Appropriate Size and Angulation for Axis Screw Placement

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Background: *A screw larger than 4.0-4.5-mm-diameter screw has now become the preferred size for providing maximum anchorage during atlantoaxial segmental fixation and transarticular screw fixation. At present, there are no studies available of Axis (C2) morphology related to screw placement specifically in Thai patients, a situation that might result in surgical complications.*

Objective: *The purpose of this study was to determine the typical width, height and angulations in both C2 pars interarticularis and C2 pedicle in Thai population.*

Material and Method: *A radiographic-based study was conducted in 54 Thai patients aged over 20 from July 2011 to January 2012 in Chiang Mai University Hospital. C2 parameters including the height, width, medial angulation and superior angulation of the pars interarticularis and the pedicle were measured by using a CT scan. All parameters were measured using the ONIS 2.3 program.*

Results: *The C2 pedicle in Thais was found to have a mean width of 5.47 mm (range 3.28-6.81 mm), a height 7.54 mm (5.9-9.54), a superior angulation of 27.54° (range 20.65°-33.95°), and a medial angulation of 38.95° (range 28.07°-52.85°). C2 Pars interarticularis had a mean width of 7.72 mm (range 5.93-10.61 mm), a height of 4.47 mm (range 2.33-6.3 mm), a superior angulation of 49.85° (range 41.89°-58.65°), and a medial angulation of 6.76° (range 1.18°-13.5°).*

Conclusion: *Because the mean height of pars interarticularis is 4.47 mm, atlantoaxial arthrodesis should not use 4.5-mm-diameter screw, especially transarticular screws, due to the possibility of vascular and nerve damage.*

Keywords: *Second cervical vertebra (Axis), Screw placement, Size and angulation*

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Various traumatic and non-traumatic disorders can create instability in the atlantoaxial (C1-C2) articulation, resulting in neck pain, deformity, limitation of motion and spinal cord compression. Posterior atlantoaxial (C1-C2) fusion and fixation is the main surgical treatment. That procedure can be divided into posterior wiring, transarticular screw fixation and segmental fixation (Fig. 1).

For C1-C2 transarticular screw fixation, the screws are passed from the posterior neural arch of the axis (C2), through the C2 pars interarticularis or isthmus, the facet joints and the lateral mass of the atlas (C1). Segmental fixation consists of C1 lateral mass fixation and C2 fixation, including C2 pars or C2 pedicle fixation (Fig. 2), followed by assembly with rods or plates. Accurate positioning of the screws in the pars interarticularis and the pedicle of C2 is vital. The C2 pedicle is the bony area that bridges between the vertebral body and the posterior neural arch. However, these two anatomical areas join the narrowest region between the superior and inferior articular process of C2, so major surrounding structures are at risk during screw insertion including the spinal cord medially and the vertebral artery laterally[1,2].

C1-C2 transarticular screw fixation and segmental fixation have been demonstrated to provide higher biomechanical strength than wiring. However, there is a possibility of screw perforation out of the pedicle and pars interarticularis of the axis. Ondra et al[3] found that there were screw perforations in 8 of 150 screws, and complications from the resulting injury to blood vessels and nerves occurred in 2.7% of the cases. Furthermore, Lauryssen et al[4] reported a 4.1% vertebral artery injury rate after C2 screw fixation with a mortality rate of 0.1%.

Placement of C1-C2 transarticular screws and C2 screws in the smaller size patients requires appropriate screw diameters and accurate trajectories to minimize neurovascular injury; the practice in Thailand generally uses 3.5-mm-diameter screws. However, 3.5-mm-diameter screws have significant biomechanical disadvantages compared to the larger screws, e.g. 4.0-mm or 4.5-mm. The purpose of this study was to measure the width, height and angulations in both C2 pars interarticularis and C2 pedicle in Thai

