TOMOGRAPHIC ANALYSIS OF C7, T1 AND T2 VERTEBRAE ANATOMY IN CHILDREN

ABSTRACT

Objective: To evaluate and compare anatomical measurements of C7, T1 and T2 vertebrae in children from 3 to 12 years of age to provide useful epidemiological data for determining the safe anatomical margin for transpedicular and translaminar fixation with screws in this population. Methods: This observational retrospective cross-sectional study evaluated 76 computed tomography scans obtained over 6 months, analyzing the following parameters: the angle of attack, length, thickness and diameter of the pedicle; and the angle of attack, length and thickness of the lamina. Results: The lamina length and thickness, as well as pedicle length varied in size according to age. Although the angle of attack was similar across different ages, age-dependent variation occurred in the T1 vertebra. Conclusion: Screws with a 3.5 mm diameter are safe to use in the pedicles of C7 and T2 vertebrae, while the T1 pedicle allows the introduction of larger screws ranging from 3.5-4.5 mm in diameter. In the lamina, 3.5 mm screws are safe for use only in children older than 7 years. However, each case should be analyzed individually, with the present study not aiming to replace the preoperative use of CT. Level of Evidence III, Retrospective comparative study.

Keywords: Tomography, X-Ray Computed. Cervical Vertebrae. Retrospective Studies.

INTRODUCTION

Having anatomical structures of unique importance, the cervicothoracic region presents a shift from the more mobile vertebral segments of the cervical spine to the more rigid segments or the thoracic spine; thus, during surgical treatments performed in this region, it is important to use implants that provide adequate mechanical support, rigidity, stability, and secure fixation. As spinal disorders often occur in this region, including fractures, tumors and deformities, having a detailed knowledge of vertebral morphology becomes essential for any surgical approach using pedicular or translaminar screws at the C7, T1 or T2 level. As reported by previous studies,1–3 even within a population comprising individuals with similar ages but different ethnicities, the anatomical dimensions of the vertebral body, spinal canal and transverse diameter of the pedicle can vary. For this reason, tomographic analysis is of great assistance during preoperative planning, helping minimize surgical complications, such as incorrectly positioned implants, violation of the vertebral cortex or neurovascular lesions.4

All authors declare no potential conflict of interest related to this article.
Since surgical transpedicular fixation in pediatric patients, in whom structures have smaller sizes, entails technical difficulties,\(^5\) it is necessary and useful to evaluate the angle of attack, length and thickness of cervicothoracic junction vertebrae structures. Also relevant is to correlate anatomic measurements with commercially available pedicular and translaminar implants and their screws due to the high prevalence of use, the association with fixation rigidity and the higher rates of arthrodesis consolidation\(^6\) of the screws themselves.

Based on the above, the present study used computed tomography (CT) to evaluate the pedicle and lamina anatomy of the C7, T1 and T2 vertebrae in children from 3 to 12 years of age. The aim was to provide a published record of epidemiological data obtained in this pediatric population, which can be useful for determining the safety margins of transpedicular and translaminar fixation in cases that may require implants.

MATERIALS AND METHODS

The study evaluated 76 computed tomography (CT) scans, routinely performed for polytrauma cases during the 6-month period from July 2018 to December 2018, following the institutional protocol. To increase data veracity,\(^9\) two researchers conducted the analysis of this continuously selected sample simultaneously. Morphometric analysis was performed using the iSite PACS Philips Healthcare Informatics\(^\circ\) program.

The selected cases were separated in two groups according to the patients’ age, with cutoff age based on the fusion period of the primary ossification centers of C7, T1 and T2 vertebrae, complete at 8 years old.\(^9\) Group 1 included patients from 3 to 7 years of age, and Group 2 patients from 8 to 12 years of age. Each group was then subdivided into 2 subgroups according to gender: Female and Male. Ethnicity and race were not investigated due to extensive miscegenation in the studied population.

