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Characteristics of pedicle screw misplacement using freehand technique in degenerative scoliosis surgery

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Abstract

Purpose This study aimed to estimate the accuracy of pedicle screw (PS) placement in degenerative scoliosis surgery, characterize a patient population with PS misplacement, and analyze the association between misplaced PS vector and lumbar coronal curve.

Methods In this study, 122 patients (average age 68.6 years), who underwent corrective and decompression surgery, were selected retrospectively. PS accuracy was evaluated in the thoracic to lumbar spine. We identified characteristics of misplacement in each patient. Screw positions were categorized into grade A, entirely in the pedicle; grade B, < 2 mm breach; grade C, 2–4 mm breach; and grade D, > 4 mm breach using postoperative computed tomography.

Results The mean preoperative lumbar coronal curve was 32.3 ± 18.4°, and the number of fused vertebrae was 8.9 ± 2.8. A total of 2032 PS were categorized as follows: grade A, 1897 PS (93.3%); grade B, 67 (3.3%); grade C, 26 (1.3%); and grade D, 43 (2.1%). One PS (grade D), inserted at T5, needed surgery for removal due to neurological deficit. The misplacement group (grades C and D) had a significantly stronger lumbar coronal curve and apical vertebral rotation than the accuracy group (grades A and B). Misplaced PS vector (direction and degree) was significantly correlated with inserted vertebral rotation. Grade D misplacement was distributed mainly around the transitional vertebra of the lumbar curve.

Conclusions The accuracy of PS insertion in the thoracic to lumbar spine was high in DS surgery, but the need for care was highlighted in the transitional vertebra.

Keywords Pedicle screw · Freehand technique · Degenerative scoliosis · Transitional vertebra · Upper instrumented vertebra

Introduction

Pedicle screws (PS) are the most prevalent spinal segmental fixation system that allows to stabilize all three columns of the spine in adult spinal deformity (ASD) surgery [1]. They provide stable anchor points connected to rods, but PS misplacement has the potential risk of correction loss, neurological deficits, and organ damage [2, 3]. The freehand technique has the advantage of no radiation exposure during surgery. Compared with surgical assistant technologies, such as fluoroscopy and navigation techniques, the freehand technique achieves the same accuracy level in the thoracic-to-lumbar screw insertion [4]. Many studies described the accuracy and safety of the freehand technique, and screw misplacement rates vary from 1.7 to 15% in several etiologies. [5–10].

With the aging of the society, the number of patients with degenerative scoliosis (DS), who are treated with ASD surgery, is increasing [11]. However, the characteristics of PS misplacement remain to be elucidated. Therefore, the aims of this study were to investigate the accuracy of PS placement and to elucidate the characteristics of screw misplacement using a freehand technique in DS cases. Here, we

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present the high accuracy of PS insertion in the thoracic to lumbar spine, but the misplacement screw was distributed around the transitional vertebra.

Materials and methods

This retrospective radiological study was based on a prospective patient database from a single academic spinal surgery department. Between 2016 and 2019, we conducted a retrospective review of patients with ASD who underwent surgical decompression, reconstruction, and realignment with fusion and pedicular segmental instrumentation using a freehand technique. The exclusion criteria were patients with less than 10° of coronal curve or those with other pathologies such as neuromuscular disease or iatrogenic kyphosis [12]. Postoperative computed tomography (CT) images were evaluated for PS placement in the thoracic to lumbar spine (T1–L5). For best accuracy, axial scans, as well as sagittal and coronal reconstructions, were reviewed. This study was approved by our Institutional Review Board (#20-189). The requirement for informed consent was waived because of the retrospective nature of the research.

Surgical technique

All surgeries were performed under general anesthesia with the patient in the prone position on the Jackson table. Freehand technique involves presurgical evaluation of the deformity using routine radiographs of the spine. CT scans, magnetic resonance images, or both, were used to identify the anatomic variation resulting from the rotation, angulation, and translation of each vertebral segment as well as the extent of spinal canal abnormalities. These were performed, in most cases, for diagnostic assessment of the spinal canal for stenosis, which required routine scans, in contrast to the extensive CT scan cuts used for stereotactic guidance. During surgery, the facets were identified after careful exposure of the involved spinal segments. The localizing pedicle probe was placed at the base level of the superior articular facet and at the midpoint of the transverse process and the pars interarticularis. The first operator was positioned on the patient's left side and introduced all implants on one side, while the assistant operator was on the opposite side.

