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Cortical bone trajectory screws placement via pedicle or pedicle rib unit in the pediatric thoracic spine (T9-T12)

A 2-dimensional multiplanar reconstruction study using computed tomography

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Abstract

Thoracic cortical bone trajectory (CBT) screw fixation can maximize the thread contact with cortical bone, and it is 53.8% higher than that of the traditional pedicle screws. Moreover, it can also enable less tissue dissection and retraction for reduced muscle disruption.

Eighty pediatric patients are divided into 4 age groups and their thoracic vertebrae are analyzed on computed tomography (CT) images. The maximal screw length, maximal screw diameter, screw diameter, and the cephalad angle are measured. The statistical analysis is performed using the Student's *t*-test and Pearson's correlation analysis.

Maximal screw length increases from T9 to T12 and there are significant differences between girls and boys at T9, T10, T11, and T12 in majority of groups ($P < 0.05$). The maximal screw diameter and screw diameter increase from T9 to T12. The maximal screw diameter ranges from 6.27 mm to 10.20 mm, whereas the screw diameter ranges from 3.87 mm to 6.75 mm. Meanwhile, the maximum cephalad angle is 23.06° and the minimum is 13.11°. No statistically significant differences in the cephalad angle are found at all levels.

Our study establishes the feasibility of 4.5 to 5.5 mm CBT screws fixation via pedicle or pedicle rib unit in the pediatric thoracic spine. The entry point of the pediatric thoracic CBT screws is 6 o'clock orientation of the pedicle. Findings of our study also provide insights into the screw insertion angle and screw size decision.

Abbreviations: CA = cephalad angle, CBT = cortical bone trajectory, MSD = maximal screw diameter, MSL = maximal screw length, SD = screw diameter.

Keywords: cortical bone trajectory, pediatric thoracic spine, pedicle rib unit, rescue failed screws, rigid fixation strength

1. Introduction

Pedicle screw instrumentation of thoracic spinal segments has been described for various surgical indications, including deformity (scoliosis and kyphosis), fracture, and tumor.[1–4] However, complications such as screw loosening, pullout of screws, and broken screws often lead to the loss of surgical construct stability, especially patients with poor bone quality. Thus, Santoni et al[5] introduced a novel cortical bone trajectory (CBT) for lumbar pedicle screws fixation and demonstrated that it had equivalent pullout and toggle characteristics as compared with the traditional pedicle screw. Sansur et al[6] found that lumbar CBT screws may offer a viable alternative method to traditional pedicle screw fixation, particularly for stabilization of lower lumbar segments with definitive osteoporosis.

Matsukawa et al[7] investigated CBT screw fixation in the thoracic spine (T9-T12), which was angulating cranially toward the posterior one-third of the superior endplate in the sagittal plane and without convergence in the transverse plane (Fig. 1A and B). They also demonstrated that the insertional torque of the CBT technique was 53.8% higher than that of the conventional technique. Similarly to the lumbar CBT screws, this thoracic CBT technique can also insert screws via a minimally invasive approach with less tissue disruption. At last, the trajectory of thoracic CBT screws is parallel to the mid-sagittal line, decreasing the risk of neurovascular injury.

To the best of our knowledge, the feasibility of thoracic CBT screws placement in the pediatric thoracic spine has not been studied. In the present study, we conduct morphometric measurements of thoracic pediatric spine (T9-T12) using computed tomography (CT).

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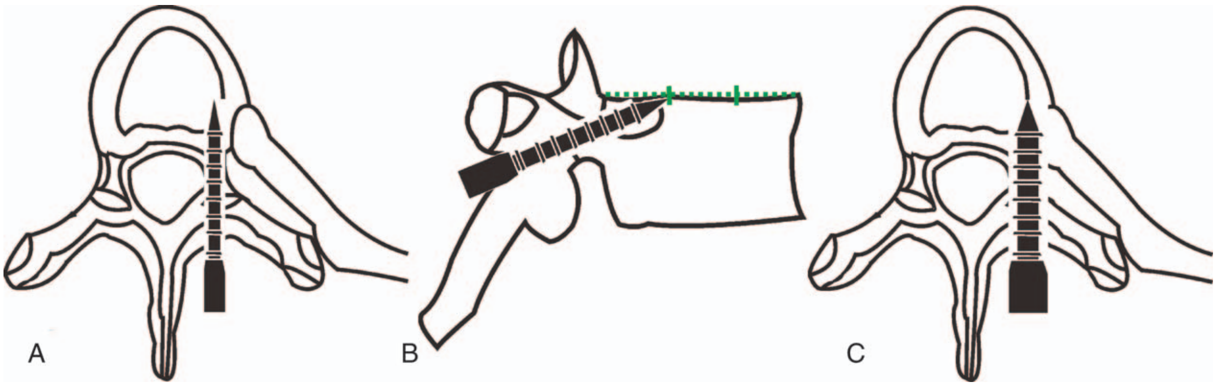

