How is the trachea at risk of injury from pedicle screw insertion in proximal thoracic curve of adolescent idiopathic scoliosis patients?

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Abstract

Purpose The rotation or translation of vertebrae in adolescent idiopathic scoliosis (AIS) patients could cause the relative migrations of surrounding vital structures and lead to smaller safe zones for pedicle screw insertion. This study aimed to determine the changed relative position of trachea to spine in the proximal thoracic curve (T1–T4) and to analyze the potential risks of tracheal injuries from pedicle screw insertions in AIS patients.

Methods Twenty-three patients with complete proximal thoracic curve (CPT group), 25 patients with fractional proximal thoracic curve (FPT group) and 19 normal subjects with a straight spine (normal group) were included. Axial computed tomography images from T1 to T4 level were obtained to evaluate trachea–vertebral distance (TVD, the closest distance between trachea and vertebral body) and trachea–vertebral angle (TVA, defined as 0° when the trachea was located directly laterally to the left and 180° when directly laterally to the right). The extension line of pedicle axis could cross the anterior wall of vertebra and the posterior wall of the trachea at two points when the trachea was located in the trajectory of the screw passage. If the distance between the two points was less than 5 mm, the trachea was considered to be at a potential risk of injury. The percentages of vulnerable trachea were calculated at each level.

Results The TVA in the CPT group was significantly larger than that in the FPT group and in the normal group, while the TVA in the FPT group was significantly larger than that in the normal group at the T2–T4 level. The TVD in the FPT group was significantly smaller than that in the CPT group and in the normal group at each level, while the TVD in the CPT group was significantly smaller than that in the normal group at the T2 and T3 levels. No trachea was found to be at risk from screw insertion on both sides in both the CPT group and the normal group. However, it was at a high risk of injury from anterior cortex penetration during right screw insertion in the FPT group. The percentage of trachea at risk from right screw insertion was 40 % at T1 level, 92 % at T2 level, 100 % at both T3 and T4 levels.

Conclusions This CT-based study demonstrates that the FPT curve has a smaller safe zone with respect to tracheal injury during screw insertion. Spine surgeons should choose the appropriate screw length to avoid anterior wall perforation.

Keywords Scoliosis · Pedicle screw · Computed tomography · Trachea

Introduction

The use of thoracic pedicle screw (TPS) is becoming increasingly popular in the surgical treatments of patients with adolescent idiopathic scoliosis (AIS) [2, 11, 13, 18]. Although numerous advantages of the TPS have been reported, there have been some concerns about the potential neurological, vascular and visceral complications resulted from screw misplacements [5, 14, 16]. Several vital structures had been shown to be at a high risk of injury

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Fig. 1 Postoperative CT scan of a 15-year-old female thoracic AIS patient with PT curve instrumented at T4 level. The trachea was located in close proximity to anterior wall of the third thoracic vertebra and at a potential risk of injury from anterior cortical penetrated pedicle screw

during TPS insertion due to their close proximity to vertebrae [3]. Such risks of injuries may be further increased in AIS patients since the safe zones for the adjacent structures diminished due to the translation or rotation of the vertebrae [17]. For example, as the scoliotic vertebrae translated to the convex side, the convex pleura was found to be located much more closer to the anterior wall of the vertebra than the concave pleura, indicating an increased risk of pleural injury from anterior cortical perforation on the convex side [17]. Therefore, knowledge of the altered anatomic relationships between the scoliotic vertebrae and adjacent structures is crucial for spine surgeons to minimize these risks.

The trachea is one of the most vital organs in the proximal thoracic (PT) region. Kuklo [9] reported that no trachea was found to be closer than 5 mm (average 8.2 mm) from the anterior cortex of the PT vertebrae in normal teenagers, indicating that the trachea was safe from posterior TPS insertion. However, on the preoperative CT images of some thoracic AIS patients, we noticed that the trachea was located in close proximity to anterior wall of vertebrae in the PT region. This changed position could place the trachea at a potential high risk of injury from anterior cortical penetration during posterior TPS insertion (Fig. 1). Hence, we believe the changed position of the trachea needs to be further evaluated in AIS patients. However, there is paucity in the current literature concerning on the relative migration of trachea in AIS patients.

