Original Article

The Feasibility Study of C1 Posterior Arch Crossing Screw Fixation in Adult Thai Population: A Computed Tomographic Morphometric Analysis Study

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Objective: Atlantoaxial instability can be caused by various etiologies and surgical fixation is often required. Various methods have been described for atlantoaxial fixation. Screw fixation is associated with an increased risk of vertebral artery injury especially in patients with an anomalous vertebral artery location or abnormal bony anomalies. A new C1 posterior arch crossing screw fixation technique was proposed to reduce the risk of vertebral artery injury. The present study aimed to assess morphometric CT analysis of atlas for C1 posterior arch crossing screw fixation in Thai people.

Materials and Methods: The present research was an observational study that reviewed 150 computed tomography (CT) scans of the patients who had neck trauma or any other complaint requiring craniocervical investigations. Atlantoaxial articulation deformities due to trauma, infections, neoplasm, congenital anomaly, inflammatory disease, incomplete CT scan analysis, and history of surgical intervention of the cervical spine were excluded. All the images were measured for the height of the posterior tubercle, the width of the posterior arch was measured bilaterally in three parts on the axial plane, part 1: medial of the VA groove, where the arch transforms into the VA groove, part 2: the middle part between the posterior tubercle and medial of the VA, and part 3: posterior tubercle, length of the screw, and the screw projection angle was calculated.

Results: Out of the 139 CT scans analyzed, the mean measurement of posterior arch height was 7.45±1.03 mm, wherein 73.3% exceed 7 mm. The mean width of the left posterior arch in part 1, 2, and 3 was 4.50±0.70 mm, 4.90±0.70 mm, and 5.70±0.80 mm, respectively, and the width of the right posterior arch in part 1, 2, and 3 was 4.50±0.70 mm, 4.80±0.70 mm, and 5.60±0.80 mm, respectively. The mean crossing screw length of the Left and Right was 17.02±3.04 mm and 17.37±2.75 mm, respectively. The mean angle of screw of the Left and Right was 24.62±3.38 degrees and 24.78±3.57 degrees, respectively. There were no significant differences in these variables between gender or sides ($p>0.05$) except the mean angle of the screw between gender ($p<0.05$).

Conclusion: C1 posterior arch screw fixation is feasible in the adult Thai population. Preoperative thin-cut CT is essential for planning successful posterior arch crossing screws placement.

Keywords: C1 posterior arch, Computed tomography, Crossing screw fixation

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Atlantoaxial instability can be caused by various etiologies and may result in disability pain, paresis, and even sudden death. Surgical fixation is often required to provide stability, realignment, decompression, and prevent neurological compromise until bony fusion occurs. Various methods have been described for atlantoaxial fixation. The methods widely used in C1 posterior fixation have included posterior wiring (Brooks and Gallie technique)[1,2], Halifax clamps, C1 to C2 transarticular screw (TAS) (Magerl technique)[3], and Segmental C1 to C2 fixation (Goel and harms techniques)[4,5].

Currently, the use of wiring or clamps has been replaced by screw fixation, which provides immediate stability, high fusion rate, and eliminate the need for postoperative external immobilization[6,7]. Posterior screw fixation of the atlas is the most popular technique among various methods for C1 fixation. However, screw fixation is associated with an increased risk of vertebral artery (VA) injury, especially in patients with an anomalous VA location or abnormal bony anomalies[8]. To reduce the risk of VA injury, salvage procedure, a new technique of the C1 posterior arch crossing screw (PAS) combined with C2 laminar screws (LMS) fixation when there is anatomical variation, traumatic, or iatrogenic VA

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injury or occlusion, was considered[9]. Thus, the authors analyzed the feasibility of a new technique of the C1 PAS fixation based on anatomical evaluation of the C1 posterior arch in the adult Thai population.

The present study aimed to assess morphometric computed tomography (CT) analysis of atlas for C1 PAS fixation in the adult Thai population.

Materials and Methods

The study was approved by the Institutional Research Ethics Committee of Sunpasitthiprasong Hospital (065/2561). The retrospective medical chart and image reviews were conducted at the Department of Orthopedics Sunpasitthiprasong Hospital, Ubon Ratchathani, Thailand between January 2017 and December 2019. One hundred fifty patients, over 20 years old, who had neck trauma or any other complaint requiring craniocervical investigation were randomly selected and included in the present study. All CT images of the patients were taken using a General Electric CT Scanner (Optima CT 660; GE Healthcare Japan Corporation) with a slice thickness of 2 mm (120 kV, 62.5 mA, 512×512 matrix). Bone windows were used for analyses. Parameters on CT's were measured using the computerized image analysis software PACS (Picture Archiving Communication System, Agfa Corporation, Ridgefield, NJ)

Eleven patients with incomplete CT analyses were excluded. Furthermore, Atlantoaxial articulation deformities due to trauma, infections, neoplasm, congenital anomaly, inflammatory disease, and those with a history of surgical intervention were also excluded. All the images were measured using the PACS by two independent surgeons. An interval of three months was used between the repeated measurements for analysis of intra- and inter- observer reliability. Standardization of the measurements was performed before the study by thorough discussion and interpretation of the instructions.