Figure 1. Schematic illustrations showing that thoracic CBT screw fixation. (A) CBT screw fixation via pedicle. (B) The trajectory of the CBT technique is angulating toward the posterior one-third of the superior endplate in the sagittal plane. (C) CBT screw fixation via pedicle rib unit. CBT = cortical bone trajectory.

2. Methods

2.1. Clinical materials

The study was approved by the institutional review board of the hospital (the date is May 2, 2015, the number of ethical approval is 2015-12). We retrospectively reviewed the thoracic spine CT scans of Chinese pediatric patients who came to the Second Affiliated Hospital of Wenzhou Medical University for lung disease from January 2011 to March 2014. The CT images (the thickness: 5 mm) were initially achieved by Philips Brilliance 256 iCT scan machine (Philips Medical Systems, Eindhoven, the Netherlands). Then, reformatted CT images (the thickness $\leq$1 mm) were obtained from those images. Scan parameters included: 120 kV, 180 MA, 512 $\times$ 512 matrix, collimation of 128 $\times$ 0.625 mm, pitch of 0.6 mm, DoseRight of Z-DOM, and 250 mAs/Slice. CT scans of thoracic vertebrae were randomly selected for this study and 80 children were classified into 4 groups: group 1 (5–7 years of age; 20 patients); group 2 (8–10 years; 20 patients); group 3 (11–13 years; 20 patients); group 4 (14–16 years; 20 patients). Each group contained 10 boys and 10 girls. The patients who had thoracic spinal abnormalities such as congenital deformities, trauma, tumor, or infection were excluded.

2.2. Measurement methods

To ensure consistency of the data, all parameters were measured by the same investigator who was familiar with the anatomy of the thoracic spine. The investigator measured every parameter 3 times in the pediatric patient, and the mean was achieved for calculation of the ultimate value. First, we shifted the horizontal and sagittal axes to the inferior border and middle portion of the thoracic pedicle, respectively. Then, we found a point approximately located at 6 o'clock orientation of the thoracic pedicle and it was the screw insertion point (Fig. 2). Third, we adjusted the horizontal axis to shift it toward the posterior one-third of the superior endplate to get an axial plane. Eventually, we measured 4 parameters (Figs. 2, 3): (1) maximal screw length, (2) screw diameter, (3) maximal screw diameter, and (4) cephalad angle.

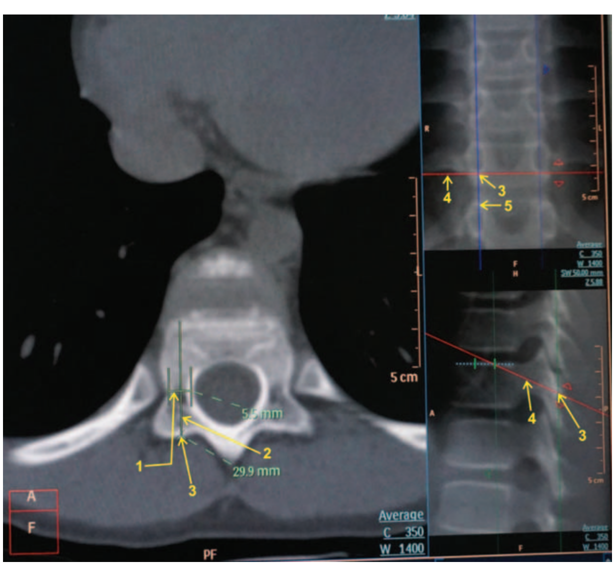

Figure 2. CT scan showing that the diameter and the length of thoracic CBT screws: (1) the screw diameter; (2) maximal screw length; (3) screw insertion point; (4) the red line was horizontal axis, which can be used to calibrate the axial plane; (5) the blue line represents the sagittal axis, which can adjust the sagittal plane. CBT = cortical bone trajectory, CT = computed tomography.

