Uniplanar cannulated pedicle screws in the correction of Lenke type 1 adolescent idiopathic scoliosis (AIS)

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Abstract

Background

In the present study, we reported the clinical use of uniplanar cannulated pedicle screws for the correction of Lenke type 1 adolescent Idiopathic scoliosis (AIS), and its safety and clinical outcomes were also evaluated.

Methods

68 patients with Lenke type 1 AIS were included, among which 38 patients were treated with uniplanar cannulated screws at the concave side of periapical levels and multiaxial screws at the other levels (group A). Moreover, the remaining 30 patients were treated with all multiaxial screws (group B). The preoperative and postoperative radiographic parameters of the Lenke type 1 AIS, axial vertebral rotation, and the safety of the pedicle screws were evaluated by X-rays and computed tomography (CT).

Results

Preoperative data was comparable between two groups. The postoperative proximal thoracic (PT) curve, main thoracic (MT) curve, thoracolumbar/lumbar (TL/L) curve, and apical vertebral rotation were significantly improved compared with the preoperative data. The coronal correction rates in group A and B were 83% and 81.9%, respectively ($P > 0.05$). The derotation rates in group A and B were 60.8% and 43.2%, respectively ($P < 0.05$). The rotation classification in the group A was also better compared with the group B. The misplacement rate in group A and B was 7.9% and 11.8%, respectively ($P < 0.05$), and the total misplacement rate on the concave side (11.4%) was higher than that of convex side (8.4%). The lateral perforation was found at the concave side, while the medial perforation was found at the convex side. On the concave side, the misplacement rate in group A and B was 9.7% and 12.3%, respectively ($P < 0.05$). The grades 2 and 3 perforations were three (3.5%) in the group A and eight (8.2%) in the group B ($P < 0.05$). On the convex side, the misplacement rate in group A and B was 5.9% and 11.1%, respectively ($P < 0.05$). The grades 2 and 3 perforations were one (0.9%) in the group A and four (4.4%) in the group B ($P < 0.05$).

Conclusion

Collectively, uniplanar cannulated pedicle screws could effectively increase the accuracy of pedicle screws and facilitate the derotation of the apical vertebra compared with the multiaxial pedicle screws.

Trial registration

retrospectively registered

Background

Adolescent idiopathic scoliosis (AIS) is associated with coronal, axial and sagittal plane deformities. Pedicle screws, vertebral derotation, rod rotation and segmental translation are most used techniques for scoliosis correction [1]. In 1985, Roy-Camille first applied the pedicle screw-plate system for the lumbar spine. Cotrel et al. [2] have introduced pedicle screws for scoliosis correction. The use of thoracic pedicle screws in the management of AIS is first described by Suk et al. [3].

Axial vertebral rotation remains the main reason of rib hump. Recently, more attention has been paid to strategies to improve the correction of vertebral rotation in order to further reduce the rib hump. With the development of instrumentation, uniplanar pedicle screws have been used for scoliosis correction. The advent of uniplanar screws allows freedom of motion in the sagittal plane while allowing surgeons to derotate patients in the axial plane during a scoliosis correction. This would potentially allow freedom of motion in the sagittal plane during correction with potentially less flattening of the thoracic spine. There is little difference in the coronal plane correction of thoracic curves between uniplanar pedicle screws and multiaxial screws. However, more patients have a greater thoracic apical vertebral derotation in the uniplanar pedicle screw group [4]. Moreover, a superior correction of the sagittal thoracic alignment can be achieved by uniplanar screws compared with the fixed screws [1].

Although many studies have reported the morphometric aspects of the thoracic and lumbar spine and the details of the pedicle sizes and dimensions by X-rays and computed tomography (CT) [5], the insertion of pedicle screws in scoliosis cases still remains challenging because of vertebral rotation and smaller pedicle size, especially at the concave side. It is hard to insert the pedicle screw in cases with severe scoliosis due to the difficult placement techniques and the potential of causing serious complications. The rates of misplaced pedicle screws using the freehand technique range from 5% to 28 ~ 43% [6, 7]. As to scoliosis cases, even the pedicles' trajectories are made and tapped correctly, the pedicles may be incorrectly inserted due to axial rotation, especially at the apical levels. In order to avoid misplacement of the pedicle screws, Lee et al. [8] have described extra-pedicular screw placement using the cannulated screw system and found that cannulated screw system significantly reduces the screw perforation rate in dysplastic pedicle for AIS surgery. Yilar et al. [9] have reported that the use of cannulated screws can decrease the perforation and complication rates in the treatment of AIS. Although it does not significantly lower the medial perforation rate, the cannulated screw can dramatically reduce the lateral perforation rate. In the present study, we reported the clinical use of uniplanar cannulated pedicle screws for the correction of Lenke type 1 AIS and evaluated its safety and clinical outcomes.

