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Radiographic measurements of C-2 in patients with atlas assimilation

Clinical article

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Object. The object of this study was to evaluate the radiographic characteristics of C-2 using multiplanar CT measurements for anchor screw placement in patients with C-1 assimilation (C1A). Insertion of a C-2 pedicle screw in the setting of C1A is relatively difficult and technically demanding, and there has been no report about the optimal sizes of the pedicles and laminae of C-2 for screw placement in C1A.

Methods. An institutional database was searched for all patients who had undergone cervical CT scanning and cervical spine surgery between April 2006 and December 2012. Two neurosurgeons reviewed the CT scans from 462 patients who met these criteria, looking for C1A and other anomalies of the craniocervical junction such as high-riding vertebral artery (VA), basilar invagination, and VA anomaly. The routine axial images were reloaded on a workstation, and reconstruction CT images were used to measure parameters: the minimum width of bilateral pedicles and laminae and the length of bilateral laminae of the atlas.

Results. Seven patients with C1A were identified, and 14 sex-matched patients without C1A were randomly selected from the same database as a control group. The mean minimum pedicle width was 5.21 mm in patients with C1A and 7.17 mm in those without. The mean minimum laminae width was 5.29 mm in patients with C1A and 6.53 mm in controls. The mean minimum pedicle and laminae widths were statistically significantly smaller in the patients with C1A ($p < 0.05$).

Conclusions. In patients with C1A, the C-2 bony structures are significantly smaller than normal, making C-2 pedicle screw or translaminar screw placement more difficult.
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Key Words • C-1 assimilation • C-1 lateral mass screw • C-2 pedicle screw • C-2 translaminar screw • computed tomography • occipitocervical fixation • cervical spine

Different strong screw anchoring techniques have recently been developed for use in the craniovertebral junction, including placements of a C-1 lateral mass screw, C-2 pedicle screw, and C-2 translaminar screw. These screw insertion techniques are helpful in treating craniovertebral junction instability commonly caused by trauma, congenital malformation, or inflammatory diseases.

C-1 assimilation (C1A) is defined as the failure of segmentation between the fourth occipital sclerotome and the first spinal sclerotome. The frequency of this anomaly is 0.25% in the general population.[8] The C-1 lateral mass in patients with C1A is usually hypoplastic and anomalous;[6] therefore, C-1 lateral mass screw insertion is often difficult, and more precise planning with CT studies is essential for safe screw placement.

C-2 screws are alternative anchors for C1–2 fixation. To the best of our knowledge, however, few reports have clarified the C-2 architecture in patients with C1A. The purpose of this study was to analyze radiological measurements of the C-2 pedicles and laminae in patients with C1A and to compare them with those in patients without C1A, discussing the possibility and risk of screw fixation.

Methods

We searched a database in the Department of Neurosurgery at Aichi Medical University for all patients who had undergone cervical CT scanning and cervical spine surgery between April 2006 and December 2012. Two experienced neurosurgeons reviewed the CT scans of the

Abbreviations used in this paper: C1A = C-1 assimilation; VA = vertebral artery.

462 patients who met these criteria, looking for C1A and other anomalies of the craniocervical junction such as a high-riding vertebral artery (VA), basilar invagination, and VA anomaly. The presence of C1A was evaluated on sagittal CT images.

C-2 morphology had been preoperatively measured on axial CT in all patients, and axial CT images were acquired using 0.5-mm-thick slices. Routine axial images were not useful for detailed evaluation of the C-2 anatomy; therefore, these files were reloaded in a workstation (AquariusNET V4.4.7.102, Yokogawa Electric Corp.), and multiplanar bone window reconstruction images were made to visualize any arbitrary slice. The workstation is essential to make the best imaging slice for the preoperative evaluation of C-2 anatomy. We could measure the size of C-2 on the reconstruction images without regard for CT gantry angles.

We measured the following areas of C-2: 1) the minimum width of the C-2 pedicles bilaterally, 2) the length of the laminae bilaterally, and 3) the minimum width of the laminae bilaterally (Fig. 1).[10,12,15] All parameters were measured at the best arbitrary angle on the workstation by the same experienced neurosurgeons (T.A. and M.Y.), and the measurements were compared between the two patient groups.

All statistical analyses were performed using the Student t-test. Statistical significance was set at $p < 0.05$.