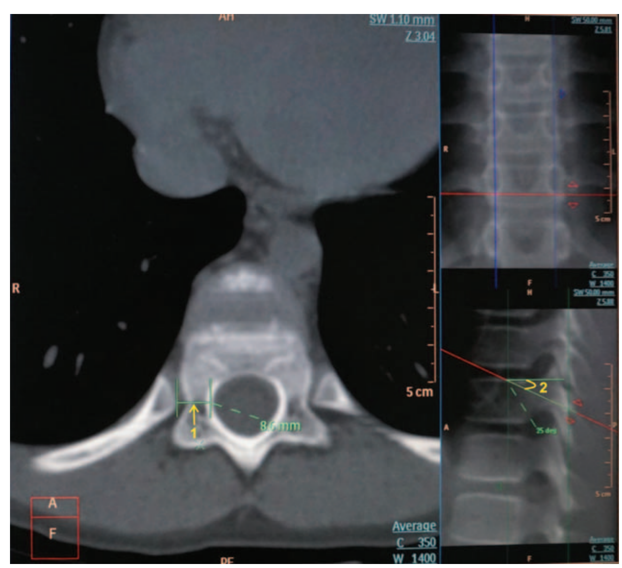

Figure 3. CT scan showing that the screw insertion angle and the maximal screw length: (1) maximal screw diameter, distance from medial wall of pedicle isthmus to the medial wall of the rib head; (2) cephalad angle. CT = computed tomography.

Table 1

Maximal screw length (mean ± SD, mm).

Level (M/F)		Group 1	Group 2	Group 3	Group 4
T9	M	25.03 ± 0.32*	26.34 ± 1.44	28.70 ± 0.58*	29.97 ± 1.01*
	F	24.54 ± 0.43	25.83 ± 0.91	27.45 ± 0.70	28.79 ± 0.51
	All	24.79 ± 0.45	26.09 ± 1.20	28.08 ± 0.90	29.38 ± 0.98
T10	M	25.88 ± 0.50*	27.72 ± 0.52*	29.48 ± 0.49*	31.16 ± 1.11*
	F	25.17 ± 0.49	26.66 ± 0.77	28.37 ± 0.73	29.70 ± 0.75
	All	25.53 ± 0.60	27.19 ± 0.84	28.93 ± 0.83	30.43 ± 1.19
T11	M	26.68 ± 0.67	28.75 ± 0.47*	30.79 ± 0.65	32.85 ± 0.99*
	F	26.12 ± 0.54	27.89 ± 0.77	29.50 ± 0.76	31.34 ± 0.83
	All	26.40 ± 0.66	28.32 ± 0.76	30.15 ± 0.96	32.10 ± 1.18
T12	M	27.65 ± 0.81†	29.84 ± 0.58*	31.78 ± 0.55*	34.49 ± 0.94*
	F	26.99 ± 0.55	28.91 ± 0.63	30.81 ± 0.74	32.69 ± 0.52
	All	27.32 ± 0.75	29.38 ± 0.76	31.30 ± 0.81	33.59 ± 1.18

SD = standard deviation.
Comparison between a male and a female:
* Statistically significant difference ($P < 0.01$).
† Statistically significant difference ($P < 0.05$).
Group 1 indicates 5–7 years of age, group 2 indicates 8–10 years of age, group 3 indicates 11–13 years of age, and group 4 indicates 14–16 years of age.

2.3. Statistical analysis

Statistical analysis was performed using SPSS statistical software program 22.0 (SPSS Inc.). Student's *t* test was used for the test of differences between the male and the female, and the correlation between the age and parameters was analyzed using Pearson's correlation coefficient. For all statistical tests, a *P* value of less than 0.05 was selected to represent statistical significance.

3. Results

3.1. Maximal screw length (MSL)

The mean values and standard deviations for MSL were presented in Table 1. MSL increased from T9 to T12, and there were no significant differences between girls and boys at T11 in group 1, T9 in group 2, and T11 in group 3 ($P > 0.05$). However, the difference reached a significant level in other thoracic vertebrae ($P < 0.05$). Age appeared to be associated with MSL (*r* range: 0.906–0.948; $P < 0.01$).