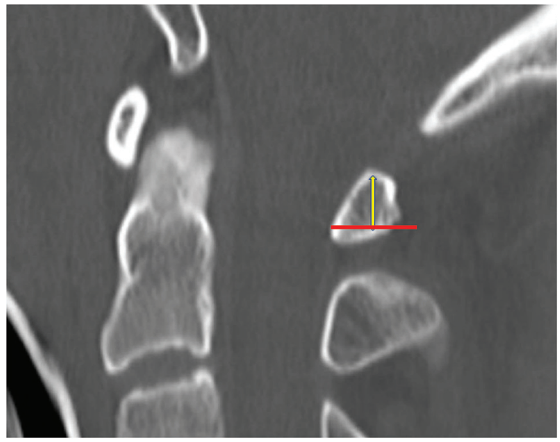

Figure 1. The yellow arrow shows the height of the posterior tubercle in the mid-sagittal section of computed tomography of the cervical spine.

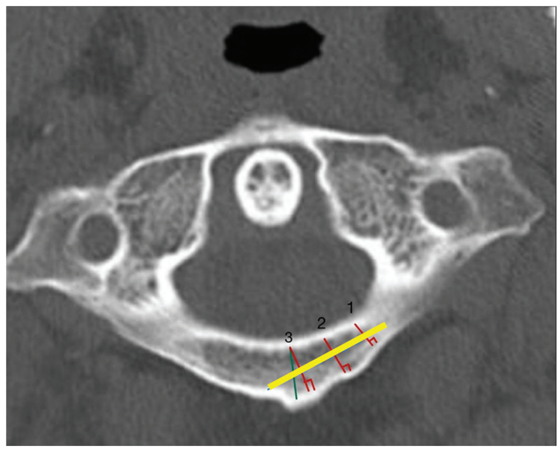

Figure 2. Axial cut selected by the greatest width of the level of the lamina. Red-colored lines on the left-sided posterior arch show the width of the posterior arch; part 1, medial of the VA groove, where the arch transforms into the VA groove; part 2, the middle part between the posterior tubercle and medial of the VA; part 3, posterior tubercle. The yellow arrow shows the screw length.

The height of the posterior tubercle was measured through the inner cortex diameter, which was the widest and perpendicular to the horizontal line in the middle plane of the posterior tubercle on the sagittal plane (Figure 1). The width of the posterior arch was measured bilaterally in three parts on the axial plane. Those were the posterior tubercle, which is the medial side of the VA groove, where the arch transforms into the VA groove, the middle part between the posterior tubercle, and the medial side of the VA groove. The measurement of the width of the posterior arch started from the inner cortex of the dorsal part posterior arch to the inner cortex of the ventral part of the posterior arch which perpendicular to the dorsal cortex of the posterior arch and screw axis (Figure 2). The length of the screw was measured bilaterally from the entry point on the opposite side of the posterior tubercle to the medial side of the VA groove, and the screw projection angle was calculated as the angle of the screw between the horizontal line on the axial plane and longitudinal axis of the posterior arch of C1 as described by Jin et al[10] (Figure 3). The patients' age, gender, and body mass index (BMI) were recorded using measurement data for statistical analysis.

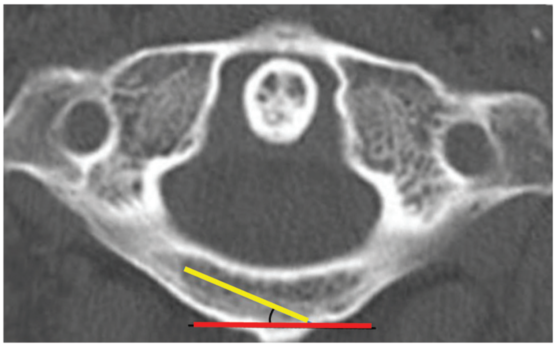

Figure 3. The yellow arrow shows the screw length, the red arrow shows the horizontal line and the black shows the screw projection angle.