Methods

Study population

The ethics committee of Qilu Hospital of Shandong University approved this study. All participants agreed with the data and publication of the manuscript. A total of 68 patients with Lenke type 1 AIS were included in this study, among which 38 patients were treated with uniplanar cannulated screws at the concave side of periapical levels and multiaxial screws at the other levels (group A). There were 31 females and seven males aged ranging from 13 to 21 years (the mean age was 14.0 ± 2.6 years). Lumbar modifier was A in 23 cases, B in 11 cases and C in four cases. Thoracic sagittal modifier was (-) in two cases, (N) in 33 cases and (+) in three cases. Moreover, the other 30 patients were treated with all multiaxial screws (group B). The mean age at surgery was 14.3 ± 1.6 years (range, 11–18 years). The demographic information of the patients was shown in Table 1.

Table 1
Demographic data of the patients

Characteristic	Group A	Group B
Gender		
Male	7	6
Female	31	24
Age (year)	14.0 ± 2.6	14.3 ± 1.6
Apical segment		
T8	18	12
T9	13	11
T8/9	5	7
Lumbar modifier		
A	23	20
B	9	7
C	6	3
Thoracic sagittal modifier		
-	2	1
N	33	27
+	3	2

Surgical Techniques

Intraoperative neurophysiological monitoring (MEPs + SEPs) was used in all patients to reduce the risk of spinal cord injury during deformity correction. A posterior midline incision was made to expose all predetermined levels. FSRS-Schwab grade 1 osteotomy was performed at all fixed segments in the two groups. The trajectories of all pedicle screws were made with freehand technique. In group A, a K-wire was inserted into the pedicles, and then the trajectory was tapped. On the apex levels (3 ~ 4 levels), uniplanar cannulated screws with extended slice (Lora Rod Percutaneous Screw System, Shanghai Sanyou Medical Co., Ltd.) were advanced over the K-wire (Fig. 1). multiaxial pedicle screws at the other levels were inserted in a usual way. In group B, routine multiaxial pedicle screws were inserted using the traditional methods.

After insertion of pedicle screws and confirmation of the screw position with fluoroscopy, asymmetrical grade 2 osteotomy (spinous process resection, inferior and superior laminectomy and complete facetectomy, the resection part of the convex side was wider than that of the concave side) was performed at 2 ~ 4 apex segments [10]. In this series, no grade 3, 4 or 5 was used for deformity correction.

After osteotomy, the contoured rod at the concave side with extra kyphosis was inserted proximally and distally, and the screws were tightened proximally and distally, leaving the rod in the correct sagittal plane. The assistant pushed down the rib hump at the convex side. After proximal and distal foundations were connected and locked, apical screws were translated to the rod segmentally, and multi-level direct vertebral bodies derotation was underwent to pulling the apical vertebrae dorsally out of the chest by pushing down the rod to the pedicle screws at the apical levels. Then convex rod with less thoracic kyphosis (TK) was inserted and pushed down on the convex side of the vertebral bodies, thus displacing them anteriorly and decreasing the rib prominence.

Assessment Methods

The coronal and sagittal assessment of the Lenke type 1 AIS

Full-length radiographs, including coronal and lateral views, as well as right and left supine side-bending views were obtained using a standard protocol. For full-length radiographs, patients were instructed to adopt a comfortable standing posture with their arms positioned with approximately 45^0 of forwarding shoulder flexion and place their fingertips on their mid-clavicular region.

The proximal thoracic (PT) curve, main thoracic (MT) curve, thoracolumbar/lumbar (TL/L) curve, lumbar spine modifiers (A, B, or C) and sagittal thoracic modifiers (-, N, or +) were used for assessment of coronal and sagittal abnormalities according to the Lenke classification [11]. For the lateral views, TK (T5-12), lumbar lordosis (LL) and pelvic incidence (PI) were used to assess the sagittal alignment.

The assessment of the apical vertebral rotation

The position of bilateral pedicle screw tips in the apical thoracic vertebrae, as observed on a standard posteroanterior radiograph, was used to estimate vertebral rotation based on a simple trigonometric relationship. When both pedicle screw tips were visible central to the two rods (classified as grade 0 vertebrae), CT measures of vertebral rotation were between 0° and 8°. In grade 1 vertebrae, the right pedicle screw tip was hidden behind the right rod, and CT measures of vertebral rotation were between 9° and 12°. In grade 2 vertebrae, the right pedicle screw tip was lateral to its respective rod, and CT measures of vertebral rotation were greater than 13° [12]. The CT was also used to evaluate the apical axial rotation. The measurement method was shown in Fig. 2 [13].

The assessment of the pedicle screws

CT was used to assess the accuracy of periapical uniplanar cannulated pedicle screws in group A and routine pedicle screws in group B. Periapical pedicle screws were defined as the pedicle screws inserted at the apical vertebrae, and two adjacent segments. When the apical of the MT curve was located at the intervertebral disc, the two adjacent upper and lower pedicle screws (if inserted) were assessed.