Radiological evaluation

Rampersaud criteria were used to evaluate the screw position along with the direction of the screw breach using an axial CT scan [13]. According to the criteria, patients were categorized into four grades from A to D (A: entirely in the pedicle, B: < 2 mm breach, C: 2–4 mm breach, D: > 4 mm breach). Oversized screws touching both the medial and lateral cortices were still considered to be part of grade A unless the breach was > 2 mm. Screws perforating the canal for up to 2 mm were recognized as acceptable [14, 15]. Grades A and B were categorized as the accuracy group (group A), and grades C and D as the misplacement group (group M). Vertebral rotation was defined as the use of preoperative axial CT scans. Clockwise and anticlockwise rotations of the vertebral longitudinal axis were defined as vertebral rotation plus [VR (+)] and vertebral rotation minus [VR (−)], respectively. Preoperative full-spine radiographs (anteroposterior and lateral) were recorded with the patients in the standing position. Lateral radiographs were recorded with patients gazing horizontally in a natural free-standing posture with their fingers on their clavicles [16]. The measured radiographic parameters were as follows: (1) lumbar lordosis (the angle between the upper endplate of the L1 vertebra and the upper endplate of the S1 vertebra); (2) thoracic kyphosis (the angle between the upper endplate of T5 and the lower endplate of T12); (3) sacral slope; (4) pelvic tilt; (5) pelvic incidence; and (6) C7 sagittal vertical axis (the distance between a plumb line from the center of the C7 vertebra and the posterior superior center of the sacrum).

Statistical analysis

Descriptive statistics, including mean and standard deviation, were calculated for demographic data and radiographic parameters. Differences in individual and radiographic parameters were assessed using unpaired *t* test, chi-squared test, and Fisher's exact test. All statistical computations were performed using Statistical Package for the Social Sciences software (version 22.0; IBM Corp., Armonk, NY, USA). A p value < 0.05 was considered statistically significant.

Results

A total of 2033 PS were analyzed in 122 patients. Table 1 shows the data on patient background. Nineteen men and 102 women (average age 68.6 years; age range 34–77 years) were included. DS consisted of the primary pathology, and the mean preoperative coronal Cobb angle was 32.3°. A total of 1964 screws (96.7%) were placed in the cortical shell on the pedicle or under 2-mm misplacement (grade A or B), while 69 screws (3.3%) were placed over 2 mm or more apart from the cortical shell (grade C or D) (Table 2). One case revealed grade-D misplacement medially, resulting in surgery for removal due to neurological symptoms. Grade-D misplacement presented bilateral symmetry (medial 21, lateral 20). Only two patients had inferior medial misplacement (Table 3).

Table 4 shows the preoperative demographic comparison between groups A and M. Spino-pelvic parameters (thoracic kyphosis and coronal Cobb angle) and vertebral rotation of the apical vertebra were significantly higher in group M than in group A. No significant difference was found in demographic characteristics between the two groups, except percentage of women.

Figure 1 shows the correlation between the rotation angle of the vertebra to which the PS was inserted and PS misplacement vector (direction and degree). On both the left (primary surgeon) and right sides (assistant surgeon), the VR was correlated significantly with the PS misplacement vector. Figure 2 demonstrates the distribution of grade-D misplacement in each case. In most cases, the misplacement occurred around the transitional vertebra in the lumbar curve, following the upper instrumented vertebra compared with the apical vertebra.

Table 1 Patient background

Number	122
Age (year)	68.6 ± 8.9
Female *N* (%)	102 (83)
BMI	23.1 ± 3.6
Lumbar BMD	98.0 ± 21.7
Pathology *N*	
KS	114
AS	8
Preoperative coronal Cobb (°)	32.3 ± 18.4
No. of fused vertebrae	8.9 ± 2.8
No. of pedicle screw	20.4 ± 5.9

Data are presented as the mean ± standard deviation

BMI body mass index, *BMD* bone mineral density, *KS* kyphoscoliosis, *AS* adult scoliosis

Representative case

A 79-year-old woman with kyphoscoliosis underwent decompression and corrective surgery from T10 to the ilium (Fig. 3). The preoperative coronal Cobb angle was 51° (L1–L4). Apical vertebra was rotated clockwise (grade 2). Postoperative CT showed grade-D misplacement on the left side (L1). She did not show any neurological deficits.