Results

Fourteen sex-matched patients without C1A were randomly selected from the same database (random sampling method to analyze measured data on CT scans statistically) as a control group. The control group comprised 2 male and 12 female patients with ages ranging from 46 to 70 years (mean 56.7 years). All of the surgical procedures were performed below C-2 in the controls. We found 7 patients with C1A (C1A group), including 1 male and 6 females with ages ranging from 17 to 70 years (mean 55.4 years) at surgery. Five patients in the C1A group had basilar invagination and the other 2 had disc herniation. In the 5 patients with basilar invagination, transoral decompression and instrumentation between the occiput and C-2 was performed with C-2 anchoring screws and the aid of an intraoperative navigation system. In the 2 patients with cervical disc herniation, C1A was found incidentally, and the levels of disc herniation were C2–3 and C3–4. These patients underwent anterior cervical discectomy and fusion, and no surgical intervention was performed at the craniovertebral junction. We identified the congenital anomaly and VA anomaly in patients with basilar invagination. Chiari malformation Type I was identified in 2 patients. There were 3 high-riding VAs and 2 persistent first intersegmental arteries. There was no such anomaly in the 2 patients with cervical soft disc herniation or the control group.

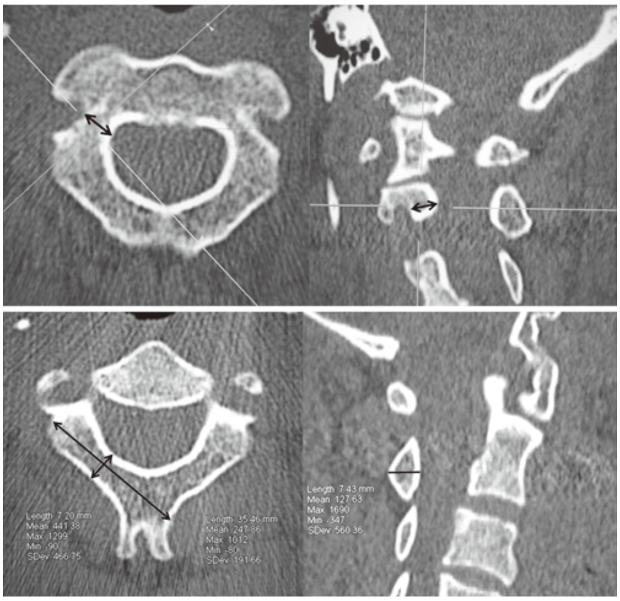

Fig. 1. Axial reconstructed CT showing the minimum pedicle width **(upper)**. Sagittal reconstructed CT **(lower)** showing the length and minimum width of the laminae.

The mean minimum width of the C-2 pedicle was 5.21 mm in the C1A group and 7.17 mm in the control group, and the difference between the two means was statistically significant ($p = 0.002$). The mean minimum width of the right C-2 pedicle was 5.52 mm (range 5.16–6.20 mm) in the C1A group and 7.30 mm (range 4.89–9.85 mm) in the control group. On the left side, the mean minimum width of the C-2 pedicle was 4.90 mm (range 1.40–9.80 mm) in the C1A group and 7.05 mm (range 6.07–9.12 mm) in the control group. Therefore, the pedicle was smaller in the C1A group than in the control group, and the difference between the two groups was statistically significant on both sides ($p = 0.0007$ and 0.014, respectively; Fig. 2).

The mean minimum width of the C-2 lamina was 5.29 mm in the C1A group and 6.53 mm in the control group, and the difference between the two groups was significant ($p = 0.0008$). The right C-2 lamina was 5.75 mm (range 4.63–7.60 mm) in the C1A group compared with 6.48 mm (range 5.26–8.13 mm) in the control group ($p = 0.12$). The mean minimum width of the left C-2 lamina was 4.83 mm (range 4.00–5.90 mm) in the C1A group and 6.58 mm (range 5.41–9.14 mm) in the control group ($p = 0.002$; Fig. 3), confirming that the C-2 laminar width was also smaller in the C1A group than in the control group.