The lateral, medial and anterior perforations were assessed using the following screw misplacement grading systems [14, 15]: grade 0, no pedicle perforation; grade 1, 0–2 mm; grade 2, 2–4 mm; and grade 3, greater than 4 mm (Fig. 3). Anterior perforation (breach beyond the anterior vertebral body or anterior to the costovertebral joint complex) was included in lateral perforation.

All evaluation was independently and blindly conducted by two experienced spine surgeons. If any different result found by observers, the senior surgeon made the final decision.

Statistical analysis

Statistical analysis was performed using SPSS 26.0 for windows (SPSS, IBM Corporation, USA). When a statistically significant difference was detected, selected pairs of groups were analyzed using the Student's t-test, Mann-Whitney U test or the Chi-square test. A P value < 0.05 was considered as statistically significant.

Results

The average follow-up was 25 months, ranging from a minimum of 24 months to a maximum of 36 months (Fig. 4). Tables 2 and 3 show the preoperative and postoperative radiographic data, respectively. There was no significant difference in preoperative data between the two groups. The postoperative PT curve, MT curve, TL/L curve and apical vertebral rotation were significantly improved compared with the preoperative data. There was no significant difference in postoperative PT curve, MT curve, TL/L curve and sagittal profile (SVA, PI, TK, LL) between the two groups. The coronal correction rates in group A and B were 83% and 81.9%, respectively ($P > 0.05$). The derotation rates in group A and B were 60.8% and 43.2%, respectively ($P < 0.05$). Table 3 shows the apical vertebral rotation classification. The rotation classification in group A was also better than that of group B.

Table 2
The preoperative and postoperative radiographic data of the patients

	Group A		Group B	
	Pre-operation	Post-operation	Pre-operation	Post-operation
PT curves	27.6°±10.4°	12.6°±8.9°*	26.7°±9.6°	10.9°±5.6*
MT curves	56.5°±6.9°	9.6°±3.8°*	59.2°±6.5°	10.7°±5.8°*
MT curves (bending)	27.8°±11.1°	/	26.1°±10.8°	/
TL/L curves	32.0°±9.6°	10.1°±2.6°*	33.5°±5.6°	11.7°±7.3°*
TL/L curves (bending)	12.6°±8.8°		10.9°±6.1°	
Apical vertebral rotation (CT)	10.2°±6.4°	4.0°±3.4°**	11.8°±0.6°	6.7°±2.3°**
Apical vertebral rotation classification	/	0.3 ± 0.4**	/	0.4 ± 0.7**
C7-S1sagittal vertical axis (C7-S1 SVA)	− (45.1 ± 11.2)	− (43.8 ± 9.7)	− (41.1 ± 14.1)	− (39.1 ± 7.9)
TK (T5-12)	25.0°±12.7°	24.3°±12.1°	27.6°±10.1°	26.4°±7.8
LL (L1-5)	38.7 ± 9.2	38.8 ± 13.1	36.1 ± 8.7	37.4 ± 10.1.
PI	44.1 ± 11.8	44.2 ± 15.6	45.3 ± 9.7	46.4 ± 7.7

Table 3
Apical vertebral rotation classification

	Group A	Group B
Grade 0	26	20
Grade 1	12	7
Grade 2	0	3

Tables 4 and 5 exhibit the distribution of the pedicle screws on the concave and convex sides, respectively. The misplacement rate was 7.9% in group A and 11.8% in group B ($P < 0.05$), and the total misplacement rate on the concave side (11.4%, 23/201) was higher compared with the convex side (8.4%, 16/191). The lateral perforation was found at the concave side, and the medial perforation was found at the convex side. On the concave side, the misplacement rate was 9.7% in group A and 12.3% in group B ($P < 0.05$). The grades 2 and 3 perforations were three (3.5%) in group A and eight (8.2%) in group B ($P < 0.05$). On the convex side, the misplacement rate was 5.9% in group A and 11.1% in group B ($P < 0.05$). The grades 2 and 3 perforations were one (0.9%) in group A and four (4.4%) in group B ($P < 0.05$) (Fig. 5).

No neurological deficit or vascular trauma related to misplaced percutaneous pedicle screws (PPSs) was observed during follow-up in group A and B.