Exclusion criteria included patients with cervical or thoracic vertebral fracture, a diagnosis of cervical or thoracic spinal deformity or malformation, poor quality imaging tests, infections, tumors, or previous surgery in the cervical or thoracic spine.

Pedicle measurements were obtained as follows:\(^10\)

1) Angle of attack: measured on axial CT as the angle between a line parallel to the spinous process and a line parallel to the long axis of the pedicle (Figure 1).
2) Pedicle diameter: measured on coronal CT as the distance between the medial and lateral cortices of the pedicle in the isthmus (Figure 2).
3) Length: measured on axial CT as the distance between the posterior cortex of the pedicle and the posterior longitudinal ligament along the axis of the pedicle (Figure 3).
4) Thickness: measured on axial CT as the distance between the lateral and medial cortices of the pedicle in the isthmus (Figure 3).

Lamina measurements were obtained as follows:\(^11\)

1) Angle of attack: measured on axial CT between a line parallel to the laminar cortex and a line parallel to the longitudinal axis of the spinous process (Figure 4).
2) Length: measured on axial CT as the distance between the posterior and anterior limit of the lamina (Figure 5).
3) Thickness: measured on axial CT as the distance between the medial and lateral cortex of the lamina in a thin slice (Figure 5).
RESULTS

After applying the exclusion and inclusion criteria, the study sample comprised 76 patients with cervicothoracic junction CT scans. Group 1 (patients from 3 to 7 years of age) included 46 individuals; Group 2 (patients from 8 to 12 years of age) included 30 individuals. The children’s mean age was 7.1 years old (SD = 3.2 years), with most being between 3 and 7 years old (60.5%) and male (68.4%) (Table 1).

C7 vertebra

Lamina length in C7 was statistically higher only in children from 8 to 12 years of age, regardless of gender (p < 0.05) (Table 2).

T1 vertebra

The angle of attack and pedicle length were significantly higher in Group 2 than in Group 1, regardless of gender (p = 0.006 and p = 0.008, respectively). The lamina length was also significantly higher in older children, regardless of gender (p < 0.001) (Table 3).

Table 2. Description and comparison of C7 vertebra measurements by age group and gender.

| Variable | 3 to 7 years of age | 8 to 12 years of age | p Age group | p Gender | p Interaction |
|----------|---------------------|----------------------|-------------|----------|---------------|
| Pedicle  |                     |                      |             |          |               |
| Angle of attack |               |                      |             |          |               |
| mean ± SD   | 33.4 ± 5.3 | 35.2 ± 5.5 | 34.4 ± 6.1 | 38.2 ± 7 | 0.188 | 0.072 | 0.526 |
| NR (95%)   | (23 - 43.8) | (24.5 - 45.9) | (22.5 - 46.4) | (24.5 - 51.8) | 0.432 | 0.202 | 0.226 |
| Length    |                     |                      |             |          |               |
| mean ± SD   | 13.1 ± 1.5 | 13.1 ± 1.4 | 12.4 ± 1.1 | 13.3 ± 1.3 | 0.222 | 0.256 | 0.611 |
| NR (95%)   | (10.2 - 15.9) | (10.4 - 15.8) | (10.2 - 14.6) | (10.7 - 15.8) | 0.269 | 0.910 | 0.332 |
| Thickness  |                     |                      |             |          |               |
| mean ± SD   | 3.2 ± 0.7 | 3.4 ± 0.8 | 3.4 ± 0.5 | 3.7 ± 1 | 0.883 | 0.458 | 0.186 |
| NR (95%)   | (1.9 - 4.6) | (1.7 - 5) | (2.5 - 4.3) | (1.8 - 5.6) | 0.658 | 0.690 | 0.337 |
| Diameter* |                     |                      |             |          |               |
| mean ± SD   | 3.3 ± 0.6 | 3.2 ± 0.8 | 3 ± 0.6 | 3.5 ± 1 | 0.010 | 0.346 | 0.981 |
| NR (95%)   | (2.1 - 4.5) | (1.6 - 4.9) | (1.8 - 4.2) | (1.6 - 5.4) | 0.269 | 0.910 | 0.332 |
| Lamina    |                     |                      |             |          |               |
| Angle of attack |               |                      |             |          |               |
| mean ± SD   | 48.4 ± 3 | 47.8 ± 3.4 | 47 ± 3.6 | 48.4 ± 5.2 | 0.000 | 0.000 | 0.000 |
| NR (95%)   | (42.6 - 54.2) | (41.2 - 54.4) | (39.9 - 54.1) | (38.2 - 56.5) | 0.010 | 0.346 | 0.981 |
| Length    |                     |                      |             |          |               |
| mean ± SD   | 28.1 ± 2.4 | 28.8 ± 2.5 | 30 ± 3.2 | 30.7 ± 3.2 | 0.658 | 0.690 | 0.337 |
| NR (95%)   | (23.4 - 32.8) | (23.8 - 33.7) | (23.8 - 36.2) | (24.3 - 37) | 0.269 | 0.910 | 0.332 |
| Thickness  |                     |                      |             |          |               |
| mean ± SD   | 2.2 ± 0.6 | 2.3 ± 1 | 2.6 ± 0.6 | 2.4 ± 0.6 | 0.658 | 0.690 | 0.337 |
| NR (95%)   | (1 - 3.3) | (0.5 - 4.2) | (1.4 - 3.8) | (1.2 - 3.6) | 0.269 | 0.910 | 0.332 |