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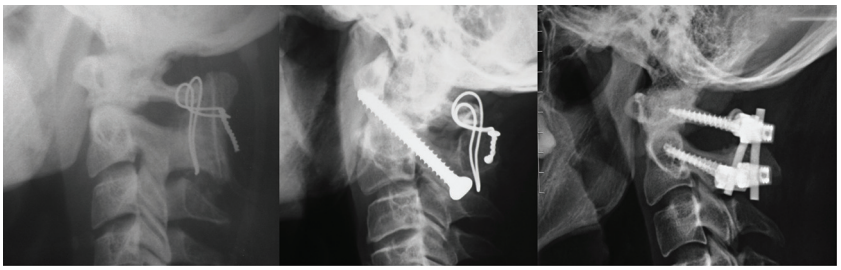

Fig. 1 Fixation techniques for atlantoaxial arthrodesis (fusion) (left: posterior wiring, middle: transarticular screw fixation, right: segmental fixation).

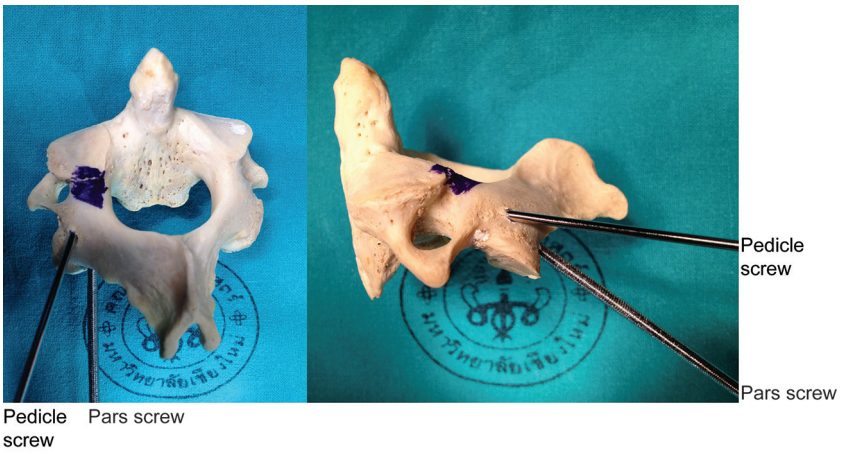

Fig. 2 Trajectories of the C2 pedicle screw and C2 pars screw. Painted area demonstrates the narrowest area of the C2 posterior element (C2 isthmus) where these two screws join their paths.

patients and to study the feasibility for using 4.0-mm and 4.5-mm-diameter screws as C2 fixation.

Material and Method

The present study was performed with patients aged over 20 who underwent a CT scan of the cervical spine. Data were collected from the Department of Radiology, Faculty of Medicine, Chiang Mai University Hospital, during July 2011-January 2012. Axis parameters measured included height, width, medial angulation, superior angulation of the pars interarticularis and the pedicle. Information collected included demographic data, gender, age, hospital number, images from the CT cervical spine scanner, record number of the radiographic study.

Exclusion criteria

Patients with a history of disease or injury to the upper cervical spine or previous upper cervical spine surgery were excluded.

A sample of 53 CT cervical spine radiographs of patients (53 pars, 53 pedicles) were collected and saved as Dicom files, which allowed adjustment of the images in various dimensions. Patient data were collected using a prepared record form.

Measurement

The measurement of axis parameters including height, width, medial angulation and superior angulation of the pars interarticularis and the pedicle were accomplished using CT cervical spine scans. Measurements were recorded as length (millimeters) and degrees by the single author repeating the measurements three times (intraobserver). Data were collected using the ONIS 2.3 program.

The ONIS 2.3 was available in three modes. The authors used the multiplanar (MPR) mode, which allowed adjustment of the angle, the plane and the axis of the radiographs. In this mode, the user had access to the radiographic study in each of the three planes. Each plane had a resolution of at least 1 image per 1 mm, so error of measurement was less than 1 mm.