There are two different types of PT curves according to the anatomic characteristics, namely complete PT curve and fractional PT curve [7, 10]. Theoretically, different anatomic types of PT curves could cause different relative migrations of adjacent organs. In one of our recent studies,

we also found that different anatomic patterns of PT curves could cause different altered positions of esophagus relative to spine and result in different potential risks of esophageal injuries during TPS insertion [7]. The purpose of this study is to determine the changed relative position of trachea to spine in two different types of PT curves of AIS patients and to analyze the potential risks of tracheal injuries from TPS insertion using preoperative CT images.

Methods

Patients

With institutional review board approval, a retrospective review of patients who had CT images of the thoracic spine from 2008 to 2009 was performed. This study consisted of 23 AIS patients with complete PT thoracic curve (CPT group), 25 AIS patients with fractional PT curve (FPT group) and 19 patients with a straight spine (normal group) (Fig. 2a). A complete PT curve was defined as left elevated upper corner of T1 vertebrae (positive T1 tilt) with apical vertebra located on the convex (left) side of C7 plumb line (Fig. 2c) and a fractional PT curve was defined as neutral or mild negative T1 tilt without true apical vertebra (Fig. 2e) [7]. In AIS patients the CT scan was made as part of their planned surgery while in normal subjects the CT scan was requested because of the suspicion of infection, hemorrhage or tumor of the lung. Anteroposterior and lateral radiographs were also obtained from all the subjects. The measured coronal radiographic parameters included PT Cobb angle and MT Cobb angle while the assessed sagittal radiographic parameters included T2–T5 thoracic kyphotic (TK) angle and T5–T12 TK angle [12].

CT Measurements

The CT image was performed using a 16-multidetector-spiral CT (MDCT) scanner (LightSpeed, GE Healthcare) with the following parameters: 320 mAs, 120 kVp, 3 mm slice thickness, with a 3 mm gap between slices. The axial CT images from T1 to T4 at midvertebral body level were analyzed with respect to the following parameters (Fig. 3): (1) trachea–vertebral angle (TVA, subtended by a line connecting the centers of vertebral body and trachea and the transverse axis perpendicular to the longitudinal axis of vertebra through the center of vertebral body). TVA was defined as 0° when the trachea was located directly laterally to the left and 180° when directly laterally to the right; (2) trachea–vertebral distance (TVD, the closest distance between trachea and vertebral body); (3) vertebral rotation angle (VRA), this angle was measured by Rasag's method [8]. At T5 level, most of the patients had the trachea

bifurcated into left and right bronchia which deviated into left and right cavity, respectively, as shown in the CT images. So the changed position of the trachea in the PT curve was not measured below this level in our study. All the parameters were measured using PacsClient software (PACS) on workstation with the use of angular and linear measurement software.

Potential risks of tracheal injuries from TPS insertion

In the axial CT image, the axis of the pedicle was drawn on both sides. The extension line of the pedicle axis could cross the anterior wall of vertebra and the posterior wall of the trachea at two points when the trachea was located in the trajectory of the screw passage (Fig. 4). If the distance

Fig. 2 The different anatomic positions of trachea in PT regions between three groups at T3 level. In a straight spine (a), the trachea is positioned anteriorly to the mid-axis of the vertebrae. Although the trachea is located in the direction of pedicle screw passage, it is not vulnerable to anterior cortical penetrated screw because the trachea does not come close to the anterior cortex of the vertebra (b). In a complete PT curve (c), the trachea moves anterolaterally to the right side and deviates from the direction of pedicle screw passage (d). In a fractional PT curve (e), the trachea is in close proximity to the anterior cortex of the vertebra and located in the direction of right screw passage, indicating a potential risk of tracheal injury from excessive anterior pedicle screw penetration on the right side (f)

Fig. 3 The parameters measured on the CT images. *a* Trachea-vertebral angle (TVA) subtended by a line connecting the center of vertebral body and trachea and the transverse axis perpendicular to the longitudinal axis of vertebra through the center of vertebral body. *β* Vertebral rotation angle subtended by the longitudinal axis of vertebrae and the mid-perpendicular. *d* The closest distance between trachea and vertebral body

Table 1 Trachea-vertebral angle (TVA)