ANOVA with two factors; NR: normal range; * two cases were not evaluated for this parameter
Table 3. Description and comparison of T1 vertebra measurements by age group and gender.

| Variable | 3 to 7 years of age | 8 to 12 years of age | p Age group | p Gender | p Interaction |
|----------|---------------------|----------------------|-------------|----------|---------------|
|          | Female (n = 15)     | Male (n = 31)        | Female (n = 9) | Male (n = 21) |
| Pedicle  |                     |                      |              |           |               |
| Angle of attack | 0.006 | 0.794 | 0.974 |
| mean ± SD | (30.6 ± 5.5) | (30 ± 7.1) | (35.6 ± 8.1) | (35.4 ± 8.6) |
| NR (95%) | (19.8 - 41.3) | (16.2 - 43.9) | (20 - 51.7) | (18.6 - 52.2) |
| Length   | 0.008 | 0.531 | 0.100 |
| mean ± SD | (13.7 ± 1.3) | (14.2 ± 1.6) | (15.8 ± 1.6) | (14.7 ± 2.6) |
| NR (95%) | (11.1 - 16.3) | (11.1 - 17.4) | (12.6 - 19) | (9.7 - 19.7) |
| Thickness | 0.290 | 0.617 | 0.607 |
| mean ± SD | (3.4 ± 0.8) | (3.7 ± 1) | (3.8 ± 0.9) | (3.8 ± 0.8) |
| NR (95%) | (1.9 - 5) | (1.6 - 5.7) | (2.1 - 5.5) | (2.2 - 5.4) |
| Diameter* | 0.267 | 0.448 | 0.436 |
| mean ± SD | (3.7 ± 0.8) | (4.2 ± 1) | (3.8 ± 0.9) | (2.5 - 7) |
| NR (95%) | (1.8 - 5.6) | (2.1 - 6.2) | (2 - 5.7) | |
| Lamina  | 0.909 | 0.881 | 0.255 |
| Angle of attack |                     |                      |              |           |               |
| mean ± SD | (48 ± 3.3) | (46.6 ± 4.1) | (46.9 ± 3.1) | (47.9 ± 4.9) |
| NR (95%) | (41.5 - 54.5) | (38.5 - 54.7) | (40.9 - 52.9) | (38.4 - 57.5) |
| Length   | <0.001 | 0.948 | 0.273 |
| mean ± SD | (25.8 ± 2.4) | (26.7 ± 2.9) | (29.7 ± 3.4) | (28.9 ± 3.5) |
| NR (95%) | (21.1 - 30.6) | (21.1 - 32.3) | (23 - 36.3) | (22 - 35.7) |
| Thickness | 0.064 | 0.539 | 0.978 |
| mean ± SD | (2.8 ± 0.6) | (2.9 ± 0.8) | (3.1 ± 0.7) | (3.3 ± 0.9) |
| NR (95%) | (1.6 - 3.9) | (1.3 - 4.5) | (1.8 - 4.5) | (1.6 - 5) |