Using MPR mode, a main plane was selected; then the program automatically processed the images

into the other two planes, providing an image of all three planes. In each case, the clearest image was chosen to be the main plane. For example, if the clearest image was the sagittal image, the height and superior angulation would be measured directly from that image (Fig. 3), whereas the width and medial angulation were measured from the horizontal plane image (Fig. 4). The following parameters of the axis spine were measured:

1. Height of the C2 pars interarticularis
2. Width of the C2 pars interarticularis
3. Medial angulation of the C2 pars interarticularis
4. Superior angulation of the C2 pars interarticularis
5. Height of the C2 pedicle
6. Width of the C2 pedicle
7. Medial angulation of the C2 pedicle
8. Superior angulation of the C2 pedicle

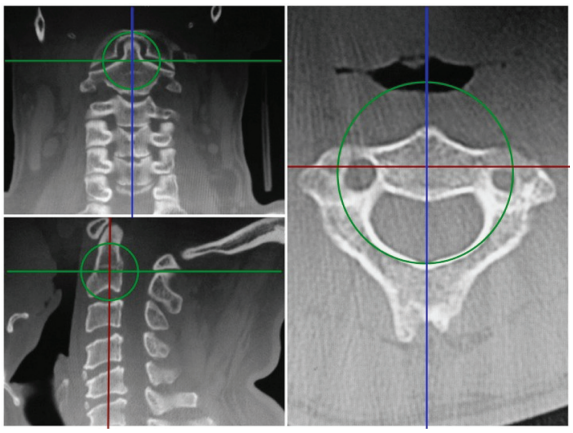

Fig. 3 Appearance of ONIS 2.3 images. A sagittal plane was selected as the main plane. The clearest image was the sagittal image (bottom left). The coronal (top left) and horizontal (right) images were appropriate for measuring the height, superior angulation of the par interarticularis and the pedicle of the Axis.

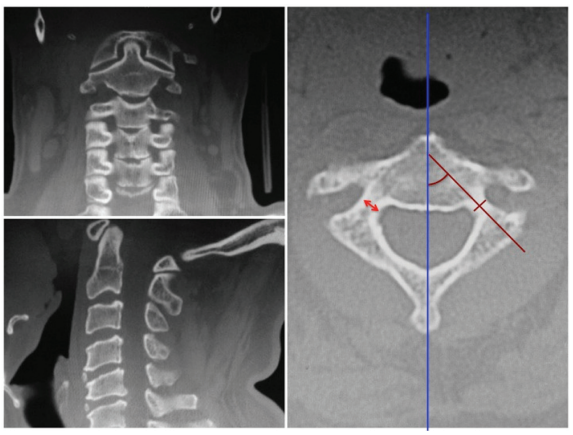

Fig. 4 A horizontal plane was selected as a main plane. The clearest image was a horizontal image (right). Measurements of the medial angulation, width of the par interarticularis and the pedicle of the Axis were recorded.

Parameter measurement with the horizontal plane image as the main plane

Parameters measured from the horizontal plane image included the width and medial angulation (when the image in the horizontal plane was the clearest image). Each time when a plane was needed to be set up, the images in all three planes would be adjusted as follows (Fig. 5).

1. In the coronal image, the odontoid (dens) must be clearly seen and be perpendicular to the horizontal plane (green line) and the sagittal plane must be symmetrically at the center of dens.
2. In the sagittal image, the superior facet of the axis spine must be parallel to the horizontal plain (green line).
3. In the horizontal image, the line of the sagittal plane (blue line) must divide the axis symmetrically.

When all three planes were well set-up, the medial inclination of the C2 pedicle was measured before adjusting the horizontal plane (green line) in the sagittal image. The image chosen in the horizontal plane was the one that showed the widest view of the pedicle. Medial angulation of the pedicle was measured

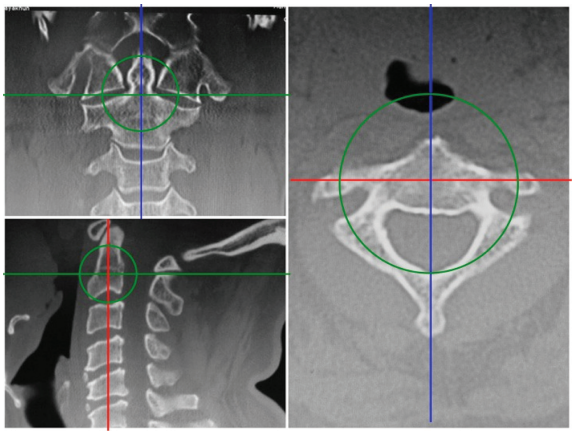

Fig. 5 Adjustment of the planes for making the parameter measurements.

as the angle from the axis of the pedicle to the sagittal plane (blue line). The width of the pedicle was then measured using the smallest one in the chosen image on a line perpendicular to the medial inclination of the pedicle (Fig. 6).