Table 4
Misplacement of the pedicle screws in group A and B

	Apical screws			**Misplacement grading of screws**						
	Total	**Concave side**	**Convex side**	**0**	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**
Group A	214	113 (uniplanar)	101	197	8	5	3	1	0	0
Group B	187	97	90	165	4	6	5	3	3	1
Total	401	210	191	362	12	11	8	4	3	1

Table 5
Misplacement of the pedicle screws on the concave side in group A and B

	concavity		**convexity**	
	Group A	Group B	Group A	Group B
Apical screws	113	97	101	90
Misplaced screws	11	12	6	10
Grade 0	102	85	95	80
Grade 1	8(a)	4(a)	5(b)	6(b)
Grade 2	3(a)	5(a)	1(b)	3(b)
Grade 3	0	3(a)	0(b)	1(b)

Discussion

The malposition of pedicle screws in AIS is mainly attributed to the abnormality of the pedicle. Liljenqvist et al. [16] have reported that the pedicles are smaller at the concave side of the apical vertebrae in thoracic scoliosis in AIS cases. Watanabe et al. [17] have described a classification system, in which pedicles are divided into four types based on intraoperative pedicle screw placement, including large cancellous channel (type A), small cancellous channel (type B), cortical channel (type C), and slit/absent channel (type D). They have found that the type C pedicles are mainly located in the PT curve or the midthoracic spine, both on the concave side. In addition, the majority of type D pedicles are located on the concave side of the PT curve. Sarwahi et al. [18] have modified Watanabe's classification of the pedicle morphology as follows: type A (a cancellous channel of > 4 mm), type B (a cancellous channel of 2 to 4 mm), type C (a cortical channel of > = 2 mm), and type D (a cortical or cancellous channel of < 2 mm). According to Sarwani's opinion, 31.9% of pedicles in the thoracic region are abnormal in AIS patients. The prevalence of abnormal pedicles is 10.0% on the concave side and 2.9% on the convex side. Moreover, the prevalence of abnormal pedicles is 7.2% in the periapical region and 5.8% in the remainder of the curve. Therefore, there is an increased chance of abnormal pedicles on the concave side and in the periapical region. Many scholars have reported the accuracy of the pedicle screws in AIS cases. Kwan et al. [19] have investigated the accuracy and safety of 2,020 pedicle screws placed in 140 AIS patients. After exclusion of lateral thoracic perforations, the overall perforation rate is 8.6% with a critical perforation rate of 2.2% (44/2,020). The rate of symptomatic screw perforation leading to radicular symptoms is 0.1%. In this series, the perforation on the concave side was all lateral perforation. Meanwhile, the medial perforation was only found on the convex side. The overall misplacement rate on the concave side (11%) was also higher than that of the convex side (8.4%).

In order to reduce the misplacement of pedicle screws in AIS, extra-pedicle screws [20], PPSs, cannulate pedicle screws [8], intraoperative navigation, robot-assisted pedicle screws [21] and 3D-printing drill guide template [22] have been developed. Recently, some studies have reported the clinical use of cannulated pedicle screws. Lee [8] has compared the accuracy of cannulated pedicle screws and conventional pedicle screws for extra-pedicular screw placement in dysplastic pedicles without cancellous channel in AIS. Overall, the screw perforation rate for dysplastic pedicle (grade C and D) is 9.9%. The medial and lateral perforation rates in the cannulated pedicle screw group (4.5%) are much better compared with the conventional pedicle screw group (15.6%). The anterior perforation rate is 1.9% and 8.8% in above-mentioned two groups, respectively. Yilar et al. [9] have compared the accuracy of 376 cannulated pedicle screws and 327 conventional pedicle screws in the treatment of AIS. Pedicle screw perforation rate is lower in the cannulated pedicle screw group. There is no statistically significant intergroup difference in medial perforation. Lateral perforation is significantly less common in the cannulated pedicle screw group. Their results indicate that the use of cannulated screws enables intraoperative confirmation of placement accuracy. Consistent with the above-mentioned results, our results showed that the misplacement rate in the group A (7.9%) was much better compared with the group B (11.8%). The grades 2 and 3 perforation rates on the concave and convex sides were both higher in the group B. These results indicated that the lateral perforation on the concave side could be effectively avoided by inserting the pedicle screws through the K-wire. Moreover, although the pedicle screws used on the convex side in the group A were multiaxial screws, taping through K-wire could also effectively avoid medial perforation on the convex side.

Kuklo et al. [7] have compared the deformity correction of monoaxial and multiaxial thoracic pedicle screws in AIS, and reported that although both screw types achieve excellent coronal plane correction, the monoaxial screws exhibit a better vertebral derotation. However, monoaxial screws may make rod-screw engagement more difficult, especially in patients with large/rigid deformities, limiting the ability to manipulate the sagittal contour of the spine [4]. In AIS patients, pedicle fixation for AIS correction may cause a “thoracic flat back”, which contributes to the development of adjacent segment disease [23, 24]. Therefore, the preservation of TK plays a critical role in maintaining cervical [25] and LL curves in AIS surgery. The advent of uniplanar screws allows freedom of motion in the sagittal plane while allowing surgeons to derotate patients in the axial plane during a scoliosis correction. This would potentially allow freedom of motion in the sagittal plane during correction with potentially less flattening of the thoracic spine. Badve et al. [1] have compared the sagittal profile between uniplanar screws and fixed screws. They have found that the coronal correction is comparable between the two groups, and the postoperative sagittal curvature measurements are greater when using the uniplanar screws. Moreover, the TK was also well preserved. As thoracic sagittal profile in most of this series was normal, the postoperative TK had no significant difference with preoperative kyphosis in both group A and B. The postoperative TK also had no significant difference between group A and B. Our results indicated that uniplanar pedicle screws, similar with multiaxial pedicle screws, had comparable performance in preserving the TK.