3.2. Screw diameter (SD)

The mean values and standard deviations for SD were presented in Table 2, and it increased from T9 to T12 in all groups. The difference did not reach a significant level at T9 and T11 in group 1 and T9 in group 2 ($P > 0.05$), whereas there were differences between girls and boys at other levels ($P < 0.05$). Age appeared to demonstrate an associative effect with SD (*r* range: 0.738–0.861; $P < 0.01$).

3.3. Maximal screw diameter (MSD)

The mean values and standard deviations for MSD are presented in Table 3 and it also increased from T9 to T12 in all groups. There were no significant differences between girls and boys at T10–T12 in group 3 ($P > 0.05$); however, the difference reached significant level in other groups at all levels ($P < 0.05$). There was a positive correlation between MSD and age (*r* range: 0.776–0.864; $P < 0.01$).

3.4. Cephalad angle (CA)

The mean values and standard deviations for CA were presented in Table 4 and it increased from T9 to T12 for boys and girls in all groups. There were no significant differences between girls and boys at all levels in all groups ($P > 0.05$). Age appeared to be associated with CA (*r* range: 0.578–0.693; $P < 0.01$).

Table 2

Screw diameter (mean ± SD, mm).

Level (M/F)		Group 1	Group 2	Group 3	Group 4
T9	M	3.94 ± 0.20	4.22 ± 0.19	4.96 ± 0.26*	5.22 ± 0.50*
	F	3.80 ± 0.18	4.11 ± 0.18	4.39 ± 0.28	4.51 ± 0.35
	All	3.87 ± 0.20	4.17 ± 0.19	4.68 ± 0.39	4.87 ± 0.56
T10	M	4.24 ± 0.22†	4.61 ± 0.17*	5.41 ± 0.37*	5.95 ± 0.58*
	F	4.05 ± 0.15	4.33 ± 0.24	4.84 ± 0.38	5.00 ± 0.40
	All	4.15 ± 0.21	4.47 ± 0.25	5.13 ± 0.47	5.48 ± 0.69
T11	M	4.57 ± 0.13	5.17 ± 0.18*	6.11 ± 0.67†	6.79 ± 0.64*
	F	4.43 ± 0.19	4.77 ± 0.23	5.53 ± 0.36	5.92 ± 0.60
	All	4.50 ± 0.17	4.97 ± 0.29	5.82 ± 0.60	6.36 ± 0.75
T12	M	4.77 ± 0.12†	5.51 ± 0.20*	6.48 ± 0.63†	7.20 ± 0.78*
	F	4.63 ± 0.17	5.02 ± 0.24	5.89 ± 0.25	6.29 ± 0.44
	All	4.70 ± 0.16	5.27 ± 0.33	6.19 ± 0.55	6.75 ± 0.77

SD = standard deviation.
Comparison between a male and a female:
* Statistically significant difference ($P < 0.01$).
† Statistically significant difference ($P < 0.05$).
Group 1 indicates 5–7 years of age, group 2 indicates 8–10 years of age, group 3 indicates 11–13 years of age, and group 4 indicates 14–16 years of age.

Table 3

Maximal screw diameter (mean ± SD, mm).

Level (M/F)		Group 1	Group 2	Group 3	Group 4
T9	M	6.47±0.21*	7.14±0.19†	7.95±0.60†	8.45±0.88†
	F	6.07±0.24	6.74±0.40	7.39±0.34	7.60±0.47
	All	6.27±0.30	6.94±0.37	7.67±0.56	8.03±0.81
T10	M	6.86±0.24*	7.52±0.29†	8.38±0.74	9.15±0.88*
	F	6.38±0.26	7.11±0.40	7.93±0.40	8.06±0.45
	All	6.62±0.35	7.32±0.40	8.16±0.62	8.61±0.88
T11	M	7.22±0.25*	8.02±0.32†	9.02±0.97	10.19±0.89*
	F	6.79±0.34	7.61±0.40	8.57±0.34	8.92±0.72
	All	7.01±0.37	7.82±0.41	8.80±0.75	9.56±1.02
T12	M	7.65±0.20*	8.45±0.32†	9.56±0.83	10.92±0.93*
	F	7.21±0.30	8.05±0.32	8.97±0.33	9.47±0.48
	All	7.43±0.34	8.25±0.37	9.27±0.69	10.20±1.04

SD = standard deviation.
Comparison between a male and a female:
* Statistically significant difference ($P < 0.01$).
† Statistically significant difference ($P < 0.05$).
Group 1 indicates 5–7 years of age, group 2 indicates 8–10 years of age, group 3 indicates 11–13 years of age, and group 4 indicates 14–16 years of age.

