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Neuroanatomical study

Medially-shifted rather than high-riding vertebral arteries preclude safe pedicle screw insertion

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ABSTRACT

We enrolled 100 patients who underwent preoperative CT angiography before cervical spine instrumentation and investigated the morphology of the C2 pedicle from the perspective of pedicle screw (PS) trajectory using volume rendering and multiplanar reconstruction. The narrowest portion of the pedicle was identified as the pedicle isthmus. Safe C2 PS insertion was regarded to be not feasible when the height of the medullary cavity of the pedicle isthmus and/or width of the medullary cavity of the pedicle isthmus was ⩽4 mm. Forty-five (22.5%) pedicles were ⩽4 mm in width, and safe insertion of a PS was determined to be not feasible. Among these, seven pedicles were ⩽4 mm in both height and width. The remaining 38 pedicles were ⩽4 mm in width with heights >4 mm. There was no pedicle with a width >4 mm and height <4 mm. In other words, short pedicles were always concomitantly narrow. Therefore, the seven pedicles ⩽4 mm in both height and width were considered to be morphologically narrow. The heights of the pedicle isthmus were not limited by the vertebral artery groove (VAG) and safe C2 PS insertion can be considered feasible where the VAG is marginally cranial, whereas the widths of the pedicle isthmus are limited by the VAG. Therefore, safe C2 PS insertion is precluded only when the VAG courses cranially and medially. It is a medially-shifted, rather than a high-riding, vertebral artery that precludes safe C2 PS insertion. Therefore to avoid vertebral artery injury an axial CT scan, parallel to the pedicle axis, should be evaluated before C2 PS insertion.

1. Introduction

Pedicle screw (PS) instrumentation of the epistropheus or axis (C2) is widely used to treat occipitocervical, atlantoaxial, and subaxial spinal pathologies, serving as one of the strongest anchors in the cervical spine [1–3]. However, variation of C2 anatomy can make PS insertion challenging and prone to potentially catastrophic complications such as vertebral artery (VA) injury [4–7]. To avoid such complications, it is recommended that C2 PS insertion should be abandoned in patients with a high-riding vertebral artery (HRVA), and in those where the course of the VA is too medial, posterior or cranial to insert the PS safely through the isthmus of the C2 pedicle [8–10]. Therefore, surgeons should pay careful preoperative attention to the presence of a HRVA. The original concept of a HRVA was based on the trajectory of atlantoaxial transarticular screws (TAS) [11]. In previous reports of atlantoaxial TAS, a HRVA was described as a "large VA groove", and a "high-riding transverse foramen" was noted to be associated with additional risk for insertion of atlantoaxial TAS [4,12,13]. The term "high riding VA" was first used by Song et al. in 1997 [14]. Bloch et al. defined a HRVA when the height of the C2 pedicle isthmus was ⩽5 mm and/or the internal height was ⩽2 mm on a sagittal image that is 3 mm lateral to the cortical margin of the spinal canal wall at C2 [15]. However, this definition was based on the trajectory of a TAS, and it is uncertain if this definition can be applied to assess the feasibility of safely inserting a C2 PS.

The purpose of this study was to analyze the morphology of the C2 pedicle from the perspective of a PS trajectory and reveal the relationship between the feasibility of safely inserting a C2 PS and the presence of a HRVA.

2. Methods

2.1. Subjects

This study was approved by Chiba University Graduate School of Medicine Institutional Review Board, Japan. Since this was a

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retrospective radiological study, the requirement for written informed consent was waived. We enrolled 100 patients who underwent preoperative CT angiography (Aquellion 64 CX; slice thickness, 0.5 mm; Toshiba, Tokyo, Japan) before cervical spine instrumentation surgery between January 2009 and October 2014. There were 66 men and 34 women with a mean age of 61.9 ± standard deviation (SD) of 14.9 years. A total of 200 C2 pedicles were analyzed. Patients younger than 18 years old and patients with erosion of the C2 pedicle due to rheumatoid arthritis or spinal metastasis were excluded.

2.2. Patient demographics

The patient group consisted of 34 patients with ossification of the posterior longitudinal ligament, 17 with cervical spondylotic myelopathy, 17 with atlantoaxial subluxation, 10 with spinal tumors, eight with cerebral palsy, five with destructive spondyloarthropathy, three with trauma, three with Hirayama disease, two with spinal cord tumors, and one with pyogenic spondylitis.

2.3. Image analysis

Reconstructed images were obtained using an AquariusNET system (TeraRecon, San Mateo, CA, USA). Pedicles were assessed according to the previous report by Yuan [16]. First, the pedicle axis was determined along with the sagittal trajectory of the C2 PS (Fig. 1A). Then, consecutive cross-sectional slices perpendicular to the pedicle axis were used in volume rendering and multiplanar reconstruction (Fig. 1B, dotted lines). Among those consecutive sections, the narrowest portion of the pedicle was identified as the pedicle isthmus. The heights of the outer diameter (a in Fig. 1C) and medullary cavity at the pedicle isthmus (b), width of the outer diameter (c), and medullary cavity at the pedicle isthmus (d) were measured (Fig. 1C). Safe C2 PS insertion was regarded as not feasible when the height of the medullary cavity of the pedicle isthmus and/or width of the medullary cavity of the pedicle isthmus was ⩽4 mm.

