) and 3.5–4.5 mm in upper thoracic (T1–T4) pedicles. In a cadaveric study of the thoracic spine, Ebraheim et al. [8] have shown the absence of epidural space between the pedicle and the dura. Using epidural contrast, however, Reynolds et al. [19] demonstrated radiographic evidence of more than 2 mm of lateral epidural space from T7 to L4. Based on these studies, we divided the results of our misplaced screws into four grades: grade 1 (<2.0 mm), grade 2 (2.1–4.0 mm), grade 3 (4.1–6.0 mm) and grade 4 (6.1–8.0 mm) displacement. Considering the narrow margin of error [1, 17] in pedicular screw placement, we considered those screws as within the safe zone which were within the pedicle, grade 1 on the medial aspect or grade 1–2 on the lateral aspect, while the rest of the screws were considered as potentially at risk.

Most of the studies have shown the rates of misplacement to be between 28 and 43% and only a few studies have shown rates less than 5% [1]. Various post-operative investigations like radiogram, CT scan or magnetic resonance imaging (MRI) have been described to measure the accuracy [1, 12, 18, 20, 21, 25] of pedicle screw placement and CT scans have been found to be more reliable than radiograms [11, 13]. Hence we have analysed our study with post-operative CT scans.

Suk et al. [22] reported only 67 screw malpositions (1.5%) in 48 patients treated for idiopathic and congenital scoliosis with deformity correction of 69% using a post-operative radiogram. Lenke et al. [16] evaluated 93.8% accuracy in thoracic pedicle screw fixation using a post-operative CT scan with the freehand technique, mainly in idiopathic scoliosis and Scheuermann kyphosis. Belmont et al. [1] reported 99% accuracy in thoracic pedicle screw

fixation within the safe zone and concluded that accuracy was higher using a fluoroscopic-guided in-out-in technique, but the rate of breaching the pedicle wall was 43% in their study. In this study, we found a pedicle breaching rate of 31.3% and overall accuracy of 93% with 209 (77.9%) of 268 displaced screws within the safe zone.

Gertzbein and Robbins [14] in their study of 71 thoracic screws between T8 and T12 had a 26% incidence of medial cortical penetration of up to 8 mm with only two minor neurological injuries. They postulated a 4-mm safe zone for medial encroachment, which included 2 mm epidural space and 2 mm subarachnoid space. Lateral wall penetration or lateral extrapedicular screw placement of up to 6 mm resulting from the intentional use of the in-out-in technique was also considered acceptable, especially in the upper and middle thoracic spine where pedicle diameters typically measure only 4–5 mm. Fisher et al. [12] reported 98.5% accuracy of the screws in their study of thoracic spine trauma of 23 patients with 33% breach in the wall of the pedicle.

In our study, for the thoracic spine, 31.3% of the screws perforated the pedicle walls, with 10.3% on the medial side and 21% on the lateral side, and 3.6% on the anterior wall. If a safe zone of 2 mm is considered on the medial side and 4 mm on the lateral side, the total number of pedicle perforations would decrease to 2.5% on the medial wall and 4.5% on the lateral wall, which showed an accuracy of 93%. Vaccaro et al. [24] demonstrated a 23% medial cortical perforation with a mean spinal canal compromise of 5 mm in a cadaveric study without the use of fluoroscopy. Further in vivo investigations, with the majority of screws confined to the lower thoracic spine, reported medial cortical perforation rates between 8 and 24%. The percentages of screw misplacement between the various levels in the thoracic spine also did not vary much as expected. The narrowest diameters of pedicles are found between T3 and T7, and a higher percentage of screw misplacement is expected at these levels; but in this study, they did not show the figures as expected. In our study, the displacement rates were 29.1, 39.9 and 30.9% with an accuracy of 94.2, 91.6 and 93.7% in the upper, middle and lower thoracic regions, respectively. Though the perforation rate was higher in the middle thoracic spine, they were not statistically significant. The probable reason for the low accuracy in the middle thoracic region might be the narrow pedicle size as reported in the literature. A total of 31 screws perforated the anterior cortices of the vertebral bodies; however, only one screw perforated more than 4 mm.

Regarding the Cobb's angle, pelvic obliquity, thoracic kyphosis and lumbar lordosis, we achieved significant improvement in all parameters post-operatively. In addition, we did not come across any neurological or vascular complication post-operatively. Our IPEP is probably more

laterally located than other pedicle entry points, which could again explain the low rate of neurological complications with this technique. In conclusion, we can say that pedicle screw fixation with the freehand technique using IPEP in the thoracic spine appears to be a safe and reliable method showing acceptable accuracy for the treatment of scoliosis and it should be considered by surgeons during thoracic pedicle screw instrumentation.

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