

Anatomical Study of C2 Pedicle and Pars Interarticularis in Thai Population

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Background: The C2 pedicle and pars interarticularis complex have distinct anatomy and substantial variation in the population. The exact locations of the C2 pedicle and pars interarticularis are still controversial.

Objective: This study aims to determine the safe trajectory and length of C2 pedicle and pars screw insertion.

Material and Method: Thirty-six dried cadaveric C2 vertebrae were used in this study. The authors measured four linear and four angular parameters of C2 pedicle and pars interarticularis by using a Vernier caliper and a digital goniometer.

Results: Regarding C2 pedicle screw placement, the entry point is a point 5 mm inferior to the superior border of the C2 lamina and 7 mm lateral to the lateral border of the spinal canal, the axial angle is 30°, the sagittal angle is 28° and the length of the distance is 27 mm. For C2 pars screw insertion, the appropriate entry point is a point 3 to 4 mm superior and lateral to the medial aspect of the C2-3 facet joint, the axial angle is 16°, the sagittal angle is 36° and the length of the distance is 30 mm.

Conclusion: The authors proposed recommendation for safe C2 pedicle and pars screw placement. These landmarks are suitable for Thai population.

Keywords: C2 vertebra, Axis, Pedicle, Pars interarticularis, Anatomy, Screw placement

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There are various surgical procedures for occipitocervical fixation, such as wiring and screw fixation. This surgical management has evolved continuously in the past two decades. Transpedicular screw fixation of the C2 plays an important role for spinal stabilization in this area. Borne et al found that transpedicular screw fixation of the C2 rendered consistently good anatomical and functional results in patients with fracture of the C2 pedicle⁽¹⁾.

Several anatomical studies were published to establish guidelines for C2 transpedicular screw placement; however, there is still controversial regarding the location of the C2 pedicle. Naderi et al proposed that the C2 pedicle is situated beneath the C2 isthmus. It connects the lateral mass and inferior articular process to the body of the axis. They defined this structure as pediculoisthmus components (PICs)⁽²⁾. Recently, there

are two most popular screw entry points for C2 screw placement. Xu et al described the posterior projection of the axis of the C2 pedicle for pedicular screw placement. The entry point is about 5 mm inferior to the superior border of the C2 lamina and 7 mm lateral to the lateral border of the spinal canal⁽³⁾. For C2 pars screw placement, the entry point is 3 to 4 mm superior and lateral to the medial aspect of the C2-3 facet joint^(4,5), which is identical to that of C1-2 transarticular screw fixation.

The present study endeavors to investigate anatomy of the C2 vertebra in terms of the pedicle width, pedicle (isthmus) height, and a distance between the screw entry point to the junction of the pedicle and vertebral body, and to determine axial and sagittal orientation of trajectory required for screw placement.

Material and Method

Thirty-six dried C2 vertebrae (a total of 72 C2 pedicles and pars interarticularis) were used in the study. The authors measured four linear and four angular parameters by using a Vernier caliper (accurate to 0.02 mm) and a digital goniometer (accurate to 0.01°). The

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following parameters were measured and recorded.

Pedicle height and width (inferior width) were measured using the external cortical borders (Fig. 1A and 1B).

The length, axial (mediolateral) and sagittal (rostrocaudal) angulations were measured from two consistent points. The first entry point, for C2 pedicular screw placement, was a point 5 mm inferior to the superior border of the C2 lamina and 7 mm lateral to the lateral border of the spinal canal. The second entry point, for C2 pars screw placement, was a point 3-4 mm superior and lateral to the medial aspect of the C2-3 facet joint. The length of the distance of screw placement was defined as the distance from the screw entry point to the junction of the pedicle and the body of the axis (Fig. 1C).

Two angular parameters were measured parallel to the medial and superior aspect of C2 pedicle with the sagittal and axial planes, respectively (Fig. 2 and 3).

Results

In the 72 pedicles, the means, standard deviations (SD) and ranges of four linear and four angular parameters were measured and calculated for the right and the left sides, respectively. The results are presented in Table 1.