Vertebral rotation is a component of the 3D deformity of AIS. The correction of vertebral rotation is an important goal of surgery. Dalal et al. [4] have compared the residual postoperative apical vertebral rotation between uniplanar and multiaxial bilateral pedicle screws in thoracic AIS (Lenke 1–3). At 1-year follow-up, there is little difference in the coronal plane correction of thoracic curves between the two types of screws. There are 34% of patients with grade 0 rotation in the uniplanar group, 52% with grade 1, and only 14% with grade 2. In the multiaxial group, only 14% of patients were grade 0, while 35% were grade 1, and 51% were the most rotated grade 2. In addition, more patients had a greater thoracic apical vertebral derotation (less residual apical vertebral rotation) in the uniplanar pedicle screw group compared with the multiaxial screw group. In this series, the cannulated pedicle screws connected to extender at the apical convexity in the group A allowed easier capturing of the rod within the screw heads compared with monoaxial and common multiaxial screws. Moreover, as the derotation technique in this series was based on multi-level direct vertebral derotation, such screws were also beneficial for vertebral derotation by engaging the extra-kyphosis rod to the screws. According to our results, the derotation rate of the cannulated pedicle screw group was significantly higher compared with the multiaxial screw group.

Abbreviations

AIS: adolescent idiopathic scoliosis; CT:computed tomography; PT:proximal thoracic; MT:main thoracic; TL/L:thoracolumbar/lumbar; TK:thoracic kyphosis; LL:lumbar lordosis; PI:pelvic incidence; PPS:percutaneous pedicle screws

Declarations

Ethics approval and consent to participate:

This research was approved by the ethics committee of Qilu Hospital of Shandong University. All participants agreed with the data and publication of the manuscript. All participants provided written informed consent, and written informed consent was obtained from a parent or guardian for participants under 16 years old.

Consent for publication:

All patients provided written informed consent for the study.

Availability of data and materials:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests.

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Not applicable.

Source:

All images used in this parer are our own creation.

Authors' contributions:

YW and XY participated in the design of the study. YW and WB collected data. YW and WB performed the statistical analysis. YW, YH, SM and XY conceived of the study, participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

