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Accuracy evaluation of placements of three different alternative C2 screws using the freehand technique in patients with high riding vertebral artery

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Abstract

An observational study.

To evaluate the safeties of placing three different alternative C2 screws using the freehand technique under high riding vertebral artery (HRVA) and to analyze the C2 morphometry in patients with HRVA.

A retrospective analysis of radiologic data was performed on patients that underwent C2 instrumentation from September 2004 to December 2017. Two hundred fifty-one patients were included, and 90 of these patients (35.9%) had a unilateral or bilateral HRVA. We placed three alternative C2 screws including superior pars, inferior pars, and translaminar screws. Computed tomography was used to assess cortical breeches of screw placement and obtain morphometric measurements of C2 pars and lamina, that is, superior pars height/length, inferior pars length, and laminar thickness/length. We used the modification of the all India Institute of Medical Sciences outcome to define cortical breach.

In total, 117 alternative C2 screws were inserted in 90 patients; 7 superior pars screws (6%), 69 inferior pars screws (59.0%), and 41 translaminar (35%) screws. Although cortical breaches occurred during 31 screw placements (26.5%), these were unacceptable in only two cases (1.7%). No symptomatic neurovascular complication was observed after screw placement in any case. Mean height of C2 superior pars was 3.8 ± 1.8 mm and mean thickness of C2 lamina was 5.2 ± 1.1 mm. Mean lengths of superior pars, inferior pars, and lamina were 17.8 ± 3.0 mm, 13.6 ± 2.2 mm, and 26.7 ± 3.3 mm, respectively. Superior pars height and lamina thickness < 3.5 mm that was a minimal diameter of cervical screw were 49.6% and 6.8%, alternative C2 screw was not available in these cases.

Placements of alternative C2 screws using the freehand technique were achieved accurately and safely in patients with HRVA. However, preoperative morphometric evaluation is essential to determine the best option for C2 instrumentation and C2 screw length to avoid neurovascular complications.

Abbreviations: CT = computed tomographic, HRVA = high riding vertebral artery, OPLL = ossification of posterior longitudinal ligament, TF = transverse foramen, VA = vertebral artery, VAI = vertebral artery injury.

Keywords: accuracy, alternative C2 screw, axis, high riding vertebral artery, morphometry

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1. Introduction

Posterior instrumentation of the upper cervical spine has been developed over decades. The technique was first used by Gallie in 1939, who used wiring techniques. However, these techniques could not provide sufficient atlantoaxial joint stability.[1] To solve this problem, the C1-2 transarticular screw fixation technique was developed by Magerl.[2] Recently, the Hams technique was developed to enable fixation of C1 lateral mass and C2 pedicle and/or pars screws independently.[3] As a result, of this development, posterior C2 instrumentation has become an invaluable surgical technique for treating occipitocervical, atlantoaxial, and subaxial spinal pathologies.[4]

The C2 pedicle screw is considered the primary option for C2 instrumentation because of its biomechanical stability. However, C2 pedicle screw placement is technically demanding for some C2 morphometries, especially when associated with neurovascular structures such as a high riding vertebral artery (HRVA). Furthermore, the presence of HRVA, which is not uncommon, can make instrumentation difficult and prone to severe, even life-threatening neurovascular complications,[5,6] and some authors have reported C2 pedicle screws are unsuitable up to 22% to