Discussion

The term “pedicle” or “pars interarticularis” in the C2 vertebra is controversial. Benzel proposed that the C2 pedicle is the portion of bone connecting the posterior elements with the vertebral body, whereas the bony portion which connects the superior and inferior articulating processes is called “pars interarticularis”⁽⁶⁾. Ebraheim et al defined the C2 pedicle as the portion posterolateral to the vertebral body, beneath the superior articular facet and anteromedial to the transverse foramen⁽⁷⁾. They agreed with Benzel regarding the anatomical position of the pars interarticularis (Fig. 4). According to this literature, the two entry points are on the pars interarticularis and the screw travels in the pedicle. However, we have used the term pedicle and pars screws entry points for minimize the confusion.

In an anatomical study concerning pedicular screw placement by Xu et al⁽³⁾, the average axial angle was 30° and the sagittal angle was 20° to the midline sagittal and transverse planes, respectively. Based on this angle, the projection axis from the pedicle screw entry point (5 mm inferior to the superior border of the



Fig. 1 Anatomy of the C2 vertebra: (A) lateral view showing pedicle height (a); (B) inferior view showing pedicle width (b); (C) superior view showing pedicular screw trajectory (c) and pars screw trajectory (d).

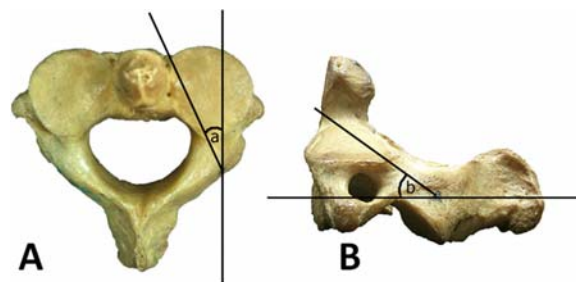


Fig. 2 Trajectory of C2 pedicle screw placement: (A) superior view showing axial angle (a); (B) lateral view showing sagittal angle (b).

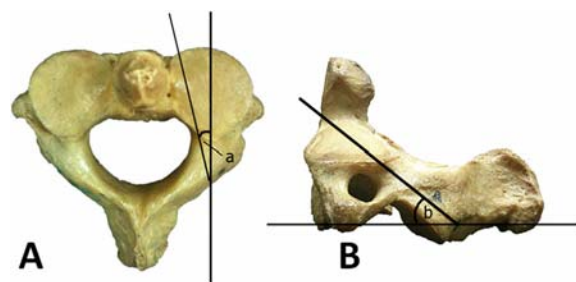


Fig. 3 Trajectory of C2 pars screw placement: (A) superior view showing axial angle (a); (B) lateral view showing sagittal angle (b).

C2 lamina and 7 mm lateral to the lateral border of the spinal canal) is along the true axis of the pedicle. Ebraheim et al suggested placing screw on the superomedial border of the C2 pedicle for a safe placement⁽⁸⁾. The pars screw entry point (3 to 4 mm superior and lateral to the medial aspect of the C2-3 facet joint); identical to that used in C1-2, transarticular screw placement is more medial and inferior than the pedicle screws entry point. The projection axis of this entry point is more lateral and rostral in axial and sagittal angles, respectively. We used these two entry points in this study.

The true C2 pedicle places in lateral to medial and inferior to superior angulations. For the C2 pedicle screw entry point, the axial angulation was reported to

Table 1. The results of all measurements

Parameter	Side	Mean \pm SD	Range
Pedicle width (mm)	Right	5.68 \pm 1.28	2.86 to 7.92
	Left	5.96 \pm 1.27	3.80 to 8.68
Pedicle height (mm)	Right	7.90 \pm 1.61	3.70 to 11.62
	Left	8.56 \pm 1.44	5.42 to 11.48
Pedicle screw placement			
Length (mm)	Right	27.79 \pm 1.64	24.30 to 31.80
	Left	27.43 \pm 1.47	23.84 to 30.44
Axial angle ($^{\circ}$)	Right	29.88 \pm 2.70	22.42 to 34.80
	Left	29.55 \pm 2.07	24.57 to 33.09
Sagittal angle ($^{\circ}$)	Right	27.66 \pm 2.82	23 to 34.87
	Left	28.35 \pm 2.59	22.74 to 33.74
Pars screw placement			
Length (mm)	Right	30.90 \pm 1.77	27 to 35.90
	Left	30.66 \pm 1.82	27.20 to 35.20
Axial angles ($^{\circ}$)	Right	16.85 \pm 3.27	11.37 to 22.69
	Left	16.13 \pm 2.80	10.56 to 22.21
Sagittal angle ($^{\circ}$)	Right	36.19 \pm 3.25	30.58 to 42.48
	Left	36.21 \pm 2.93	30.26 to 41.57