Discussion

The accuracy rate of PS was high (96.7%), and only one case required revision surgery. High coronal Cobb angle was a characteristic of screw misplacement, and vertebral rotation influenced the breached screw vector. Furthermore, screw misplacement occurred mainly around the transitional vertebra in each case.

The freehand technique for PS insertion is cost-effective and avoids the harmful effects of radiation exposure to both patients and surgeons [17]. It also shortens surgery duration, reducing the incidence of surgical site infection in procedures involving spinal instrumentation [18]. In the freehand technique, Laudato et al. reported 93.6% accuracy in the thoracic to lumbar spine [4], and Kim et al. showed 93.8% accuracy in the thoracic spine in patients with adult degenerative scoliosis and deformity [5]. Our study exhibited high accuracy and low revision rate in DS surgery, which was similar to the findings of a previous study. There were two notable reasons for the low revision rate in our study. First, inferior medial misplacement occurred in few cases (Table 3). Spinal roots are vulnerable to damage when PS misplacement

Table 2 Pedicle screw distribution and grading

	Left (primary surgeon)				Right (assistant)				
	Grade				Grade				
	A	B	C	D	A	B	C	D	Total
T4	7	1	0	1	7	2	1	0	19
T5	15	0	0	1	15	2	0	2	35
T6	18	1	0	2	17	1	0	1	40
T7	20	2	2	0	17	2	0	0	43
T8	1	0	0	2	21	2	0	0	26
T9	68	2	2	1	59	7	0	1	140
T10	101	4	0	0	101	3	0	0	209
T11	102	0	0	0	102	2	2	1	209
T12	97	1	2	2	100	0	2	3	207
L1	95	5	1	2	100	2	1	3	209
L2	104	2	1	5	99	9	4	1	225
L3	106	2	1	5	105	2	2	3	226
L4	100	6	0	2	107	4	2	2	223
L5	107	2	2	2	106	1	1	1	222
Total	941	28	11	25	956	39	15	18	2033

occurs infero-medially to the pedicle [19]. Second, cases included adult patients who presented increased spinal cord tension and not young patients with adolescent idiopathic scoliosis (AIS). [20].

Preoperative coronal Cobb angle and vertebral rotation are risk factors of PS misplacement in spine surgery [21]. Zhu et al. reported that PS misplacement rate is higher in patients with a Cobb angle > 80° than in patients with < 80° in congenital scoliosis [22]. Harimaya et al. demonstrated a positive relation between vertebral rotation and PS misplacement occurrence in infantile and juvenile patients [23]. Similar to the findings of these studies, our study revealed that misplacement occurred in cases with high preoperative coronal curve and apical vertebral rotation (Table 4) and that the misplacement vector was affected by the inserted vertebral rotation (Fig. 1). Notably, the misplacement occurred more frequently around the transitional vertebra than the apical vertebra, which has the highest rotation (Fig. 2). Chan et al. reported that the PS misplacement rate is highest at the transitional proximal thoracic to main thoracic regions in AIS surgery because of the pedicle trajectory change. [24] These results imply that surgeons would be more influenced by the change in trajectory at the transitional vertebra than at the apical vertebra in DS surgery.

Table 3 Direction distribution of grade D misplacement

	Lateral	Medial	Inferior medial	Total
T4	1	0	0	1
T5	2	1	0	3
T6	1	2	0	3
T7	0	0	0	0
T8	2	0	0	2
T9	1	1	0	2
T10	0	0	0	0
T11	1	0	0	1
T12	0	5	0	5
L1	1	4	0	5
L2	3	3	0	6
L3	6	2	0	8
L4	1	2	1	4
L5	1	1	1	3
Total	20	21	2	43

In some cases, grade-D misplacement occurred at the upper instrumented vertebrae (Fig. 2). This result may be explained by the fact that the screw insertion maneuver would be influenced by inadequate skin incision at the proximal site. With the least sagittal pedicle width among the lumbar spine [25], L5 misplacement most likely occurs in the lumbar spine with degenerative spinal disease [26]. However, in this study, misplacement in L5 was less prone to occur than in other lumbar spines (Table 3). This might be because L4 total laminectomy for decompression allowed visualization of the L5 pedicle while inserting the PS.