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Figures

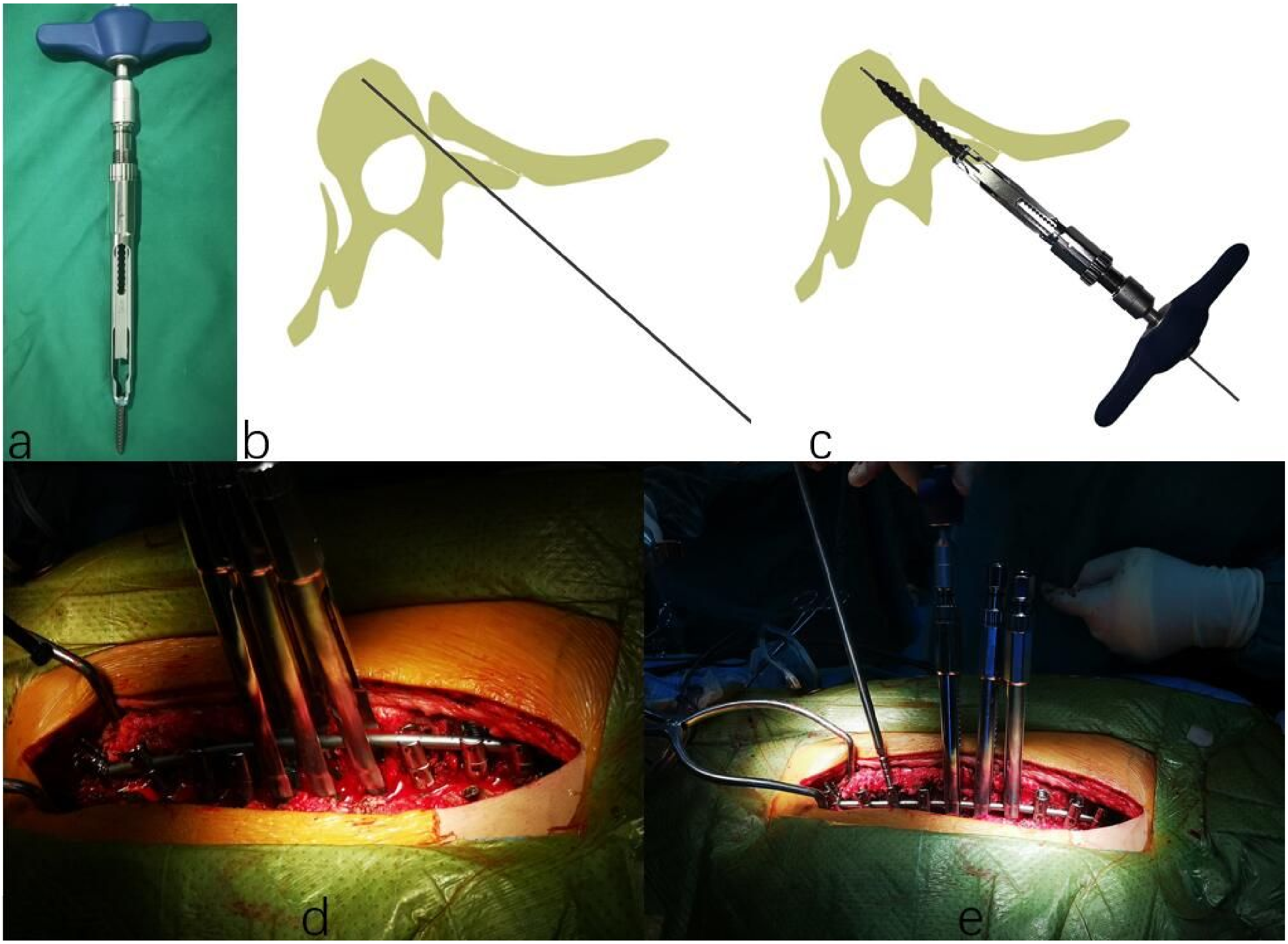

Figure 1

The insertion procedure of uniplanar cannulated pedicle screws. a. The uniplanar cannulated pedicle screws used in this series. b. The trajectory of the pedicle screw was made with freehand technique, a K-wire was inserted into pedicles, and then the trajectory was tapped. c. Uniplanar cannulated screws connected with extender were advanced over the K-wire. d. The contoured rod at the concave side with extra kyphosis was inserted proximally and distally, and the set screws were tightened proximally and distally, leaving the rod in the correct sagittal plane. e. Multi-level direct vertebral body derotation was carried out to pull the apical vertebrae dorsally out of the chest by pushing down the rod to the pedicle screws at the apical levels.