ANOVA with two factors; NR: normal range; * two cases were not evaluated for this parameter

T2 vertebral

Lamina length and thickness were significantly higher in children from 8 to 12 years of age than in children from 3 to 7 years of age, regardless of gender (p < 0.001 and p = 0.003, respectively) (Table 4). T2 mean pedicle length was significantly higher in 8-12 years old female children than in 3-7 years old female children (p = 0.012) and 3-7 years old male children (p = 0.046) (Table 5).

Table 4. Description and comparison of T2 vertebra measurements by age group and gender.

| Variable | 3 to 7 years of age | 8 to 12 years of age | p Age group | p Gender | p Interaction |
|----------|---------------------|----------------------|-------------|----------|---------------|
|          | Female (n = 15)     | Male (n = 31)        | Female (n = 9) | Male (n = 21) |
| Pedicle  |                     |                      |              |           |               |
| Angle of attack | 0.054 | 0.842 | 0.851 |
| mean ± SD | (20.9 ± 4.7) | (20.9 ± 5.6) | (23.8 ± 3.9) | (23.3 ± 5.8) |
| NR (95%) | (11.8 - 30.1) | (10 - 31.8) | (16.3 - 31.4) | (11.8 - 34.8) |
| Length   | 0.003 | 0.309 | 0.028 |
| mean ± SD | (13.9 ± 1.6) | (14.5 ± 1.6) | (16.3 ± 1.5) | (14.8 ± 2.1) |
| NR (95%) | (10.7 - 17.2) | (11.4 - 17.6) | (13.3 - 19.3) | (10.8 - 18.9) |
| Thickness | 0.321 | 0.239 | 0.679 |
| mean ± SD | (3 ± 0.7) | (3.1 ± 0.9) | (3.1 ± 0.5) | (3.4 ± 0.8) |
| NR (95%) | (1.6 - 4.3) | (1.3 - 5) | (2.1 - 4) | (1.8 - 5) |
| Diameter* | 0.113 | 0.544 | 0.825 |
| mean ± SD | (3.2 ± 0.8) | (3.4 ± 0.9) | (3.7 ± 1.3) | (3.8 ± 1.2) |
| NR (95%) | (1.6 - 4.8) | (1.7 - 5.1) | (1.1 - 6.3) | (1.4 - 6.2) |
| Lamina  | 0.319 | 0.648 | 0.972 |
| Angle of attack |                     |                      |              |           |               |
| mean ± SD | (50 ± 3.1) | (49.5 ± 4.5) | (48.9 ± 4.2) | (48.5 ± 4.2) |
| NR (95%) | (44 - 56.1) | (40.8 - 58.3) | (40.7 - 57.1) | (40.2 - 56.8) |
| Length   | <0.001 | 0.571 | 0.652 |
| mean ± SD | (21.9 ± 1.6) | (22.5 ± 2) | (24.3 ± 2.2) | (24.3 ± 2.9) |
| NR (95%) | (18.8 - 25) | (18.6 - 26.4) | (19.9 - 26.8) | (18.6 - 30.1) |
| Thickness | 0.003 | 0.574 | 0.468 |
| mean ± SD | (2.5 ± 0.6) | (2.8 ± 0.8) | (3.2 ± 0.8) | (3.2 ± 0.7) |
| NR (95%) | (1.3 - 3.7) | (1.2 - 4.4) | (1.7 - 4.8) | (1.7 - 4.7) |