Statistical analysis

Statistical analysis was performed using the statistical software Stata, version 14.2 (StataCorp LP, College Station, TX, USA). The t-test was used to assess the statistical significance of the result between the two groups. A p-value of less than 0.05 was considered to be statistically significant. The values were presented as mean ± standard deviation. The kappa coefficients were used to assess intra-and interobserver reliability.

Results

Between 2017 and 2019, there were 84 males and 55 females who had neck trauma or any other complaint requiring craniocervical investigations and underwent CT analysis. The patients' age ranged from 21 to 75 years in the male group and 20 to 76 years in the female group. Both groups had normal BMI, which were 21.6±0.3 in male and 21.7±0.4 in female. The demographics and characteristic data are summarized in Table 1. Within age and gender group, the measurements of mean posterior tubercle height, the width of the posterior arch, screw length and projection angle are shown in Table 2.

Table 1. Demographic data

Variable	Male (n=84)	Female (n=55)	p-value
Age (year)			0.31
Mean±SD	45.30±1.70	48.20±2.10	
Minimum	21	20	
Maximum	75	76	
BMI (kg/m^2)			0.91
Mean±SD	21.60±0.30	21.70±0.40	
Minimum	14.20	17.10	
Maximum	31.50	30.40	

BMI=body mass index; SD=standard deviation

Table 2. Summary of results of the study

Variable	Mean±SD	Min-max
Height of the posterior tubercle (mm)	7.45±1.03	5.04 to 10.92
Length of the screw (mm)		
Right	17.37±2.75	11.96 to 27.01
Left	17.02±3.04	11.39 to 26.36
Angle of screw (°)		
Right	24.78±3.57	15.68 to 36.20
Left	24.62±3.38	14.42 to 36
Width of posterior arch (mm)		
Right (parts 1, 2, 3)*	4.50±0.70, 4.80±0.70, 5.60±0.80	3.10 to 7.20, 3.10 to 7.20, 3.40 to 8.10
Left (parts 1, 2, 3)	4.50±0.70, 4.90±0.70, 5.70±0.80	3.00 to 7.20, 3.00 to 6.70, 3.70 to 7.80

SD=standard deviation

* Part1: medial of the VA groove, where the arch transforms into the VA groove; part 2: the middle part between the posterior tubercle and medial of the VA; part 3: posterior tubercle

Height of the posterior tubercle

The mean values for the posterior tubercle height were 7.45±1.03 mm with a range of 5.04 to 10.92 mm, which was 7.52±0.11 in the male group, and 7.35±0.14 in the female group. The posterior tubercle had a height of 7 mm or greater in 73.3% (102/139) and had a height 8 mm or greater in 25.8% (36/139). There was no significant difference in this variable between gender (Table 3).

Width of the posterior arch

The mean width of the left posterior arch (part 1) was 4.5±0.7 mm with a range of 3.0 to 7.2 mm, left posterior arch (part 2) was 4.9±0.7 mm with a range of 3.0 to 6.7 mm, and left posterior tubercle (part 3) was 5.7±0.8 mm with a range of 3.7 to 7.8 mm. The mean width of the right posterior arch (part 1) was 4.5±0.7 mm with a range of 3.1 to 7.2 mm, right posterior arch (part 2) was 4.8±0.7 mm with a range of 3.1 to 7.2 mm, and right posterior tubercle (part 3) was 5.6±0.8 mm with a range of 3.4 to 8.1 mm. The width of the left posterior arch in males was over 3.5 mm. in 95% (80/84). The width of the right posterior arch in males was over 3.5 mm. in 90.4% (76/84). The width of left and right posterior arch in the female was over 3.5 mm. in 96.3% (53/55). There were no significant differences in these variables between gender or sides (Table 3, 4).

Table 3. Comparison of the variable between gender

Variable	Male; mean±SD	Female; mean±SD	p-value
Height of the posterior tubercle (mm)	7.52±0.11	7.35±0.14	0.35
Width of posterior arch: left (mm)			
Part 1	4.53±0.07	4.58±0.10	0.70
Part 2	4.98±0.08	4.79±0.08	0.16
Part 3	5.66±0.08	5.87±0.10	0.14
Width of posterior arch: right (mm)			
Part 1	4.56±0.08	4.68±0.10	0.75
Part 2	4.91±0.09	4.83±0.09	0.55
Part 3	5.57±0.09	5.81±0.11	0.14
Screw length (mm)			
Left	17.21±0.32	16.72±0.42	0.35
Right	17.69±0.29	16.90±0.36	0.09
Screw angle (°)			
Left	24.11±0.30	25.40±0.54	0.02
Right	24.26±0.32	25.59±0.57	0.03