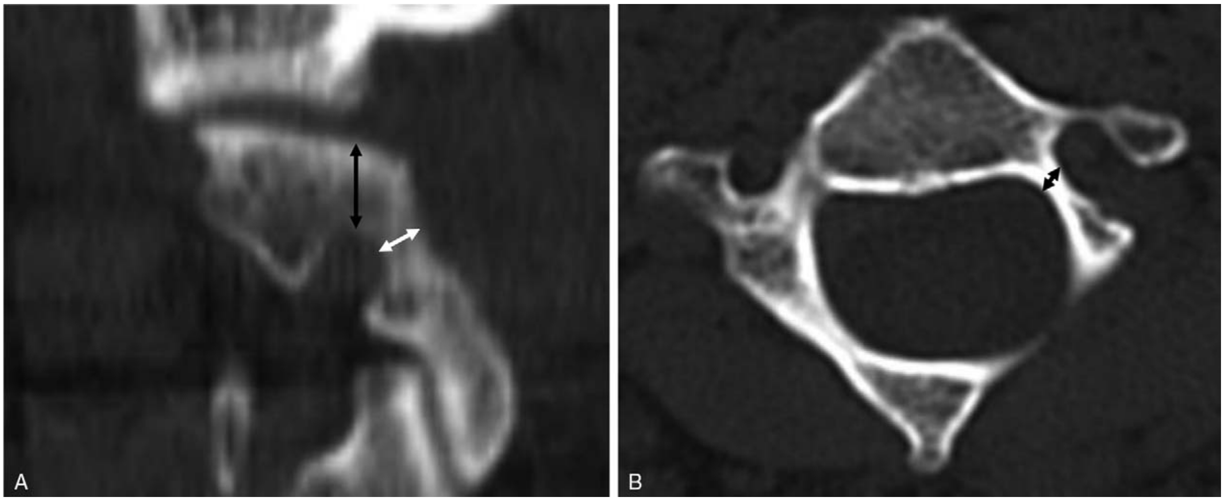

Figure 1. The three radiologic measurements used to define the presence of a high riding vertebral artery (HRVA) on cervical computed tomographic (CT) images. (A) A parasagittal CT image showing heights of the superior pars (black arrow) and isthmus (white arrow). (B) Axial CT image showing a narrow left C2 pedicle (black arrow). HRVA was defined as the superior pars height of ≤2 mm, and/or isthmus height of ≤5 mm, and/or pedicle width of ≤4 mm.

31% of patients.[7–9] To address this problem, fixation techniques have been developed for alternative C2 screws.[10,11]

Advances in the placement of alternative C2 screws allow surgeons to choose methods best suited for specific anatomies.[12–14] These alternative screws, such as translaminar, superior, and inferior pars screws, are frequently used to avoid neurovascular injury in patients with HRVA. However, few studies have addressed the accuracies of alternative C2 screws.[15–17]

The first goal of this study was to evaluate the accuracy of alternative C2 screw placement alongside HRVAs using the freehand technique and the second was to analyze measurements of C2 morphometries alongside HRVAs to decrease the risk of neurovascular injury.

2. Materials and methods

2.1. Patient selection

A retrospective analysis of medical records and radiologic data was performed on patients who had undergone posterior C2 instrumentation using the freehand technique from September 2004 to December 2017. Institutional Review Board approval was obtained. In total 251 patients were included; patients under 18 years of age old were excluded. The presence of HRVA was defined as an isthmus height of ≤5 mm and/or an internal height of ≤2 mm on sagittal image 2 to 3 mm lateral to the cortical border of the spinal canal at C2 and/or a pedicle width of ≤4 mm on axial images (Fig. 1).[18,19] According to this definition, 90 patients (35.9%) had unilateral or bilateral HRVA in our cohort. Pedicle screws were inserted at normal sides in patients with unilateral HRVA.

2.2. Alternative screws

We used three alternative screws, that is, translaminar, superior pars, and inferior pars screws, for C2 instrumentation in patients with HRVA. Translaminar screws were placed into lamina as described by Wright.[13] The inserting point was at the junction between the lamina and spinous process, and the screw path was directed contralaterally with a trajectory slightly less than the downward slope of lamina. A gearshift and tapper were used to determine intralaminar screw paths. We relied on tactile feedback using a ball-tip probe to identify cortical breaches. Screws were placed when there was no abnormal finding (Fig. 2A). If in doubt, we made a small hole in the opposite lamina to see whether the screw inserted into the intra-lamina precisely or not. We can see the probe, tapper and screw through the hole and ensure the adequate placement of C2 laminar screw.

The entry point of the superior pars screw was just under the C1-2 facet joint around the superomedial quadrant of the C2 isthmus. Its trajectory was between the C1-2 facet joint and C2 transverse foramen (TF), screw trajectory was 10° to 20° medial along the C2 pedicle, and vertical along the C1-2 facet joint (Fig. 2B and C). The gearshift, tapper, and ball-tip probe were used in the same manner. The entry point of inferior pars screws was 2 to 3 mm lateral and 2 to 3 mm above the medial aspect of the C2-3 facet (similar to a C1-2 transarticular screw) and the end point of the screw was just behind the C2 TF (Fig. 2D and E). The gearshift, tapper, and ball-tip probe were used in the same manner. For superior and inferior pars screw, we always chose the entry point and length of the screw based on preoperative CT scan. In addition, tactile feedback using a ball-tip probe is important for safety and accuracy of C2 pars screw. We confirmed the exact location of each alternative screw by intraoperative fluoroscopy after inserting screws. The selection of C2 screws was determined by a presence or absence of C2 lamina and C2 roots. Translaminar screws were used only when pars screws were not available in the presence of C2 lamina. We prefer pars screw to translaminar screw in terms of biomechanical stability and the ease of connecting rods.[4,20] Among the two types of pars screws, we preferred inferior pars screws because superior pars screw is too close to venous plexus and C2 nerve root. However, when the C2 root was resected and the juxtafacetal area widely exposed, we placed superior pars screw just below the C1-2 facet joint, because cortical bone is thicker in this region. C2 screw fixation was not performed in 6 sides because C2 morphometry was not favorable for any type of alternative C2 screw. In the high-risk group of VAI, Doppler sonography can be used as an intraoperative tool not only for the