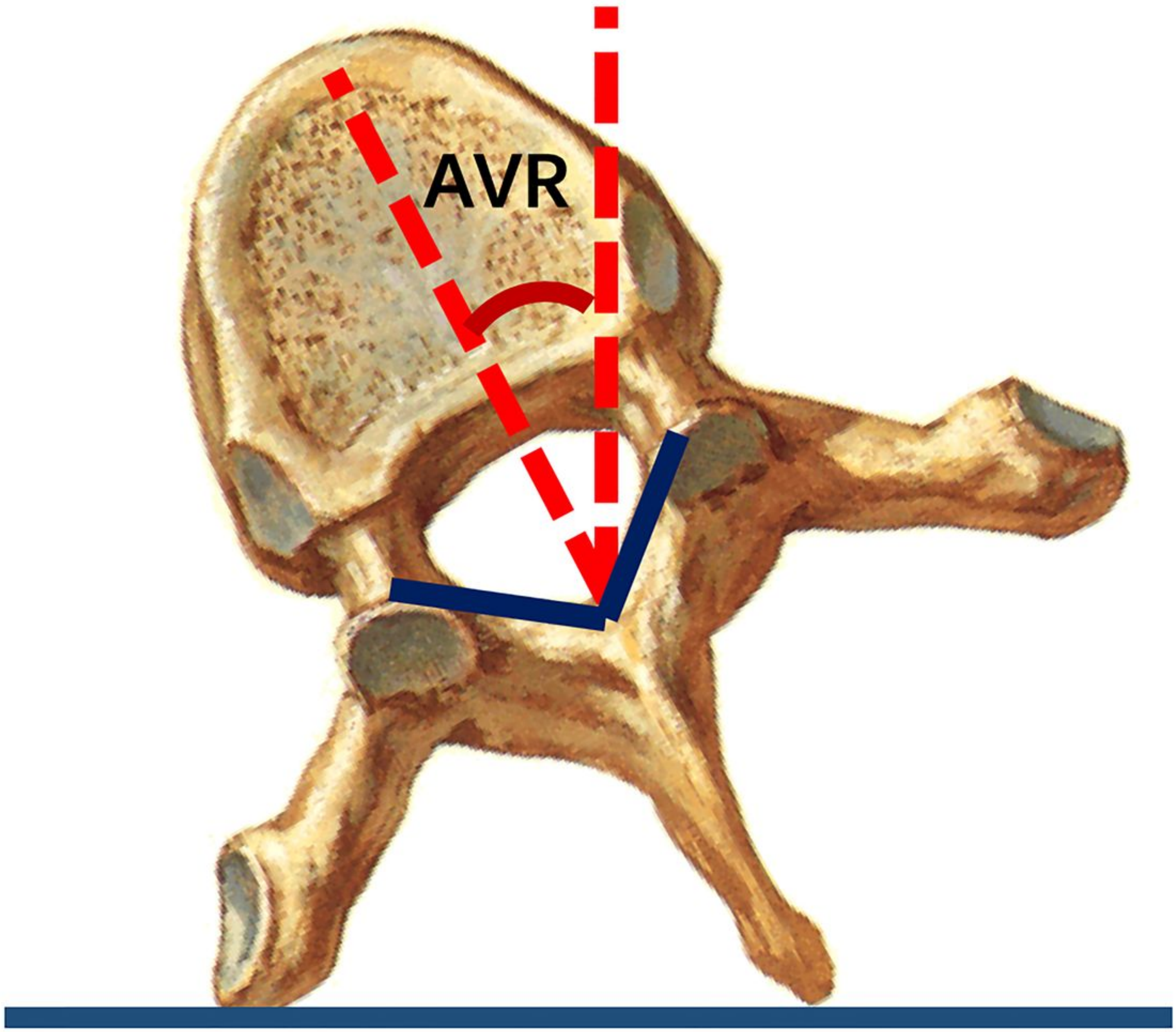

Figure 2

The CT measurement of apical axial rotation.

Figure 3

The screw misplacement grading of the pedicle screws.

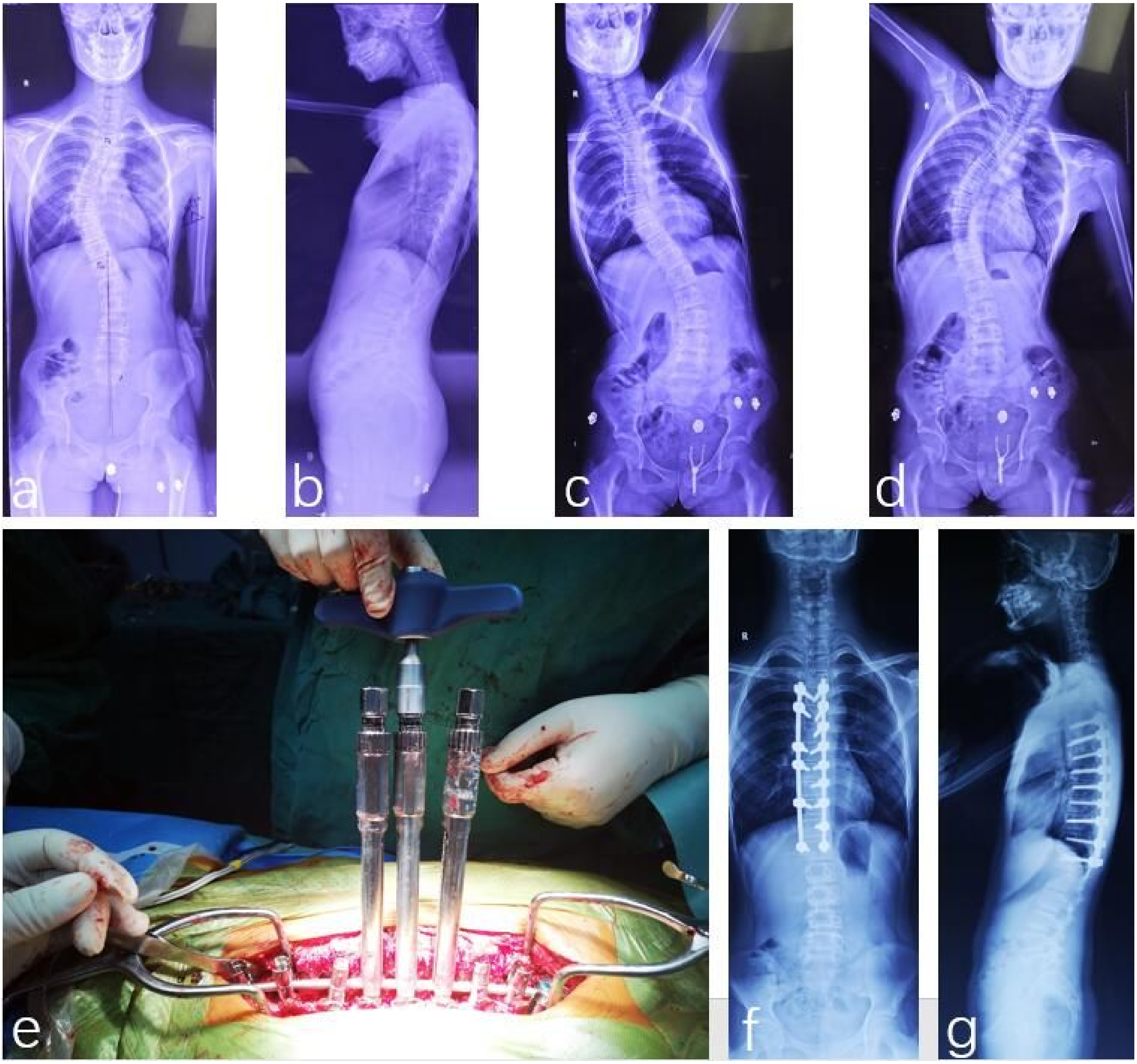

Figure 4

Female, 13 years old, Lenke type 1 AIS. a-d. The preoperative X-rays (MT curve 450). e. The operative image. f-g. The 2-year follow-up X-rays with grade 0 apical vertebral rotation.