Correlation between the heights and the widths of the medullary cavity at the isthmus was analyzed. The feasibility of safe PS insertion was based on the above parameters and the conventional definition of a HRVA by Bloch et al. was used.

2.4. Statistics

Two experienced spinal surgeons measured the diameters of 60 pedicles in 30 patients at two time points more than 2 weeks apart. Intra-class correlation coefficients (ICC) were used to determine inter-observer and intra-observer reliabilities. We provide 95% prediction limits for the errors in measurements. Student's *t*-test was used to compare the isthmus widths and heights. A Pearson correlation coefficient was used to determine the correlation between the heights and widths of the medullary cavities at the isthmuses. A chi squared test was used to compare the feasibility of safe insertion of a C2 PS or TAS. $p < 0.05$ was considered significant. All analyses were conducted using JMP version 10.0.2 (SAS Institute, Cary, NC, USA).

3. Results

The ICC values for inter- and intra-observer reliability for the height of the medullary cavity were 0.85 and 0.85, respectively, and the ICC values for the width of the medullary cavity were 0.95 and 0.94, respectively, showing excellent inter- and intra-observer agreement. The average height (a on Fig. 1C) and width

Table 1
The average height and width of the outer diameter and medullary cavity of the pedicle isthmus

	Outer diameter	Medullary cavity
Height (mm)	10.3 ± 1.2	7.9 ± 2.0
Width (mm)	7.2 ± 1.4	5.6 ± 1.9

Values are presented as mean ± standard deviation.

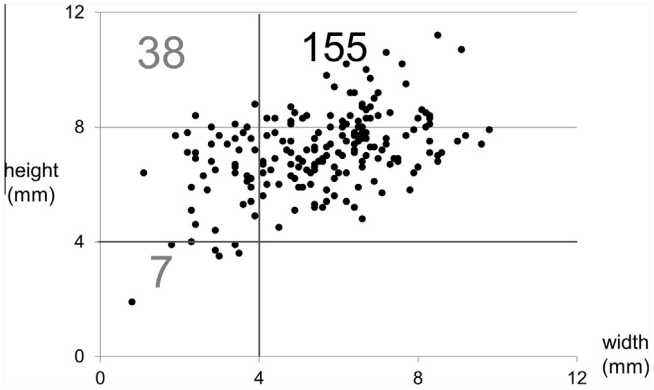

Fig. 2. Graph showing the distribution of pedicle width and height. Safe C2 pedicle screw insertion was considered feasible in 155 pedicles that were ⩾4 mm in both width and height, whereas safe pedicle screw insertion was precluded in 45 pedicles that were considered too narrow (<4 mm). Among these, seven pedicles were ⩽4 mm in both height and width. The remaining 38 pedicles were ⩽4 mm in width, with heights >4 mm.

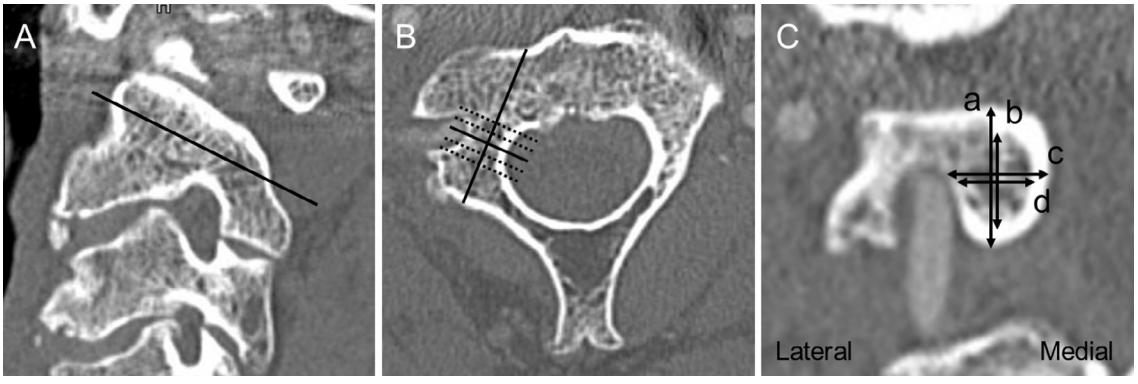

Fig. 1. A CT scan in the plane perpendicular to the pedicle axis was obtained by volume rendering and multiplanar CT scan reconstruction, and the narrowest portion of the pedicle was identified. (A) Sagittal, (B) axial and (C) coronal planes parallel to the pedicle axis. Measured parameters are (a) the height of the outer diameter and (b) the height of the medullary cavity at the pedicle isthmus, (c) the width of the outer diameter, and (d) the width of medullary cavity at the pedicle isthmus.