Measurement of the width and medial inclination of the pars interarticularis was quite difficult because of its relatively superior angulation, which meant that the entire pars interarticularis could not be seen in the horizontal plane. The horizontal plane image had to be adjusted until its angulation was close to the superior angulation of the pars interarticularis. That adjustment meant the entire pars interarticularis was seen in the horizontal image (which is not the true horizontal plane). When the green line moved, the horizontal image changed. The horizontal image that showed the widest pars interarticularis was chosen. Medial inclination of the pars interarticularis was the line that angulate with the sagittal plane (blue line). The width of the pars interarticularis was then measured perpendicular to its medial inclination at the narrowest area of the pars interarticularis.

Parameter measurement with the sagittal plane as the main plane

The measured parameters in the sagittal plane included height and superior angulation. Fig. 3 shows an image where the sagittal plane is the clearest picture. The plane must be set up by adjusting all three planes correctly. Measurement of the horizontal plane image required the followings:

1. In the coronal image, the odontoid process (dens) must be seen clearly and be perpendicular to the horizontal plane (green line) and the sagittal plane line must divide the dens symmetrically.

2. In the sagittal image, the superior facet of the axis spine must appear parallel to the horizontal plane (green line).

3. In the horizontal image, the sagittal plane (blue line) must divide the axis symmetrically.

When the accurate planes had been appropriately set-up, the height and superior angulation of the C2 pars interarticularis were measured by adjusting the blue line in the horizontal image (see the change in the sagittal image). The image in which the pars interarticularis could be seen most clearly was selected and superior angulation was measured using the angle between the line of pars interarticularis and the horizontal plane (blue line). Then, the narrowest pars interarticularis was measured. The narrowest point was the distance from the superior aspect of the vertebral foramen to the superior facet of the axis (Fig. 7).

Next, the height and superior angulation of the C2 pedicle were measured. That was quite difficult to accomplish using the horizontal plane because of the relatively high medial angulation of the C2 pedicle. Typically, the pedicle would not be seen in its entirety in the sagittal plane. Adjustment of the sagittal image had to be done before measuring the height and superior angulation of the pedicle. The image of C2 pedicle was then seen in this sagittal view (which is the true sagittal plane). The position of the blue line was adjusted to select the sagittal image that showed the widest pedicle. The superior angulation of the C2 pedicle was measured at the angle between the line of the pedicle axis and the horizontal plane (green line). Then, the

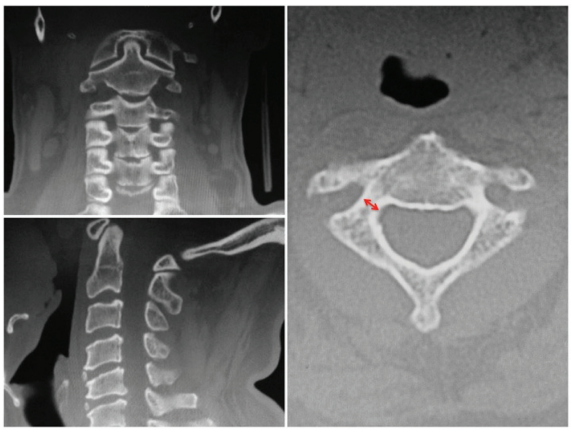

Fig. 6 Measuring the width of the C2 pedicle.