This study has several limitations. First, PS misplacement possibly occurred during correction maneuvers. Even if PS insertion is achieved accurately, correction forces,

Table 4 Demographic comparison between accuracy and misplacement groups

		Group A	Group M	
	N	73	49	*p*
Demographic characteristics	Age (years)	69.2 ± 8.3	67.6 ± 9.6	0.32
	Female *N* (%)	56 (76.7)	46 (97.9)	0.012*
	BMI (kg/m^2)	23.1 ± 20.6	23.1 ± 4.2	0.9
	BMD (%YAM)	99.5 ± 20.6	96 ± 23.2	0.43
Spino-pelvic parameters	C7SVA (°)	113 ± 79.8	106 ± 67.1	0.59
	TK (°)	18.7 ± 16.9	26.1 ± 21.3	0.045*
	LL (°)	11.2 ± 21.2	13.7 ± 19.3	0.51
	SS (°)	18.0 ± 12.4	18.2 ± 9.1	0.95
	PT (°)	34.9 ± 10.4	34.0 ± 11.8	0.67
	PI (°)	52.8 ± 12.1	51.6 ± 11.5	0.57
	Coronal Cobb (°)	26.3 ± 17.4	39.1 ± 18.6	< 0.0001*
Vertebral rotation (Nash & Moe scale)	0	17	2	0.0002*
	1	18	12	
	2	31	22	
	3	3	13	
	4	0	0	

Data are presented as the mean ± standard deviation

BMI body mass index, *BMD* bone mineral density, *KS* kyphoscoliosis, *AS* adult scoliosis, *SVA* sagittal vertical axis, *TK* thoracic kyphosis, *LL* lumbar lordosis, *SS* sacral slope, *PT* pelvic tilt, *PI* pelvic incidence

*Statistically significant

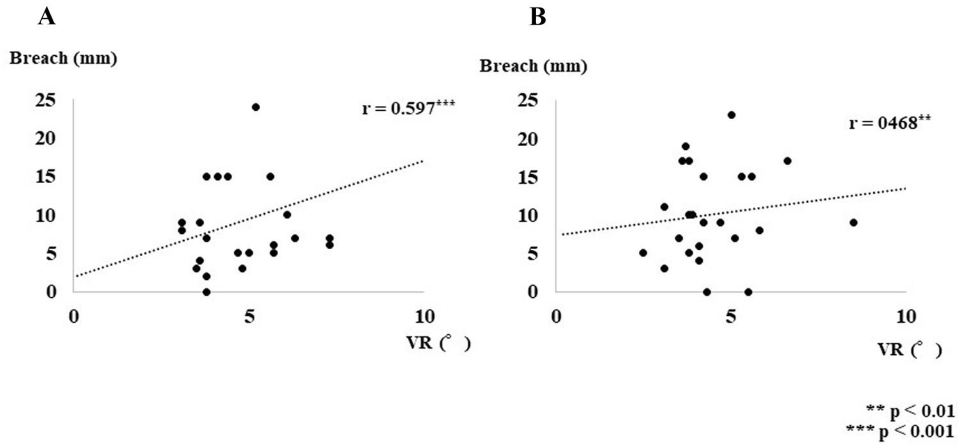

Fig. 1 Association between preoperative apical vertebral rotation and misplacement direction, and distance from the pedicle. **A** Left side (primary surgeon). **B** Right side (assistant surgeon).