The mean length of the C-2 lamina was 30.35 mm in the C1A group and 34.06 mm in the control group and

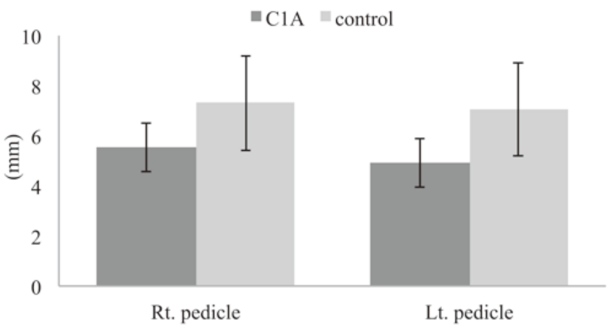

Fig. 2. Mean minimum pedicle width.

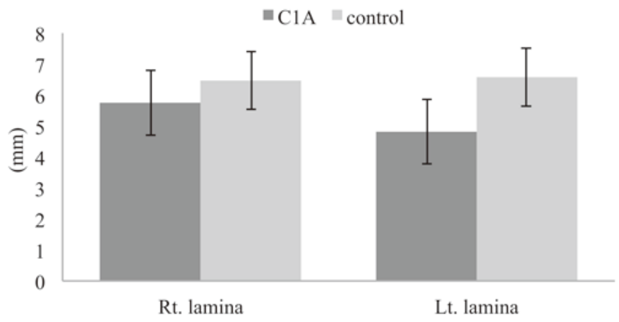

Fig. 3. Mean minimum laminar width.

therefore statistically significantly shorter in the C1A group than in the control group ($p < 0.0001$). The length of the right C-2 lamina was 31.00 mm (range 28.50–33.50 mm) in the C1A group and 34.02 mm (range 31.16–40.51 mm) in the control group ($p = 0.015$). The mean length of the left C-2 lamina was 29.71 mm (range 25.50–33.70 mm) in the C1A group and 34.11 mm (range 31.03–40.41 mm) in the control group ($p = 0.001$; Fig. 4).

Discussion

Our radiological measurements of C-2 in the C1A group revealed smaller pedicle and laminar width and shorter laminae than in the control group. Of the 7 patients with C1A in our series, 5 who had basilar invagination underwent occiput-C2 fixation using an intraoperative navigation system and fluoroscopy. Two patients safely underwent C-2 pedicle screw placement on both sides. In one patient, a C-2 pedicle screw was selected for one side and a C-2 translaminar screw for the other. In the other 2 patients, C-2 translaminar screws were selected for both sides because of the small pedicle width. Fortunately, C-2 screw placements were accomplished without screw breach in all 5 patients. None of the patients experienced any clinical complications such as VA injury or neural damage. We used navigation in all 5 patients to place the pedicle screws, and their placement was successful in all of these cases. We believe that the navigation system was helpful in performing the procedure safely and easily. All of the patients fared well with good bone fusion on follow-up CT scans, and there were no instrument failures during the follow-up, which ranged from 1 to 57 months (mean 17.6 months).

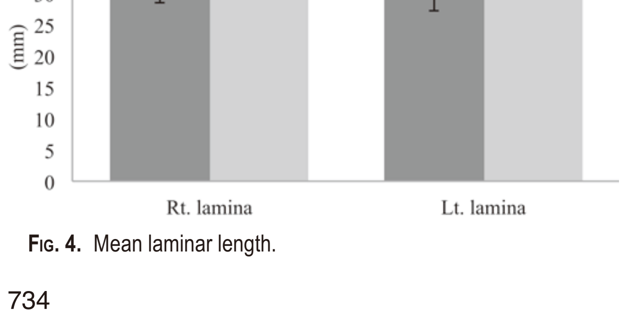

Fig. 4. Mean laminar length.

C-1 assimilation is often associated with other congenital anomalies, such as Klippel-Feil syndrome, basilar invagination, and Chiari malformation,[8] and it leads to excessive load on the atlantoaxial portion, which subsequently causes instability. In our study, 2 patients had Chiari malformation Type I. In such cases, occipitocervical fixation and stabilization is a reasonable strategy for surgical treatment.

In normal anatomy, the volume of the C-1 lateral mass is large enough to insert a 3.5-mm- or 4.0-mm-diameter screw. However, Jian et al. reported that C-1 lateral mass screw placement is relatively difficult and dangerous in C1A, because the C-1 lateral mass is hypoplastic and the morphology differs from normal anatomy.[6] It is also difficult to expose the lateral mass for screw insertion, because in C1A the C-1 lateral mass is usually situated deeper and is often covered by the occipital bone.[5] Note also that C1A is sometimes accompanied by a VA anomaly. Hong et al. reported an abnormal course of the VA, including a persistent first intersegmental artery and VA fenestration,[3] which are risk factors in C-1 lateral mass screw placement. We identified 3 high-riding VAs and 2 persistent first intersegmental arteries in the 5 patients with basilar invagination. We selected translaminar screws for these C-2 levels associated with VA anomaly.