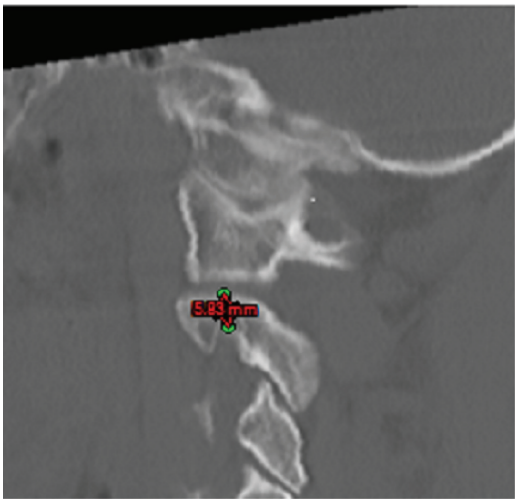

Fig. 7 Measuring the height at the narrowest part of the pars interarticularis.

height of C2 pedicle was measured perpendicular to the superior angulation of the pedicle at the narrowest area of the pedicle in the image.

After all eight parameters had been measured; the process was repeated twice, with the set-up of all planes being re-accomplished each time. Data values obtained by the three measurements were then averaged.

Results

Of the 60 cases studied, 54 cases were completely studied. Two were found to have abnormal anatomy (absence of the transverse foramen and presence of the odontoid pseudathrosis). Four cases were younger than age of 20 years were also excluded. Results are shown in Table 1 and 2.

Table 1. Parameters of C2 pars interarticularis

C2 pars interarticularis	Mean	Mode	SD
Width (mm)	7.72 (5.93-10.61)	7.735	1.08
Height (mm)	4.48 (2.33-6.3)	4.46	0.87
Superior angulation (degree)	49.85 (41.89-58.65)	49.72	4.36
Medial angulation (degree)	6.76 (1.18-13.5)	6.62	3.09

C2 = Axis

Table 2. Parameters of C2 pedicle

C2 Pedicle	Mean	Mode	SD
Width (mm)	5.47 (3.28-6.81)	5.495	0.82
Height (mm)	7.54 (5.9-9.54)	7.695	0.87
Superior angulation (degree)	27.54 (20.65-33.95)	27.67	3.39
Medial angulation (degree)	38.95 (28.07-52.85)	38.21	6.17

Discussion

Understanding the anatomy of the axis (C2) can help us to avoid adverse complications during fixation. Due to the physiological differences of Thai patients, whose body size is on average smaller than that of western people, the appropriate position and angulation for C2 screw fixation may not be identical.

Karaikovic et al[5] measured the pedicle diameter of the cervical spine using CT scans and found that pedicle diameter of the 2nd and 7th cervical spine are larger than the others. The ratio between the width and height of the cervical spine pedicle increased from the 2nd through the 7th. That means that the characteristics of the pedicle of the cervical spine (C2-C4) are more oval or round shaped in the lower cervical spine (C6-C7). The least medial angulation was at C2 and C7. The C2 and C3 pedicles also had superior angulation. Cervical pedicles were thicker in the medial part, which serves to protect the spinal cord, and reduced to half that thickness in the lateral part, which serves to protect the vertebral artery. Fixation of the 2nd cervical pedicle is less vulnerable to injury because at this level the vertebral artery lied more posteriorly and laterally.

Howington et al[6] found that the C2 pedicle made a medial angulation of approximately 35.2°-38.8° with the midline. Height, width, and length were 9.1 mm, 7.9 mm, and 16.6 mm, respectively. Onibokun et al[7] reported the average width of the C2 pedicle to be 5.8±1.2 mm and medial angulation of 43.9±3.9°. Ebraheim et al[8] suggested the proper position for pedicle screw insertion into the axis is 5 mm inferior, and 7 mm lateral to the midline of the cervical spine with 30° convergence and 20° cephalad. Xu et al(9) studied American people and found that the proper position for pedicle screw placement for that group is 5.4±1.2 mm inferior and 7.2±1.3 mm lateral to the midline of the cervical spine with 33° medial angulation and 20° superior angulation. Foley et al[10] studied the angle of the C2 screws used in pars interarticularis and pedicle screw fixation and found the proper angulation was 45° (range 24°-56°) medial angulation with 41° (range 23°-58°) superior angulation for pedicle screw fixation and 7.3° (lateral 10°-medial 21°) angulation, with 58.2° (range 49°-68°) superior angulation for pars screw fixation. Mandel et al[11] reported the width of the pars interarticularis was 8.2±1.5 mm in men and 7.2±1.3 mm in women. Height of the pars interarticularis was 8.6±2.0 mm in men and 6.9±1.5 mm in women.