	Normal group (<i>n</i> = 19)	CPT group (<i>n</i> = 23)	FPT group (<i>n</i> = 25)	<i>P</i> value
T1 (°)	96.4 ± 5.5	100.4 ± 6.3	98.8 ± 6.7	0.125
T2 (°)	97.8 ± 5.7	113.9 ± 6.9	106.7 ± 7.7	<0.001*
T3 (°)	101.8 ± 6.7	124.6 ± 7.5	112.5 ± 10.1	<0.001*
T4 (°)	102.8 ± 6.1	129.1 ± 9.9	111.6 ± 10.2	<0.001*

CPT complete proximal thoracic curve, FPT fractional proximal thoracic curve

* The difference is statistically significant

between the two points was less than 5 mm, the trachea was considered to be at a high potential risk of injury from screw insertion [20]. The percentages of trachea at high risks of injuries on both sides were calculated in all patients.

Statistical analysis

Statistical analysis was performed by SPSS software for Windows (13.0, Chicago, IL, USA). The measurements were made by two of us and the data at each level for each parameter were averaged. The comparisons between the three groups were made with the use of one way of ANOVA followed by Bonferroni post hoc analysis for individual comparisons between these groups. The percentages of trachea at potential risks of injuries were calculated on both sides in these three groups to analyze the

Table 2 Trachea-vertebral distance (TVD)

	Normal group (<i>n</i> = 19)	CPT group (<i>n</i> = 23)	FPT group (<i>n</i> = 25)	<i>P</i> value
T1 (mm)	6.9 ± 1.8	6.0 ± 1.7	4.9 ± 1.2	<0.001*
T2 (mm)	7.5 ± 1.7	5.0 ± 1.9	2.8 ± 1.1	<0.001*
T3 (mm)	8.7 ± 2.3	6.2 ± 2.2	2.0 ± 0.9	<0.001*
T4 (mm)	8.8 ± 2.2	7.5 ± 2.5	1.5 ± 0.9	<0.001*

CPT complete proximal thoracic curve, FPT fractional proximal thoracic curve

* The difference is statistically significant

risks of tracheal injuries from TPS insertions in the PT region. Significance was established at the $P < 0.05$ level.

Results

Patient characteristics

The average age was 15.7 in the CPT group, 15.1 in the FPT group, and 15.9 in the normal group. The CPT group consisted of 20 females (87 %) and 3 males (13 %); the FPT group consisted of 23 females (92 %) and 2 males (8 %), and the normal group consisted of 17 females (89 %) and 2 males (11 %). No significant difference was found between the three groups with respect to the mean age or the gender distribution ($P > 0.05$).

The average PT Cobb angle was 40.3° (range 33°–60°) in the CPT group and 26.1° (range 15°–45°) in the FPT group. The average MT Cobb angle was 50.4° (range 40°–60°) in the CPT group and 49.1° (range 40°–75°) in the FPT group. The PT Cobb angle was significantly larger in the CPT group when compared with the FPT group ($P < 0.05$); however, the MT Cobb angles were comparable in these two AIS groups ($P > 0.05$).

The mean T2–T5 TK angle was 15.1° (range 10°–26°) in the CPT group, 7.3° (range –2° to 13°) in the FPT group, and 15.2° (range 11°–18°) in the normal group. The mean T5–T12 TK angle was 18.0° (range 5°–35°) in the CPT group, 11.1° (range –5° to 25°) in the FPT group, and 20.6° (range 15°–25°) in the normal group. Both T2–T5 TK angle and T5–T12 TK angle were significantly smaller in the FPT group when compared with the CPT group and the normal group ($P < 0.05$) but were not significantly different between the two latter groups ($P > 0.05$).

TVA and TVD

The TVAs and TVDs of all the patients at each level were illustrated in Tables 1, 2 respectively. The TVA in the CPT group was significantly larger than that in the FPT group and that in the normal group ($P < 0.05$), while the TVA in the

FPT group was significantly larger than that in the normal group at the T2–T4 level ($P < 0.05$). The TVD in the FPT group was significantly smaller than that in the CPT group and that in the normal group at each level ($P < 0.05$), while the TVD in the CPT group was significantly smaller than that in the normal group at the T2 and T3 levels ($P < 0.05$).