4. Discussion

The CBT technique was first advocated by Santoni et al in 2009 and they found that cortical trajectory screws demonstrated a 30% increase in uniaxial yield pullout load relative to the traditional pedicle screws. Baluch et al[8] demonstrated that CBT screws had superior resistance to craniocaudal toggling compared with traditional pedicle screws. Perez-Orribo et al[9] studied the biomechanical behavior of CBT screw fixation construct relative to traditional pedicle screw fixation construct. They found that bilateral CBT screws-rod fixation provided about the same stability in cadaveric specimens as traditional screw-rod fixation. By inserting a screw from a more medial and caudal entry point, muscle dissection can be minimized and iatrogenic damage to the cranial facet joint can be avoided. Gonchar et al[10] reported that single level posterior lumbar fusion with CBT screw was less invasive as compared with percutaneous pedicle screw. Furthermore, Calvert et al[11] demonstrated that CBT screw might be a useful method to rescue a failed pedicle screw.

According to above advantages, the CBT technique was a more rigid, safe, and an alternative method to rescue failed screws. In our study, we conducted morphometric measurements of thoracic vertebrae using CT to evaluate the feasibility of CBT screws in pediatric patients. Matsukawa et al[7] inserted 5.5 mm CBT screws and obtained sufficient fixation strength in their study; however, several biomechanical and clinical studies demonstrated that 4.5 to 5.5 CBT screws still could provide superior fixation strength as compared to traditional screws.[8,9,11–14] Concerning above factors, we recommended 4.5, 5.0, and 5.5 mm as the limit size of CBT screws.

When we considered 5.5 mm as the limit diameter of CBT screws fixation only via pedicle, it was not suitable for almost all groups at T9 (Fig. 4). In group 3 and group 4, patients in whom CBT screws were correctly placed at T10 accounted for 30% and 45%, respectively. However, CBT screws cannot be inserted in all patients at T10 in group 1 and group 2. Similarly to T10, the CBT technique was not suitable for almost all patients at T11 in group 1 and group 2. On the contrary, 70% of patients can be placed with CBT screws in group 3 and in the majority of patients of group 4 CBT screws can be inserted at T11. The CBT technique was not suitable for all patients of group 1 and in 35% of patients CBT screws can be placed at T12; however, the CBT technique was suitable for all patients at T12 in group 3 and group 4.

Table 4

Cephalad angle (mean ± SD, °).

Level (M/F)		Group 1	Group 2	Group 3	Group 4
T9	M	13.14±1.07	14.58±1.34	16.22±1.93	16.91±3.33
	F	13.07±1.08	14.24±1.25	15.76±1.20	16.19±1.37
	All	13.11±1.05	14.41±1.27	15.99±1.58	16.55±2.50
T10	M	14.77±1.54	15.96±1.31	18.77±3.02	18.70±3.75
	F	14.38±1.47	15.94±1.34	18.00±1.63	17.96±1.88
	All	14.58±1.48	15.95±1.29	18.39±2.39	18.33±2.91
T11	M	16.03±2.10	19.05±1.55	21.80±3.69	20.72±1.60
	F	15.82±1.63	17.41±2.33	20.12±1.41	20.68±3.91
	All	15.93±1.83	18.23±2.11	20.96±2.85	20.70±2.91
T12	M	17.73±2.34	19.80±2.05	23.24±3.04	23.31±3.50
	F	17.22±1.60	19.56±1.74	22.16±1.90	22.81±2.11
	All	17.48±1.97	19.68±1.86	22.70±2.53	23.06±2.82

SD = standard deviation.
Comparison between a male and a female:
Group 1 indicates 5–7 years of age, group 2 indicates 8–10 years of age, group 3 indicates 11–13 years of age, and group 4 indicates 14–16 years of age.