The authors found the average medial inclination of C2 pedicle was 38.95° (range 28.07°-52.85°), which is similar to the findings of Onibokun et al[7] (43.9±3.9°) and Howington et al[6] (range 35.2°-38.8°). The superior angulation of the pedicle was 27.67° which is different from Foley et al[10] at 41° (range 23°-58°). The width and height was 5.47 mm and 7.54 mm respectively, which is clearly less than Howington et al[6] study (7.9 mm and 9.1 mm) and somewhat less than the study by Onibokun et al[7] (5.8±1.2 mm).

The medial inclination of C2 pars interarticularis in this study was 6.62°, superior

angulation was 49.72°, which is close to the study of Foley et al[10] (medial inclination 7.3° superior direction 58.2°). The width of pars interarticularis measured from this study is 7.72 mm, which is less than the study of Mandel et al[11] at 8.2±1.5 mm. The narrowest area of C2 pars interarticularis has the average height of 4.47 mm.

The present study found that C2 pars interarticularis has an average width of 7.72 mm (range 5.93-10.61 mm) and medial angulation angle of 6.76° (range 1.18°-13.5°), which indicates that screw trajectory misplacement in horizontal plane (medio-lateral) is less likely than in the sagittal plane (supero-inferior), which has an average height of 4.48 mm (range 2.33-6.3 mm).

The measurement of C2 pedicle revealed that the width of the pedicle was less than the height. Therefore, C2 pedicle screw insertion must be done particularly carefully to avoid screw misplacement in the horizontal plane (medio-lateral).

In case of C2, pars screw fixation or C2 pedicle screw fixation, 4.5 mm-diameter screws were used in western countries. Consideration should be given to fixation, especially in pars screws, because Thai people have a generally smaller body size. Because the average height of pars interarticularis is only 4.47 mm in Thais, there is an increased risk of major complications during surgery such as vertebral artery injury and nerve root injury. For that reason, 4.5 mm-diameter screws are not suitable for C2 fixation in Thai people. The surgeon needs to assess not only the size of pars interarticularis pre-operatively, but also the angulation of screw insertion in each individual patient. CT scans of cervical spine provide the best imaging study for bony configuration assessment. Pre-operative CT scanning of cervical spine is recommended in patients who require surgery, whether for C2 pedicle screw or pars interarticularis screw fixation.

The present study reveals that there are the differences of pars interarticularis among the individual patients (up to 6.33 mm), and these are comparable to those of previous western studies. This study demonstrates that for patients who have sufficient C2 pars interarticularis height 4.5 mm-diameter screws, which provide better biomechanics, can be inserted, but preoperative CT scan of cervical spine scan is often need to evaluate the bony configuration of each individual patient prior to surgery.

As to the trajectory or angulation appropriate for screw fixation, the pedicle medial angulation found in this study (an average of 38.95°) was similar to that reported by Onibokun et al[7] (43.9±3.9°) and Howington et al[6] (35.2°-38.8°). For pars interarticularis, Foley et al[10] found the medial inclination averaged 7.3° versus the average of 6.76° found in this study. On the other hand, the superior angulation of both C2 pedicle and pars interarticularis is significantly different from Foley et al's study, which found a pedicle superior angulation 27.67° vs. the 41.0° in this study and a pars superior angulation 49.72° vs. 58.2°. The difference may result from using the different reference plane.

The programs and new technology used in the present study had been developed within the past 15 years, making possible CT scans that can process bone configuration in various planes. This new method is much quicker and easier than the popular cadaveric study method in the past.

Conclusion

The study suggests that in Thai patients, the 4.5 mm-diameter screws should not be used for atlantoaxial arthrodesis, especially with the transarticular screw fixation technique. Because the screw must pass through the narrowest portion of the pars interarticularis, which has an average height of only 4.47 mm, it may result in increased risk of injury to adjacent neurovascular structures. A CT c-spine scan should be performed pre-operatively for every patient to assess individual characteristics before deciding whether using a 4.5 mm-diameter screw with its better biomechanics is appropriate or not.

What is already known on this topic?