At T1 level, the trachea was located in an approximate middle position relative to vertebra and was away from the anterior cortex of vertebral body in both normal group and CPT group because the esophagus just laid posteriorly to the trachea and anteriorly to the vertebrae (average TVA was 96.4° in normal group and 100.4° in CPT group; average TVD was 6.9 mm in normal group and 6.0 mm in CPT group). In the FPT group, the trachea was also located in a middle position (average TVA was 98.8°) but closer to the vertebral body when compared with the normal group and the CPT group (average TVD was 4.9 mm). As it traversed caudally to the T4 level, the anatomic positions of the trachea were dramatically different between these three groups. In the normal group, the trachea still remained in the approximate middle position (average TVA was 97.8° at T2, 101.8° at T3 and 102.8° at T4) with the esophagus located between the trachea and the vertebrae (average TVD was 7.5 mm at T2, 8.7 mm at T3 and 8.8 mm at T4). In the CPT group, the trachea remarkably moved anterolaterally to the right with respect to the vertebra (average TVA was 113.9° at T2, 124.6° at T3 and 129.1° at T4) but still did not come close to the vertebral body (average TVD was 5.0 mm at T2, 6.2 mm at T3 and 7.5 mm at T4) because the esophagus was also located between the trachea and vertebra. In the FPT group, the trachea moved less anterolaterally to the right than it did in the CPT group (average TVA was 106.7° at T2, 112.5° at T3 and 111.6° at T4) but was positioned extremely close to the anterior wall of the vertebral body (average TVD was 2.8 mm at T2, 2.0 mm at T3 and 1.5 mm at T4).

Potential risks of tracheal injuries from TPS insertion

No trachea was at a potential risk of injury from TPS insertion on both sides in both normal group and CPT group (Fig. 2b, d). In the FPT group, no trachea was found to be at a risk of injury from TPS insertion on the left side. However, it was at a potential risk of injury from TPS insertion on the right side (Fig. 2f). The percentage of trachea at a risk of injury from right TPS insertion was 40 % at the T1 level, 92 % at the T2 level, and 100 % at both the T3 and T4 levels (Table 3).

Discussion

According to Kuklo's study [9], the trachea laid anteriorly to the esophagus and did not come closer than 5 mm from

Fig. 4 The extension line of the chord length could cross the anterior wall of vertebra and trachea at two points (points *a* and *b*) if the trachea was located in the trajectory of the screw passage. If the distance between point *a* and *b* was less than 5 mm, the trachea was considered to be at a potential risk of injury from TPS insertion

the vertebrae of PT region in normal teenagers (the average distance between the trachea and vertebrae is 8.2 mm, range 5–13 mm). Hence, the trachea seemed to be relatively safe from TPS insertion in the PT region. However, we noticed that the trachea was located in close proximity to the anterior wall of the vertebral body in some AIS patients, which was dramatically different from that in normal populations. We insisted that this changed relative positions of trachea in AIS patients needed further investigation since the trachea shifted from a “safe zone” to a “dangerous zone”, which placed the trachea at a potential risk of injury from anterior cortical penetration during TPS insertion. To our best knowledge, our study firstly evaluates the relative migrations of the trachea in PT curves of AIS patients.

Undoubtedly, different curve patterns could lead to different relative positions of the adjacent structures to the spine in AIS patients. In a recent study, we found that the esophagus shifted anterolaterally to the right relative to spine in the patients with CPT curves but shifted anterolaterally to the left in the patients with FPT curves [7]. Reasonably, we believe that the relative migrations of the trachea may be different between patients with different PT curve patterns.

In normal subjects, the trachea is located anteriorly to the mid-axis of the vertebrae in the PT region. We found that our result was in accordance with that of Kuklo's study [9], which demonstrated that the trachea was in the 12 o'clock position in the upper thoracic spine using a clock analogy. However, it moves anterolaterally to the right side in patients with CPT curves. We presume that this migration to the right is a reflection of coronal

Table 3 The percentages of vulnerable trachea during posterior screw insertion

	Normal group	CPT group	FPT group
T1 (%)			
Left side	0	0	0
Right side	0	0	40
T2 (%)			
Left side	0	0	0
Right side	0	0	92
T3 (%)			
Left side	0	0	0
Right side	0	0	100
T4 (%)			
Left side	0	0	0
Right side	0	0	100