The C-2 level is often an important alternative target for screw placement. C-2 pedicle screws are reportedly the most biomechanically rigid screws. However, C-2 pedicle screw placement has a high risk of breach as well as VA and nerve injury. According to the literature, VA injury during C-2 screw insertion occurs in 2%–8.2% of cases.[5] The size of the pedicle is a vital factor for optimal screw placement. Our measurements showed that the mean minimum width of the C-2 pedicles in C1A was less than 6.0 mm on both sides (5.5 mm on the right and 4.9 mm on the left) and significantly smaller than in the general population. Although the use of 3.5-mm screws is theoretically feasible in this pedicular size, placement is difficult. Alosh et al., for example, reported that the incidence of screw misplacement was 37% among patients with a pedicle diameter less than 6.0 mm, as compared with 21% in patients with a pedicle diameter greater than 6.0 mm.[1] Smith et al. reported that the minimum pedicle width required is 5.0 mm for 3.5-mm screw insertion, leaving at least a 0.5- to 0.75-mm safety zone from the cortex.[13,16] Based on our results, C-2 pedicle screw placement should not be regarded as easy in patients with C1A.

Because of its well-developed spinous process, C-2 is generally considered a good target for translaminar screws. Therefore, in patients with small C-2 pedicles and a VA anomaly, C-2 translaminar screw placement is an alternative technique. The advantage of C-2 translaminar screw placement is the small risk of VA injury.[2,9,11] In C1A, a VA anomaly may also be seen with a smaller C-2. Therefore, the screw insertion procedure should be more carefully chosen than usual to avoid serious vascular complications. We selected translaminar screws in 50% of C-2 anchor screws in patients with C1A because of small pedicles. Ma et al. reported that a laminar thickness of more than 4 mm may be acceptable for safe translaminar screw placement.[7] However, considering the necessary margin on either side of the translaminar screw, a minimum 5-mm laminar width is desired.[9] In our study, the mean minimum width of the C-2 laminae was 5.29 mm in the C1A group.

According to Wang, the average maximum screw length that could be accommodated by the C-2 lamina was 31.6 mm (range 27–37 mm),[14] which is similar to the mean screw length in our C1A group. However, our measurements showed that the length of the C-2 laminae in the C1A group was significantly shorter than that in the control group. Therefore, as with pedicle screws, care should be taken in C-2 translaminar screw placement in patients with C1A. In such cases, use of an intraoperative navigation system should be mandatory for precise screw placement.[4] We routinely use an intraoperative navigation system for C-2 screw placement. In the present study, there was no complication such as screw breach or VA injury. It will be necessary to study the utility of an intraoperative navigation system. The mean minimum width of the pedicles and laminae in our C1A group was 5.21 and 5.29 mm, respectively. These widths were insufficient for safe screw placement even though we could insert C-2 screws bilaterally, including pedicle screws, translaminar screws, or a combination of the two. In the current study, C-2 was measured on an arbitrary reconstruction CT section on the workstation. We freely changed the arbitrary section regardless of the original angle taken by the CT gantry. It is more precise and practical for evaluating a bony structure than an ordinary axial CT section.

Conclusions

In summary, there are considerable limitations to C-2 pedicle and translaminar screw placement in patients with C1A with respect to C-1 lateral mass screw insertion. It is mandatory to carefully choose the C-2 screw insertion procedure. Radiological measurements in patients with C1A have revealed smaller C-2 pedicles and laminae than those in persons with normal anatomy. Therefore, the preoperative evaluation of C-2 using reconstructive CT scans and intraoperative navigation systems is mandatory for determining the appropriate anchor screw type (pedicle screw and translaminar screw) and size in C-2 screw placement in patients with C1A.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Aoyama, Yasuda. Analysis and interpretation of data: Aoyama, Yasuda. Drafting the article: Aoyama, Yasuda. Critically revising the article: Aoyama, Yasuda. Reviewed submitted version of manuscript: Aoyama, Yasuda. Approved the final version of the manuscript on behalf of all authors: Aoyama. Statistical analysis: Aoyama, Yasuda. Study supervision: Hongo, Takayasu.

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