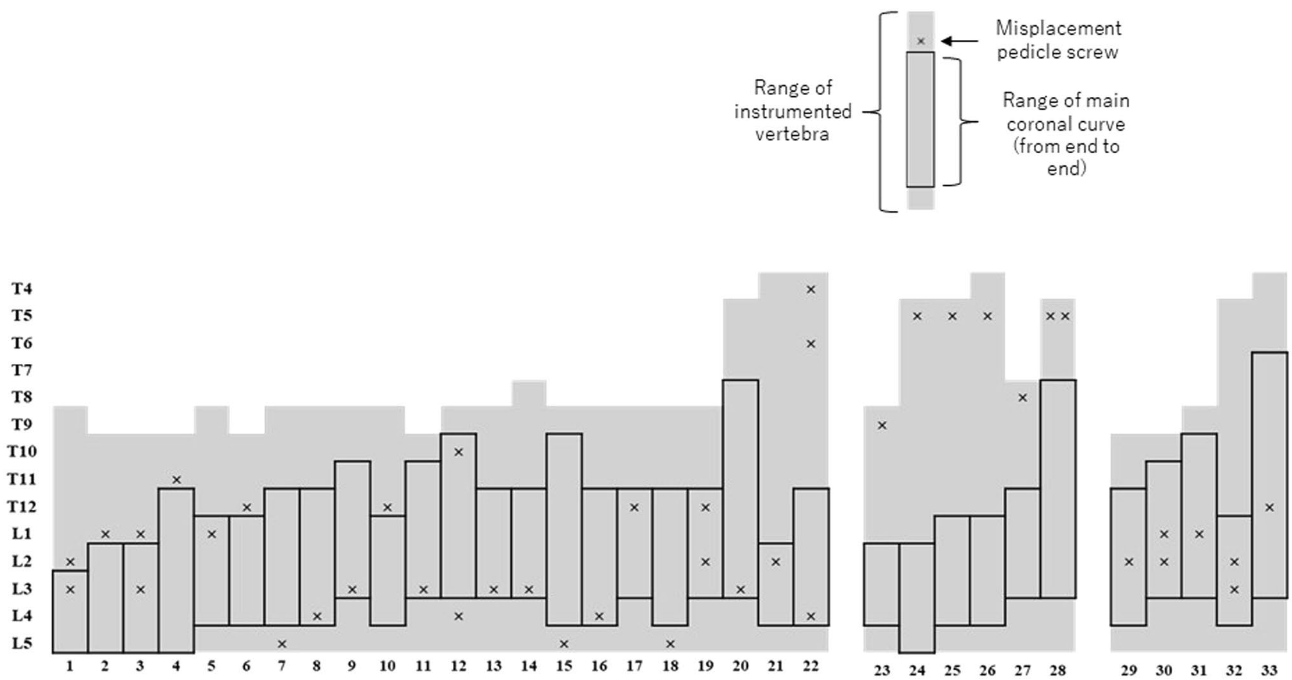

Fig. 2 Grade-4 misplacement pedicle-screw distribution for coronal curve in each case. In cases 1–22, the misplacement screw was located around the transitional vertebra. In cases 23–28, the misplacement screw was located around the UIV. In cases 29–33, the misplacement screw was located around the apical vertebra. *UIV* upper instrumented vertebra

such as distraction, compression, and rod-rotation force, induce PS breach in fragile bony cases [27]. Second, our material consisted mainly of de novo degenerative lumbar scoliosis for primary pathology and lacked details for adult scoliosis with a steep thoracic curve. Third, since the target cases were mainly scoliosis, there were few cases of adult scoliosis with steeper coronal curve than scoliosis in our series. Since the intraoperative navigation system is useful for screw insertion, especially in adult scoliosis with high-grade Cobb angles of $\geq 60°$ [28], its accuracy in cases with larger Cobb angles is unknown. However, the present study results provide useful information regarding the characteristics of PS misplacement using the freehand technique in DS surgery.

In conclusion, PS insertion using the freehand technique is an accurate, reliable, and safe method in DS surgery. The characteristics of PS misplacement include patients with high coronal curve and high apical vertebral rotation. Analysis of misplacement in each case highlighted the need to pay attention to the area around the transitional vertebra.