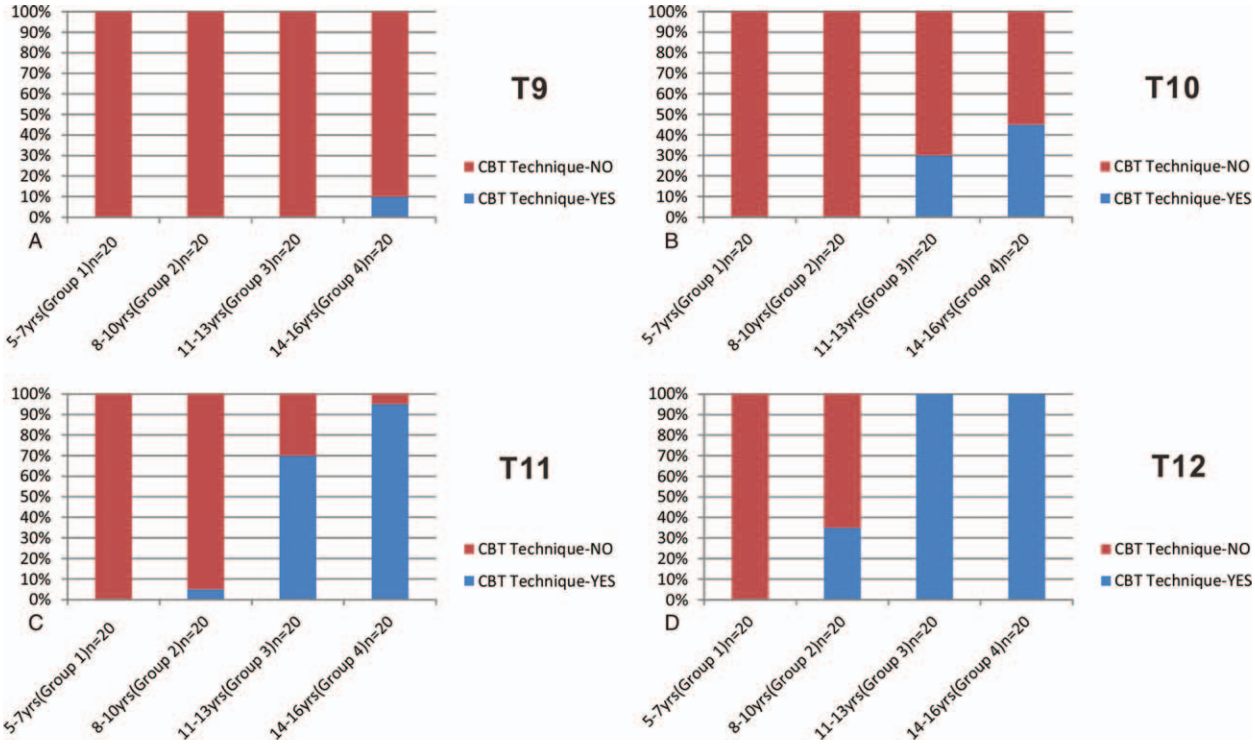

Figure 4. Graphs showing the patient population accommodating for 5.5-mm-diameter CBT screws only via pedicle in the pediatric thoracic segments: (A) T9, (B) T10, (C) T11, and (D) T12. CBT = cortical bone trajectory.

If we consider 5.0 mm as the limit size of CBT screws instrumentation only through the pedicle, we noted that the CBT technique was still not suitable for patients in group 1 and group 2 at T9 (Fig. 5). In addition, in 30% of patients of group 3 5.0 mm CBT screws can be placed at T9 and in 50% of patients of group 4, respectively. The CBT technique was also not appropriate for patients in group 1 and group 2 at T10. However, 5.0 mm CBT screws can be inserted correctly in 60% of patients of group 3 and