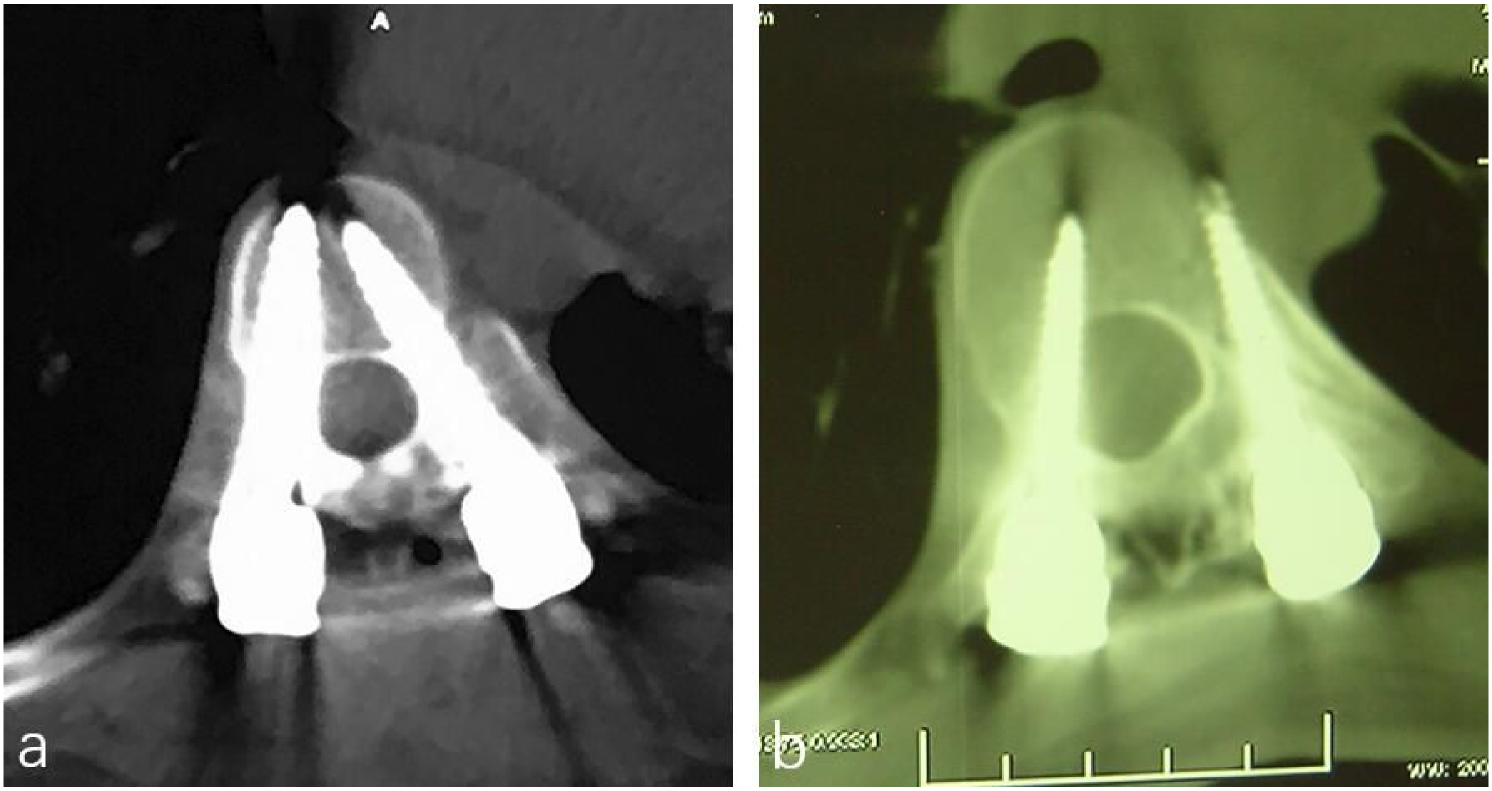

Figure 5

The misplacement of the pedicle screws. a. Accurate pedicle screw insertion in group A. b. The grade 3a multiaxial pedicle screw at the concave side and 3b screw at the convex side in group B without neurological deficit or vascular trauma.