There was limited study regarding the appropriate size and angulation for screw placement at the pars interarticularis and the pedicle of the second cervical vertebra (C2) or the axis in Thai population. In western countries, screws larger than 4.0-4.5 mm. has now become the preferred size for providing maximum anchorage. Using the parameters measured in the western population may not be suitable for Thais because screw perforation results in devastating complications to the surrounding neurovascular structures which may irreversible.

What this study adds?

The most important radiographic parameters for safety insertion of C2 pars interarticularis and pedicle screws are the width, height, superior angulation and medial angulation. The authors find that the mean height of C2 pars interarticularis is

4.47 mm (range 2.33-6.30), making 4.5-mm-diameter screw insertion is close proximity to the spinal cord and the vertebral artery. Preoperative CT scan of the cervical spine is required to study the radiographic parameters in order to realize the feasibility to place these screws. If not, the surgeons may need to fix C2 pars or C2 pedicles with the smaller screws (3.5-mm-diameter) which provide the inferior strength. Other measures may add the construct stability and prevent implant failure, e.g. wire augmentation, highly biologic potential fusion materials and prolonged postoperative immobilization.

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Potential conflicts of interest

None.

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ขนาดและมุมที่เหมาะสมในการวางตำแหน่งสกรูบริเวณกระดูกสันหลังส่วนคอข้อที่ 2 (Axis)

ต่อพงษ์ บุญมาประเสริฐ, นโรตม์ ตรีณรงค์, เอกฤทธิ์ คำขัด

ภูมิหลัง: การผ่าตัดเชื่อมข้อต่อและยึดตรึงกระดูกสันหลังส่วนคอข้อที่ 2 (C2) ด้วยสกรูที่มีขนาดเส้นผ่านศูนย์กลางใหญ่กว่า 4.0-4.5 มม. ให้ความแข็งแรงและมั่นคงสูงมาก จนถึงปัจจุบันนี้ยังไม่มีการศึกษารูปร่างของกระดูกนี้ในคนไทยว่าจะเหมาะสมกับการวางตำแหน่งสกรู ซึ่งมีผลข้างเคียงต่อการผ่าตัดหรือไม่

วัตถุประสงค์: เพื่อศึกษาความกว้าง ความสูง ตำแหน่ง และมุมที่เหมาะสมกับการใส่สกรูบริเวณ pedicle และ pars interarticularis ของกระดูกสันหลังส่วนคอข้อที่ 2 ในคนไทย

วัสดุและวิธีการ: การศึกษาแบบพรรณนาในผู้ป่วยอายุ 20 ปีขึ้นไป ที่ได้รับการตรวจ CT cervical spine จำนวน 54 ราย ระหว่างเดือนกรกฎาคม พ.ศ. 2554 ถึง มกราคม พ.ศ. 2555 โดยใช้ program ONIS 2.3 วัดค่า parameter ต่าง ๆ ของกระดูกสันหลังส่วนคอข้อที่ 2 ได้แก่ height, width, medial angulation, superior angulation ของ pars interarticularis และ pedicle

ผลการศึกษา: C2 pedicle มีค่าเฉลี่ย (mean) width 5.47 มม. (3.28-6.81), height 7.54 มม. (5.9-9.5) superior angulation 27.54 องศา (20.65-33.95) และ medial angulation mean 38.95 องศา (28.07-52.85), ส่วน C2 pars interarticularis มีค่าเฉลี่ย (mean) width 7.72 มม. (5.93-10.61), height 4.47 มม. (2.33-6.3), superior angulation 49.85 องศา (41.89-58.65), medial angulation 6.76 องศา (1.18-13.5)

สรุป: การผ่าตัดยึดตรึงกระดูกสันหลังส่วนที่ 2 ในคนไทยไม่ควรใช้สกรูขนาด 4.5 มม. โดยเฉพาะ transarticular screw เพราะจุดที่คอดที่สุดของ pars interarticularis ค่าเฉลี่ยอยู่ที่ 4.47 มม. มีความเสี่ยงต่อการบาดเจ็บต่อหลอดเลือดและเส้นประสาทที่อยู่รอบได้