CPT complete proximal thoracic curve, *FPT* fractional proximal thoracic curve

vertebral translation and transversal vertebral rotation of the scoliotic spine. As the vertebra in CPT curve translates and rotates to the convex side (left side), the trachea oppositely shifts to the right side, moving from a middle position to a right anterolateral position in relation to the vertebra. Although the positions of trachea are significantly different between normal group and CPT group, no trachea is found to be in close proximity to the vertebrae in these two groups. As shown in CT images, the esophagus lies just between the posterior wall of the trachea and anterior wall of the vertebra in both normal group and CPT group (the esophagus also moves anterolaterally to the right side in CPT curves), which makes the trachea far away from the vertebra and not vulnerable to anterior cortical penetrated screws. Besides that, in CPT group the dramatic anterolateral position makes the trachea deviate from the virtual passage of pedicle screw, which also contributes to the “safe” position of trachea. Noticeably, in a recent study evaluating anatomic locations of structures at risks with TPS insertion in the PT spine of normal subjects, Cardoso [1] reported that right-sided screws posed great risks to the trachea, which was not in accordance with our results. In fact, in Cardoso’s study, the mean distance from the tip of the right pedicle screws to the trachea was 8.6 mm at T2 level, 8.1 mm at T2 level and 7.7 mm at T4 level in normal subjects. More importantly, no specific criterion of the trachea at risk from TPS insertion was established in Cardoso’s study. We believe that it seems more reasonable to define the trachea located within 5 mm from screw tip as vulnerable trachea.

In patients with FPT curves, the trachea also moves anterolaterally to the right side but less than it does in patients with CPT curves. It is reflected by the result that

the average TVA in the FPT group is significantly larger than that in the normal group but significantly smaller than that in the CPT group. In fact, the curve pattern of the patients in the FPT group is a single right MT curve and the FPT curve is a not “true” curve because it has no true apex. In these patients, the PT spine is nearly straight in coronal plane except its distal part (T4 and below) deviates a little to the convex side of the MT curve. However, we notice that the vertebrae in PT spine mildly rotate to the left side (average VRA is 8.0° at T1, 8.7° at T2, 9.6° at T3, and 9.0° at T4). We believe that the left compensatory rotation of vertebra in PT spine is caused by the right structural rotation of the vertebra in MT spine. As the vertebra rotates to the left side, the trachea relatively migrates to the right side, which may interpret right anterolateral position of the trachea in the FPT group. However, the most pronounced change is the dramatically decreased distance between the trachea and the vertebra. The TVD was significantly smaller in the FPT group when compared with the normal group or the CPT group. The average TVD in the FPT group was only 2.8 mm (range 1.2–4.6 mm) at the T2 level, 2.0 mm (range 0.9–4.3 mm) at the T3 level, and 1.5 mm (range 0.8–3.1 mm) at the T4 level. We presume that the smaller TVD is caused by the decreased TK angle of the FPT curve. Previous morphological studies had reported the phenomenon of thoracic hypokyphosis in patients with main thoracic curve [4, 19], which was also confirmed by our study. Both T2–T5 TK and T5–T12 TK angles were significantly smaller in the FPT group when compared with the CPT group or normal group. The decreased T2–T5 TK angle could cause the forward shifts of PT vertebrae, which leads to the relative backward migration of the trachea. With the right anterolateral migration and decreased trachea–vertebra distance, the trachea may be at a potential risk of injury from excessive anterior pedicle screw penetration on the right side. This presumption is confirmed by our results of risk analysis in FPT group. The percentage of trachea at risk of injury from right TPS insertion was 40 % at T1 level, 92 % at T2 level, and 100 % at both T3 and T4 levels.

In conclusion, the current study reveals different changed positions of the trachea relative to vertebrae in two different anatomic patterns of PT curves. In patients with complete PT curves, although the trachea shifts from an anterior position to a right anterolateral position, it is still safe from TPS insertion because of the large distance between trachea and anterior cortex of vertebral body as well as the deviation from the screw passage. In the patients with fractional PT curves, the trachea is in a vulnerable position during TPS insertion on the right side due to the dramatic decreased distance between trachea and vertebral body. Although the fractional PT curve is often flexible, it still needs to be fully or partial fused when the

patient has a level or left elevated shoulder [6, 15]. For such patients, spine surgeons should be well aware of the changed position of trachea and choose appropriate screw length to avoid anterior wall perforation.

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Conflict of interest None.

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