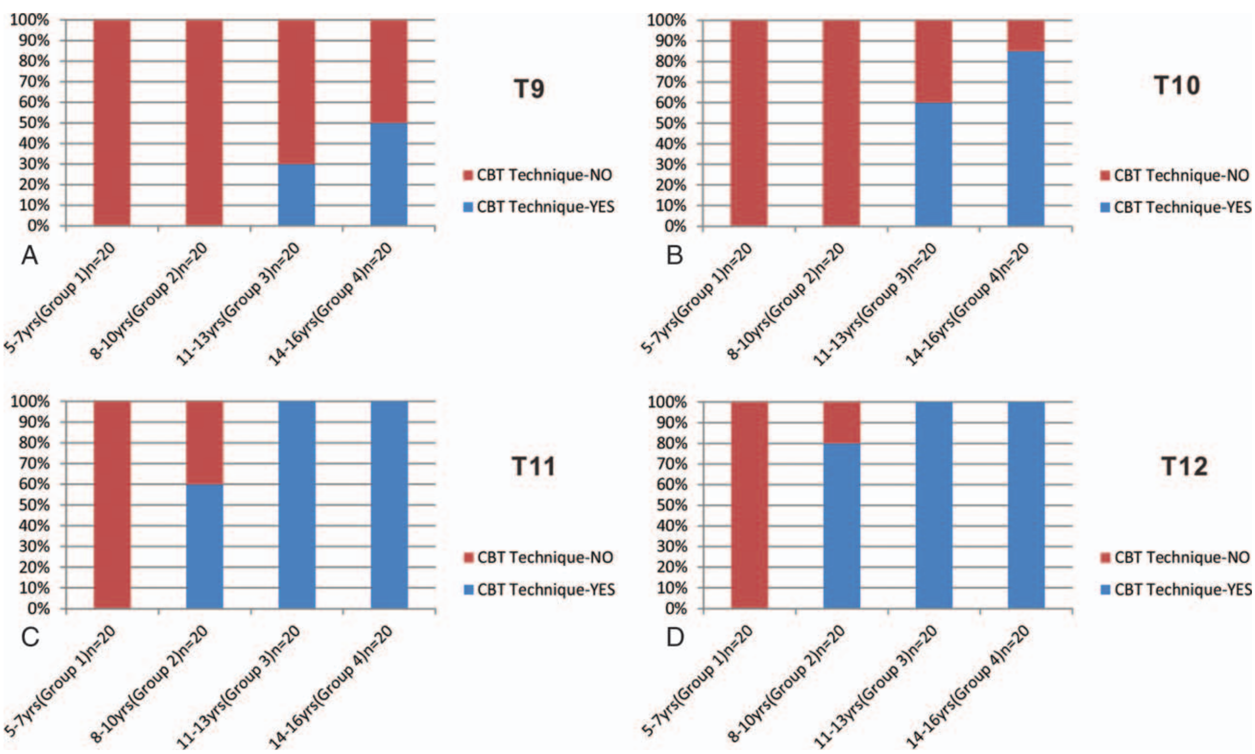

Figure 5. Graphs showing the patient population accommodating for 5.0-mm-diameter CBT screws only via pedicle in the pediatric thoracic segments: (A) T9, (B) T10, (C) T11, and (D) T12. CBT = cortical bone trajectory.