be 28 $^{\circ}$ by Naderi et al⁽²⁾, 33 $^{\circ}$ by Xu et al⁽³⁾, 35.2 $^{\circ}$ by Howington et al⁽⁹⁾, and 38.95 $^{\circ}$ by Bunmaprasert et al⁽¹⁰⁾. In our study, the mean axial angulations were 29.88 $^{\circ}$ and 29.55 $^{\circ}$ on the right and left sides, respectively. The sagittal angulations were reported to be 18 $^{\circ}$ ⁽²⁾, 20 $^{\circ}$ ⁽³⁾, 38.8 $^{\circ}$ ⁽⁹⁾, and 27.54 $^{\circ}$ ⁽¹⁰⁾; in the present study, they were 27.66 $^{\circ}$ and 28.35 $^{\circ}$ on the right and left sides, respectively. These sagittal angulations varied because the trajectory axis was different in the literatures. For the pars screw entry point, there was reported to be 10 $^{\circ}$ to 15 $^{\circ}$ and 35 $^{\circ}$ in axial and sagittal angulations, respectively, by Mummaneni et al⁽⁴⁾. In this study, the mean axial angulations were 16.85 $^{\circ}$ and 16.13 $^{\circ}$ on the right and left sides, respectively. The mean sagittal angulations were 36.19 $^{\circ}$ and 36.21 $^{\circ}$ on the right and left sides, respectively. These values were not different from the previous study.

The measured length between the distance of the screw entry point to the junction of the pedicle and body of the C2 vertebra varies depending on the technique of measurement. Xu et al described the pedicle length as a distance between the most anterior and posterior points of pedicle axis projection. It was 25.6 mm in males and 25.5 mm in females⁽³⁾. Howington et al defined the pedicle length as a distance from the posterior surface of the inferior articular process to the junction of the pedicle with the C2 vertebral body, and was reported to be 16.6 mm⁽⁹⁾. Naderi et al described

the pedicle length as a distance between the screw entry point to the junction of the PIC and C2 vertebral body, and was reported to be 28.8 mm². In the present study, the pedicle lengths were 27.79 and 27.43 mm on the right and left sides, respectively. The lengths of distance from pars screw entry point were 30.90 and 30.66 mm on the right and left sides, respectively.

The pedicle width was used in different terminology in many literatures. The pedicle (inferior) width was reported to be 7.9 mm by Howington et al⁽⁹⁾, 6.0 and 5.5 mm on the right and left sides, respectively, by Naderi et al⁽²⁾. In this study, we measured the pedicle width as the inferior width, located medial to the transverse foramen. This width can be utilized for determining the size of the screw. In our series, the mean pedicle widths were 5.68 and 5.96 mm on the right and left sides, respectively. Our mean pedicle widths were close to 5.47 mm reported by Bunmaprasert et al⁽¹⁰⁾.

The authors found the pedicle height to be 7.90 and 8.56 mm on the right and left sides, respectively. A previous study reported the mean pedicle height to be 10.5 and 9.1 mm on the right and left sides, respectively⁽⁹⁾. Bunmaprasert et al reported the mean pedicle height to be 7.54 mm in Thai population⁽¹⁰⁾, which was close to our mean pedicle height.

In the present study, the trajectory that parallel to the superomedial border of the C2 pedicle is considered to be a safe trajectory for screw placement⁽¹¹⁾. The method reported by Xu et al (about 30 $^{\circ}$ towards the midline in the transverse plane and 20 $^{\circ}$ cephalad in the sagittal plane)⁽³⁾, carried a higher risk for neurovascular injury. In their study, the screws had lateral violations into the vertebral artery in 4 of 16 screw placements.