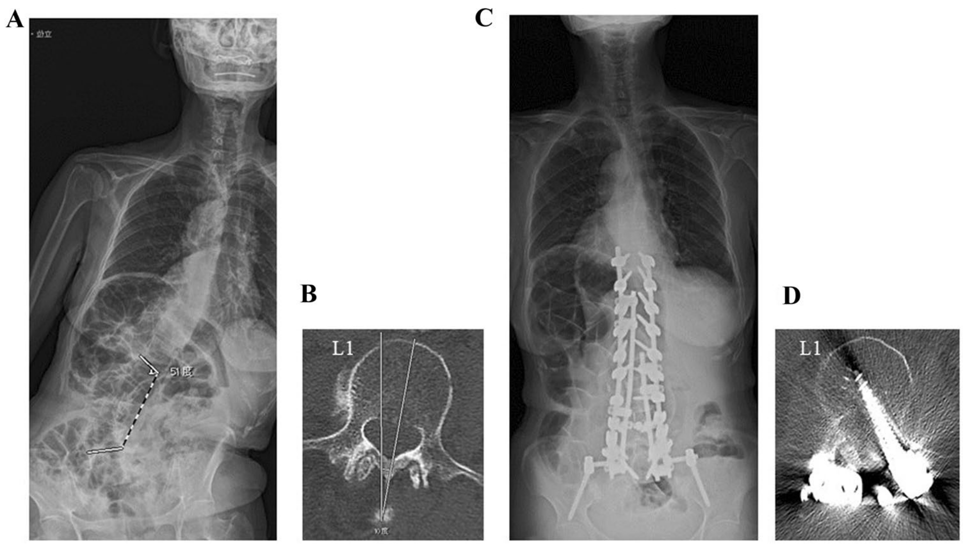

Fig. 3 Representative case with grade-D misplacement. **A** Preoperative full-standing radiograph. **B** Preoperative L2 vertebral rotation. **C** Postoperative full-standing radiograph. **D** Postoperative left L2 pedicle-screw misplacement

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Declarations

Conflict of interest Tomohiro Yamada, Tomohiko Hasegawa, Go Yoshida, Tatsuya Yasuda, Hideyuki Arima, Tomohiro Banno, Hiroki Ushirozako, Koichiro Ide, Yuh Watanabe, Keichi Nakai and Yukihiro Matsuyama have nothing to disclose. Yu Yamato and Shin Oe work at a donation-endowed laboratory in the Division of Geriatric Musculoskeletal Health.

References

1. Debnath UK, Mehdian SMH, Webb JK (2011) Spinal deformity correction in Duchenne muscular dystrophy (DMD): comparing the outcome of two instrumentation techniques. Asian Spine J 5(1):43–50
2. Jutte PC, Castelein RM (2002) Complications of pedicle screws in lumbar and lumbosacral fusions in 105 consecutive primary operations. Eur Spine J 11(6):594–598
3. Kotani Y, Abumi K, Ito M, Takahata M, Sudo H, Ohshima S et al (2007) Accuracy analysis of pedicle screw placement in posterior scoliosis surgery: comparison between conventional fluoroscopic and computer-assisted technique. Spine 32(14):1543–1550
4. Laudato PA, Pierzchala K, Schizas C (2018) Pedicle screw insertion accuracy using O-Arm, robotic guidance, or freehand technique. Spine 43(6):E373–E378
5. Kim YJ, Lenke LG, Bridwell KH, Cho YS, Riew KD (2004) Free hand pedicle screw placement in the thoracic spine: is it safe? Spine 29(3):333–342
6. Samdani AF, Ranade A, Sciubba DM, Cahill PJ, Antonacci MD, Clements DH et al (2010) Accuracy of free-hand placement of thoracic pedicle screws in adolescent idiopathic scoliosis: how much of a difference does surgeon experience make? Eur Spine J 19(1):91–95
7. Wang VY, Chin CT, Lu DC, Smith JS, Chou D (2010) Free-hand thoracic pedicle screws placed by neurosurgery residents: a CT analysis. Eur Spine J 19(5):821–827
8. Parker SL, McGirt MJ, Farber SH, Amin AG, Rick AM, Suk I et al (2011) Accuracy of free-hand pedicle screws in the thoracic and lumbar spine: analysis of 6816 consecutive screws. Neurosurgery 68(1):170–178
9. Miekisiak G, Kornas P, Lekan M, Dacko W, Latka D, Kaczmarczyk J (2015) Accuracy of the free-hand placement of pedicle screws in the lumbosacral spine using a universal entry point. J Spinal Disord Tech 28(4):E194–E198
10. Etemadifar M, Jamalaldini M (2017) Evaluating accuracy of free-hand pedicle screw insertion in adolescent idiopathic scoliosis using postoperative multi-slice computed tomography scan. Adv Biomed Res 6(1):19
11. Aizawa T, Kokubun S, Ozawa H, Kusakabe T, Tanaka Y, Hoshikawa T et al (2016) Increasing incidence of degenerative spinal diseases in Japan during 25 years: the registration system of spinal surgery in Tohoku university spine society. Tohoku J Exp Med 238(2):153–163
12. Silva FE, Lenke LG (2010) Adult degenerative scoliosis: Evaluation and management. Neurosurg Focus 28(3):1–10
13. Rampersaud YR, Pik JHT, Salonen D, Farooq S (2005) Clinical accuracy of fluoroscopic computer-assisted pedicle screw fixation: a CT analysis. Spine 30(7):183–190
14. Hicks JM, Singla A, Shen FH, Arlet V (2010) Complications of pedicle screw fixation in scoliosis surgery: a systematic review. Spine 35(11):465–470
15. Belmont PJ, Klemme WR, Robinson M, Polly DW (2002) Accuracy of thoracic pedicle screws in patients with and without coronal plane spinal deformities. Spine 27(14):1558–1566
16. Faro FD, Marks MC, Pawelek J, Newton PO (2004) Evaluation of a functional position for lateral radiograph acquisition in adolescent idiopathic scoliosis. Spine 29(20):2284–2289
17. Perisinakis K, Theocharopoulos N, Damilakis J, Katonis P, Papadokostakis G, Hadjipavlou A et al (2004) Estimation of patient dose and associated radiogenic risks from fluoroscopically guided pedicle screw insertion. Spine 29(14):1555–1560
18. Weinstein MA, McCabe JP, Cammisa J (2000) Postoperative spinal wound infection: a review of 2,391 consecutive index procedures. J Spinal Disord 13(5):422–426