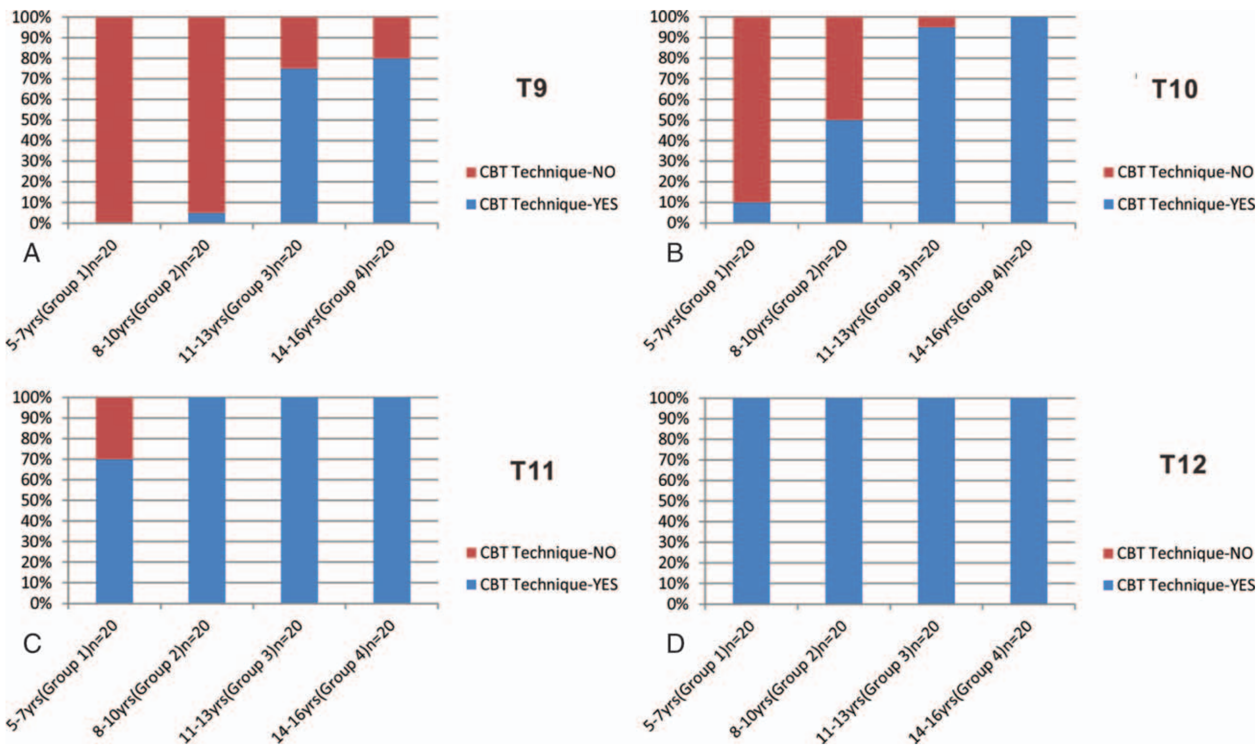

Figure 6. Graphs showing the patient population accommodating for 4.5-mm-diameter CBT screws only via pedicle in the pediatric thoracic segments: (A) T9, (B) T10, (C) T11, and (D) T12. CBT = cortical bone trajectory.

85% of patients of group 4, respectively. Although all patients in group 3 and group 4 can accommodate 5.0 mm CBT screws at T11 and T12, the CBT technique was not suitable for patients in group 1. Meanwhile, patients who can be inserted 5.0 mm CBT screws in group 2 made up 60% at T11 and 80% at T12, respectively.

However, regarding 4.5 mm as the minimum size of CBT screw placement only via pedicle, we can find almost all patients can accommodate CBT screws at T11 and T12 (Fig. 6). The CBT technique was still appropriate for few patients in group 1 at T9 and T10. In the majority of patients of group 3 and group 4, CBT screws can be placed safely at T9 plus T10. CBT screws can be inserted safely in a minority of group 2 patients, but in 50% of these patients this screws can be inserted at T10.

Several studies indicated that a significantly larger screw can be placed within the pedicle rib unit, which enlarged the transverse width of the area of insertion. O'Brien et al[15] measured the pedicle and pedicle rib unit using CT in 29 patients with right sided scoliosis, finding that the transverse width of the pedicles from T1 through T12 ranged from 4.6 to 8.25 mm, whereas the pedicle rib unit width ranged from 12.6 to 17.9 mm. Besides, Liljenqvist et al[16] measured 26 patients with right-side thoracic curves using MRI and found significantly narrower pedicles on the concave side at the apex of the curve (range of 2.3–3.2 mm compared with convex side 3.9–4.4 mm), whereas the width of pedicle rib unit was wider when compared with the convex side (ranged from 11 mm in the cephalad aspect to 14 mm in the caudad aspect of the thoracic spine). Tian et al[17] also investigated the dimensions of the pedicle rib unit for normal children, reporting a significantly larger size of the corresponding pedicle rib unit provided a more ample space. Furthermore, the minimum value of maximal screw length of CBT screws insertion via pedicle rib unit was 6.27 mm (Table 3), which indicated that 5.5 mm CBT screws can be inserted correctly via the pedicle rib unit in all patients (Fig. 1C).

In our study, there were some limitations deserved to be mentioned. On the one hand, human races can influence anatomical measurements but our CT scans included for studying were all taken from Asian pediatric patients. On the other hand, we only assessed the feasibility of CBT screws placement through CT without cadaveric studies. However, we will further make a follow-up study to provide the clinical outcomes of the CBT technique used in the pediatric thoracic spine.

5. Conclusions

Our study establishes the feasibility of 4.5 to 5.5 mm CBT screws fixation via pedicle or pedicle rib unit in the pediatric thoracic spine. The entry point of the pediatric thoracic CBT screws is 6 o'clock orientation of the pedicle. Findings of our study also provide insights into the screw insertion angle and screw size decision.

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