ANOVA with two factors; NR: normal range; * two cases were not evaluated for this parameter
who reported that pedicle length was higher in male patients than was longer in female patients. This result is consistent with Kretzer be safely applied in C7 and T2 pedicles, while T1 supports larger found significant differences in lamina length and thickness between the T2 vertebra, we our results show that while the T1 lamina length was significantly differences in the length and width of the T1 lamina according to age, Chen et al.'s17 study focused on adults instead of children. Onibokun et al., 19 in turn, found no difference in pedicle length in the population. To our knowledge, this is the first simultaneous analysis in the scientific literature that describes the pediatric C7, T1 and T2 pedicles and laminae and their correlations with the use of commercially available screws. After analyzing the collected data, we observed that the length of T1 and T2 pedicles differed significantly depending on age, similar to results found by a previous study.8 In our study, the T2 pedicle was longer in female patients. This result is consistent with Kretzer et al.,16 who showed that pedicle length depended on the patient’s gender (p < 0.001); but differs from the findings of Chen et al.,17 who reported that pedicle length was higher in male patients than in female patients. Such discrepancy may be due to differences peculiar to the ethnicity and age of each analyzed population, as Chen et al.’s17 study focused on adults instead of children. Regarding the C7 vertebra, our results show an age-dependent difference in lamina length, similar to the findings by Kanna et al.18 Onibokun et al.,19 in turn, found no difference in pedicle length according to age. Compared to the study by Marchese et al.,11 which found significant differences in the length and width of the T1 lamina according to age, our results show that while the T1 lamina length was significantly higher in older children regardless of gender (p < 0.001), there was no such difference in lamina thickness. As for the T2 vertebra, we found significant differences in lamina length and thickness between age groups, similar to the findings of Molina et al.5 Our data allow us to affirm that screws with a 3.5 mm diameter can be safely applied in C7 and T2 pedicles, while T1 supports larger pedicle screws ranging from 3.5 to 4.5 mm in diameter. These findings are similar to those of Rekate et al.,20 who concluded that pedicle fixation could be safely applied in children over 4 years old. Our results also resemble those by Ranade et al.,21 the authors showed that the pedicles of patients younger than 8 years old can safely receive 3.5-5.5 mm screws. Hassan et al.,22 however, observed that applying fixation with pedicular screws of diameter greater than 3.0 mm was unsafe in children and adolescents younger than 18 years old. These divergent findings may be due to the smaller stature of Asian patients.8

Regarding translaminar fixation, we conclude that it is possible to safely use 3.5 mm screws only in children older than 7 years old, finding similar to that of a previous study.5 Our results clash, however, with those presented by Kretzer et al.,23 who found no size-related limitations for introducing translaminar screws. Since the study published by Kretzer et al.,21 included patients aged 41.7 +/- 19.6 years, the age difference between samples could explain this divergence. Our findings suggest that it is crucial to analyze the vertebral anatomy based on computed tomography during the surgical planning of pathologies that affect a child’s spine. But this is a retrospective study of a sample composed mainly of male children under 8 years of age (hence, prior to the complete ossification of the vertebrae); thus, future studies are needed to confirm the data obtained here and to eventually collect additional information on cervicothoracic junction fixation in the pediatric population.

CONCLUSION

Our results allow us to conclude that lamina length and thickness, as well as pedicle length increase with age. We found a significant age-dependent variation in the angle of attack when considering only the T1 pedicle. Based on the morphologies of the studied vertebrae, screws with 3.5 mm diameter are safe to use in the C7 and T2 pedicles, while the T1 pedicle allows for screws up to 4.5 mm in diameter. As for translaminar fixation, the present study conclude that it is only safe to use screws thicker than 3.5 mm in children older than 7 years old. However, we must analyze each case individually, with the present study not aiming to replace the preoperative use of CT.

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