Regarding selection of screw diameter, anatomical variation may be encountered and risk of injury to the neurovascular structures may be higher. The size of screw routinely used in adult as recommend by most authors is 4 mm. Our series demonstrated that 11 of 72 pedicles (15.28%) had pedicle width less than 4 mm (Fig. 5). Bunmaprasert et al also mentioned that 4.5-mm-diameter-screw insertion is close proximity to the spinal cord and vertebral artery⁽¹⁰⁾. Consequently, 4-mm-diameter-screw cannot be routinely use in Thai population and pre-operative imaging is required before consideration of C2 screw placement, especially in female patients.

If the C2 transverse foramen is on the screw path, to reduce the risk of neurovascular injury, the length of the screw needs to be less than the distance



Fig. 4 Photograph showing the location of the pedicle and pars interarticularis purpose by Ebraheim et al⁽⁷⁾.

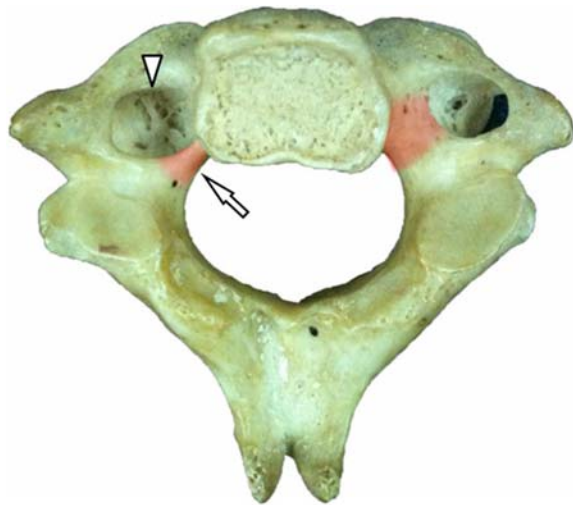


Fig. 5 C2 inferior view; the pedicle width is 2.96 mm on the right side (arrow) and 5.38 mm on the left side; the right transverse foramen (arrowhead) is located more medial than the left one.

between the entry point and transverse foramen. Therefore, pre-operative evaluation using computed tomography (CT) of the cervical spine is essential to study size and length of the C2 pedicle before C2 transpedicular screw placement.

Although the navigation system is helpful for safe screw placement, this device is still not available in most hospitals in Thailand. Fluoroscopy is play a major role in the treatment of occipitocervical disorder and is available in almost general hospitals and larger hospitals in Thailand. From the data of our present study, using the intraoperative fluoroscopy, we recommend a guideline for safe C2 screw placement as follows;

Pedicle screw placement (Fig. 6): the entry point is a point 5 mm inferior to the superior border of the C2 lamina and 7 mm lateral to the lateral border of the spinal canal, the axial angle is 30° and the sagittal angle is 28°. The length of the distance is 27 mm.

Pars screw placement (Fig. 7): the entry point

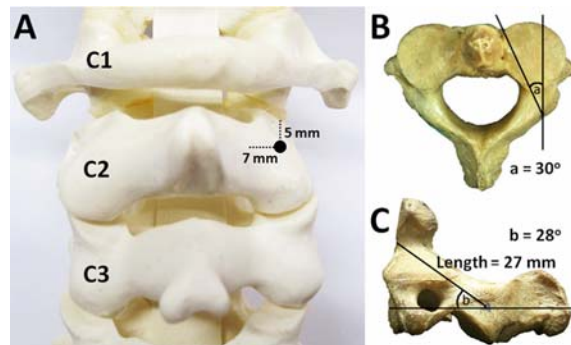


Fig. 6 Recommendation for C2 pedicle screw placement: (A) entry point (black circle); (B) axial angle; (C) sagittal angle and length.