SD=standard deviation

Table 4. Comparison of Left and Right variables in individual gender

Variable	Left; mean±SD	Right; mean±SD	p-value
Male			
Width of posterior arch (mm)			
• Part 1	4.53±0.07	4.56±0.08	0.83
• Part 2	4.98±0.08	4.91±0.09	0.61
• Part 3	5.66±0.08	5.57±0.09	0.49
Screw length (mm)	17.21±0.32	17.69±0.29	0.28
Screw angle (°)	24.11±0.30	24.26±0.32	0.74
Female			
Width of posterior arch (mm)			
• Part 1	4.58±0.10	4.60±0.10	0.88
• Part 2	4.79±0.89	4.83±0.09	0.74
• Part 3	5.87±0.10	5.81±0.11	0.67
Screw length (mm)	16.72±0.42	16.90±0.36	0.75
Screw angle (°)	25.40±0.54	25.59±0.57	0.81

SD=standard deviation

Crossing screw length and angle

The mean crossing screw length for the left and right was 17.02±3.04 mm with a range of 11.39 to 26.36 mm and 17.37±2.75 mm with a range of 11.96 to 27.01 mm, respectively. The screw length of both sides within the gender group was not significantly different (p>0.05). The mean projection angle of the right side was 24.78°±3.57° and 24.62°±3.38° on the left side. Furthermore, the results showed that the screw projection angle in male, which were 24.11° on the left and 24.26° on the right were statistically lower than in female, which were 25.40° on the left and 25.59° on the right (Table 3). There were also no significant differences in theses variables between sides and gender (p>0.05) (Table 4).

Inter-observer and intra-observer reliability

The kappa coefficients for intra-observer reliability of posterior tubercle height, the width of the posterior arch, length of the screw, and angle of the screw were 0.74 (95% confidence interval [CI] 0.61 to 0.86) and 0.64 (95% CI 0.49 to 0.79), respectively. The kappa coefficients for interobserver reliability were 0.61 (95% CI 0.45 to 0.76) and 0.61 (95% CI 0.45 to 0.76), respectively, indicating substantial agreement.

Discussion

Atlantoaxial instability has been treated by various fixation methods. Posterior wiring stabilization and fusion using Gallie or Brooks et al[1,2] technique was technically easy but did not provide adequate stability, which resulted in pseudarthrosis rates of up to 30%, carried neurologic risk, and required postoperative external orthosis. TAS that was introduced by Magerl and Seemann[3] provides excellent stability and fusion rate and eliminate the need for a postoperative cervical orthosis. However, this technique is technically demanding, and required anatomical atlantoaxial alignment before screw placement[11]. Furthermore, 20% of the patients have an anomalous VA course that places it at risk from TAS fixation[8].

Segmental screw plate or screw-rod constructs has become widely accepted because it provides excellent stability similar to TAS, allows intraoperative reduction of atlantoaxial joint, has less risk of VA injury and bony fusion in almost 100% of the cases[6]. The C1 LMS fixation is one of the most popular techniques for C1 fixation, but it is technically demanding because the anatomy of the atlas is complex and there is potential for neurovascular injury. It is also difficult to insert the screws, especially when the lateral mass is covered by an anomalous VA, rich paravertebral venous plexus, which may cause massive bleeding during screw insertion[12,13]. Failure to recognize these types of variations may lead to the formation of AV fistula, dissection, or occlusion of the VA[14], which may cause cardiovascular and respiratory impairment, medulla, or cerebellar infarction, and rarely death. C2 neuropathy is also a well-known complication after C1 LMS fixation, whether the C2 root is sacrificed or not[15-17]. The use of this technique is also influenced by anatomical constraints, for example, congenital narrowing of the pedicle, bony pathology, screw entry point, surgical techniques, and the surgeon's experience. Thus, alternative methods, for example, Occipitocervical fixation and PAS are needed to overcome these complications. Intralaminar C1 PAS is a new method for C1 fixation[10]. This method provides rigid short-segment fixation, good screw purchase, and technically simple procedure even without intraoperative fluoroscopy. Therefore, a PAS seems safe, stable, accessible, and less technically demanding and learning curve than other C1 fixation techniques. It can be performed under direct visualization and lower risk of bleeding from VAI and venous plexus at the time of screw insertion and complications of occipitocervical fixation. A Few biomechanics analysis demonstrated that the PAS had significantly superior pullout strength in the axial direction compared with C1 LMS[10,18,19]. Thus, the authors decided to study the morphometric analysis of atlas for the feasibility of C1 PAS fixation in the Thai population, which may be a safe alternative when required.