19. Boachie-adjei O, Girardi FP, Bansal M, Rawlins BA (2000) Safety and efficacy of pedicle screw placement for adult spinal deformity with a pedicle-probing conventional anatomic technique. Clin Spine Surg 13(6):496–500
20. Yamada S, Won DJ, Yamada SM (2004) Pathophysiology of tethered cord syndrome: correlation with symptomatology. Neurosurg Focus 16(2):1–5
21. Sarwahi V, Wendolowski SF, Gecelter RC, Amaral T, Lo Y, Wollowick AL et al (2016) Are we underestimating the significance of pedicle screw misplacement? Spine 41(9):E548–E555
22. Zhu F, Sun X, Qiao J, Ding Y, Zhang B, Qiu Y (2014) Misplacement pattern of pedicle screws in pediatric patients with spinal deformity a computed tomography Study. J Spinal Disord Tech 27(8):431–435
23. Harimaya K, Lenke LG, Son-Hing JP, Bridwell KH, Schwend RM, Luhmann SJ et al (2011) Safety and accuracy of pedicle screws and constructs placed in infantile and juvenile patients. Spine 36(20):1645–1651
24. Chan CYW, Kwan MK (2018) Zonal differences in risk and pattern of pedicle screw perforations in adolescent idiopathic scoliosis (AIS): a computerized tomography (CT) review of 1986 screws. Eur Spine J 27(2):340–349
25. Makino T, Kaito T, Fujiwara H, Yonenobu K (2012) Analysis of lumbar pedicle morphology in degenerative spines using multiplanar reconstruction computed tomography: what can be the reliable index for optimal pedicle screw diameter? Eur Spine J 21(8):1516–1521
26. Bydon M, Xu R, Amin AG, Macki M, Kaloostian P, Sciubb DM et al (2014) Safety and efficacy of pedicle screw placement using intraoperative computed tomography: consecutive series of 1148 pedicle screws. J Neurosurg Spine 21(3):320–328
27. Takata Y, Sakai T, Higashino K, Matsuura T, Suzue N, Hamada D et al (2015) State of the art: Intraoperative neuromonitoring in spinal deformity surgery. J Med Investig 62(3):103–108
28. Cui G, Wang Y, Kao TH, Zhang Y, Liu Z, Liu B et al (2012) Application of intraoperative computed tomography with or without navigation system in surgical correction of spinal deformity: a preliminary result of 59 consecutive human cases. Spine 37(10):891–900