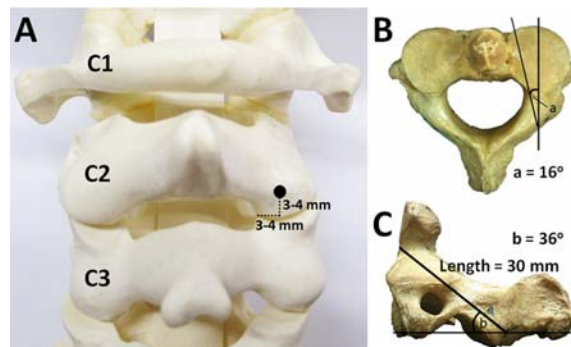


Fig. 7 Recommendation for C2 pars screw placement: (A) entry point (black circle); (B) axial angle; (C) sagittal angle and length.

is a point 3 to 4 mm superior and lateral to the medial aspect of the C2-3 facet joint, the axial angle is 16° and the sagittal angle is 36°. The length of the distance is 30mm.

Conclusion

The C2 pedicle complexes are distinct anatomical structures. The authors purpose a recommendation for safe C2 screw placement using the intraoperative fluoroscopy. Owing to our study, there were some anatomic variables that increase risk of the neurovascular injury. Preoperative spinal CT is essential to evaluate both the anatomy of C2 pedicle and vertebral artery in the transverse foramen before C2 screw placement.

What is already known on this topic?

Many anatomical studies proposed guidelines for C2 pedicle screw placement. The exact locations of the C2 pedicle and pars interarticularis are still

controversial.

What this study adds?

The appropriate entry point and trajectory for placement of pedicle and pars screws in Thai population were described. Several parameters in Thai population were close to those of previous studies.

Potential conflicts of interest

None.

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การศึกษากายวิภาคศาสตร์ของ C2 pedicle และ pars interarticularis ในประชากรไทย

อัศคพงษ์ นิตติสิงห์, กীরติ จรูญธรรมวงศ์, ชุมพล เจตจำนงค์, หลีกชัย พลวิจิตร, บรรพต สิทธินามสุวรรณ

ภูมิหลัง: C2 pedicle และ pars interarticularis เป็นโครงสร้างที่มีความจำเพาะของลักษณะทางกายวิภาคศาสตร์ และพบความแปรผันได้ของกายวิภาคศาสตร์ได้ในประชากร ยังเป็นที่ถกเถียงกันเกี่ยวกับตำแหน่งที่แท้จริงของ C2 pedicle และ pars interarticularis

วัตถุประสงค์: งานวิจัยนี้เพื่อศึกษาทิศทางและความยาวของการใส่สกรูที่ C2 pedicle และ pars interarticularis ที่ปลอดภัย

วัสดุและวิธีการ: งานวิจัยนี้ศึกษากระดูกสันหลังระดับ C2 จากผู้บริจาคร่างกายทั้งหมด 32 ชิ้น คณะผู้วิจัยวัดความยาวและมุมที่เกี่ยวข้องกับ C2 pedicle และ pars interarticularis โดยใช้อุปกรณ์สำหรับวัดของเวอร์เนีย และอุปกรณ์วัดมุมแบบดิจิทัล

ผลการศึกษา: สำหรับการใส่สกรูที่ C2 pedicle พบว่าตำแหน่งที่เหมาะสมสำหรับใส่สกรูคือตำแหน่งที่อยู่ต่ำกว่าขอบบนของ C2 lamina 5 มิลลิเมตร และอยู่นอกต่อขอบด้านข้างของช่องกระดูกสันหลัง 7 มิลลิเมตร มุมในระนาบนอน 30 องศา มุมในระนาบตั้ง 28 องศาและความยาวเท่ากับ 27 มิลลิเมตร สำหรับการใส่สกรูที่ C2 pars interarticularis พบว่าตำแหน่งที่เหมาะสมสำหรับใส่สกรูคือตำแหน่งที่อยู่เหนือและด้านข้างต่อขอบในของข้อต่อระหว่าง C2 และ C3 ประมาณ 3-4 มิลลิเมตร มุมในระนาบนอน 16 องศา มุมในระนาบตั้ง 36 องศาและความยาวเท่ากับ 30 มิลลิเมตร

สรุป: คณะผู้วิจัยได้เสนอคำแนะนำเกี่ยวกับการใส่สกรูที่ C2 pedicle และ pars interarticularis ที่ปลอดภัย ตำแหน่งดังกล่าวเป็นตำแหน่งที่เหมาะสมสำหรับประชากรไทย