According to the present study, the mean measurement of the posterior arch height was 7.45±1.03 mm with a range of 5.04 to 10.92 mm, wherein 73.3% (102/139) exceed 7 mm compared with 91.51% in the series by Jin et al(10). The average width for the medial part of the VA groove, where the arch transforms into VA groove, was 4.5±0.7 mm with a range of 3.1 to 7.2 mm on the right side and 4.5±0.7 mm with a range of 3.0 to 7.2 mm on the left. The width of the middle part was 4.8±0.7 mm with a range of 3.1 to 7.2 mm on the right side and 4.9±0.7 mm with a range of 3.0 to 6.7 mm on the left. The width of the posterior tubercle was 5.6±0.8 mm with a range of 3.4 to 8.1 mm on the right side and 5.7±0.8 mm with a range of 3.7 to 7.8mm on the left. Six cases out of 139 (4.3%) were not suitable for screw placement because their posterior arch was thinner than 3.5 mm. There were no significant differences between gender or sides.

When compared, the present study was consistent with their result. Jin et al[10], the only study before this, measured 64 CT scans and found that 93.40% of the atlas posterior arches could hold 3.5-mm-diameter multiaxial screws and the mean value of the posterior tubercle height was 7.88±0.24 mm, in which 91.51% of posterior tubercle height was greater than 7 mm, indicating that most of the posterior tubercles could contain two 3.5 mm crossing screw fixations. Hong et al[20] showed that the average width of the lateral arch in 30 cases was 4.7±1 mm. Kaplan[21] found that the anterior medial side of the VA groove to the posterior tubercle was 12 to 16 mm.

However, the present study has a different measurement compared with the others[10,20,21]. The authors measure the width of the posterior arch starts from the inner cortex of the dorsal part posterior arch to the inner cortex of the ventral part of the posterior arch which perpendicular to the screw axis. Thus, this method can be implied as a reasonable entry point for posterior arch screw fixation and determine feasible intra-operative screw size. It is possible that the direction of the screw, which was perpendicular to the posterior arch width of the present study method is ideal to be performed and reach more cancellous bone of the posterior arch than any other studies related.

The present study revealed that 73.3% (102/139) of the posterior arch height exceed 7 mm and showed that 79.8% (111/139) of part 1 of posterior arch width, 89.9% (125/139) of part 2 of posterior arch width, and 97.8% (136/139) of part 3 of posterior tubercle width had a width of 4 mm or greater, and 72.6% (101/139) of the screw were 15 mm or greater. These data imply that the surgeons can insert C1 PAS into adult Thai patients. Furthermore, the present analysis shows that if including the margin of error for screw placement in posterior tubercle height, the possibility of screw placement is likely to decrease in the adult Thai population.

PAS fixation provides a safe alternative procedure to reduce the risk of the VA injury in patients with a small pedicle of the vertebral arch, anomalies of VA, fracture of the lateral mass, and in cases of traumatic or iatrogenic unilateral VA occlusion[22].

There are some key techniques for placing the posterior arch screws successfully. First, using the same size tap as the screw diameter to reduce excessive torque, which leads to splitting and fracturing of the posterior arch. Second, placing posterior arch screws about 10 mm. from the midline can achieve an adequate length of the screw and increases the fixation strength. However, there is still some risk during surgery if the posterior tubercle height or thickness is insufficient for the screw purchase, the posterior arch can be destroyed. Besides, a deep length of screw can cause a dural tear or spinal cord injury, so the surgeon should use a spatula or Penfield to protect these tissues[23].

However, there are some limitations to the present study. First, the study gave less consideration to the surrounding anatomy such as the VA and others. Second, the study was only a CT morphometric analysis. It is necessary to consider with further clinical details, the safety and effectiveness of C1 PAS fixation. Last, the measurement on CT images may be affected by image techniques, resulting in errors that can cause the recorded values of variables to be different from the true ones.

Conclusion

Preoperative thin-cut CT is essential for planning successful PAS placement and favorable clinical results. In addition, the present study investigation found that the use of a C1 PAS was possible in adult Thai patients.

What is already known on this topic?

PAS is a novel C1 fixation method. It can be safely practiced and imposes little risk of vertebral artery injury. However, there was ethnic differences in atlas morphology, which can influence the feasibility of screw application in Thai population, thereby helping in preoperative decision making.

What this study adds?

Preliminary CT morphometry data of the posterior arch of the atlas in adult Thai population shows that C1 PAS are anatomical feasible in a large portion of Thai population. However, caution and meticulous preoperative morphometric assessment are advised when using this technique in the Thai population, as up to 25% of posterior arch may not be suitable for screw placement.

Conflicts of interest

The authors have nothing to disclose.

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