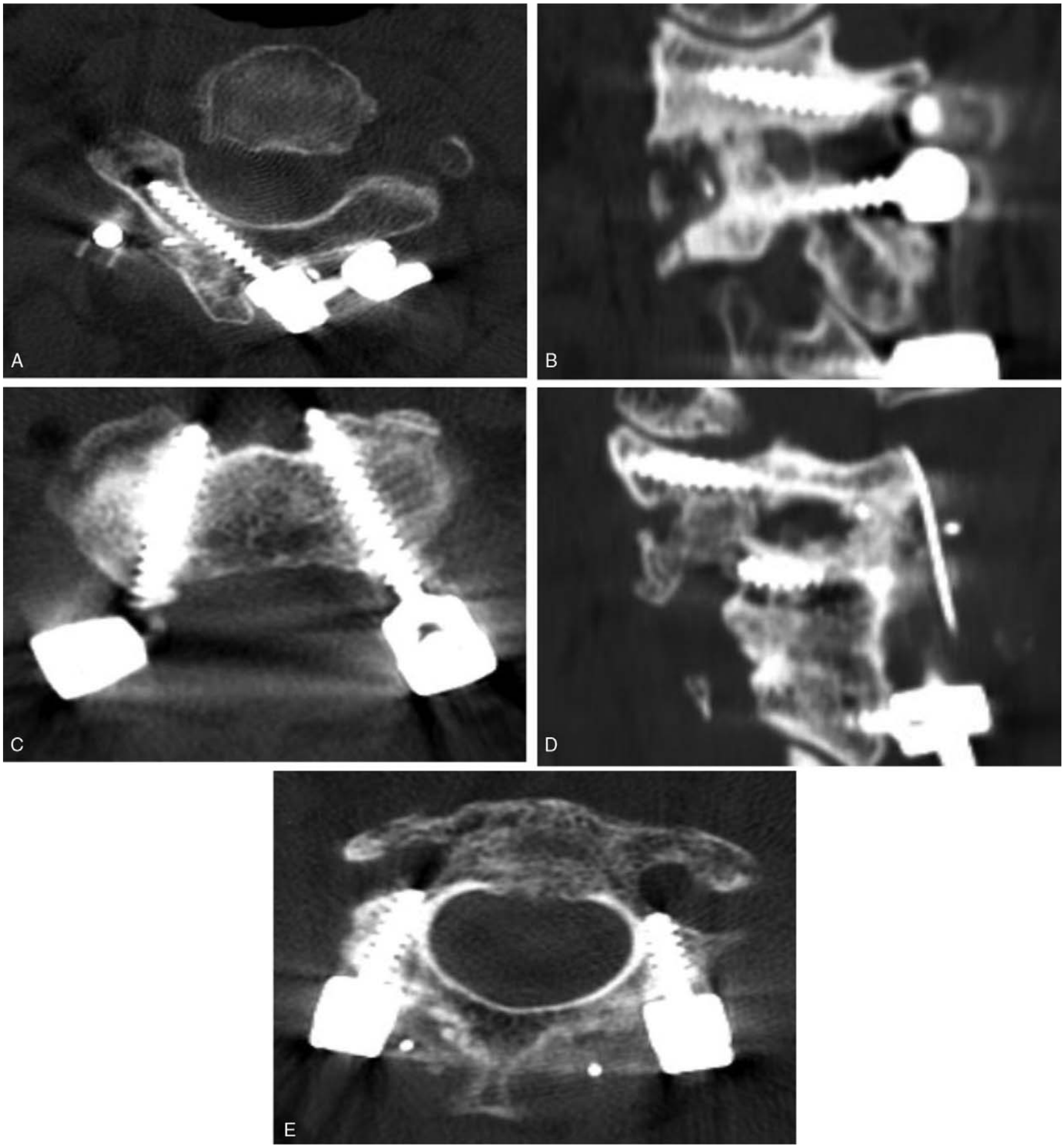

Figure 2. Trajectories and ideal placements of the three alternative C2 screw types on postoperative cervical CT images. (A) Translaminar screw. (B) and (C) Superior pars screw. (D) and (E) Inferior pars screw.

identification of the C2 TF and VA, but also for the evaluation of the VA patency during and after the procedure.

2.3. Definition of cortical breach

Postoperative computed tomography (CT) was performed on all 90 patients to analyze the accuracy of screw positioning. We used a modification of the all India Institute of Medical Sciences outcome to define cortical breach using a grading system for thoracic pedicle screws.[21] Moreover, we added Type IIb and IIc to the previous definition of cortical breach to appropriately assess inferior pars screws.

Type I: Ideal placement – screw threaded completely within bony cortex (Fig. 2).
Type IIa: Acceptable placement – <50% of the diameter of the screw violating surrounding cortex, and screw protrusion of <1 mm from the anterior cortex for pedicle and pars screws (Fig. 3A and B).
Type IIb: Relatively acceptable placement – screw violating <33% of the diameter of the C2 TF (Fig. 3C and D).

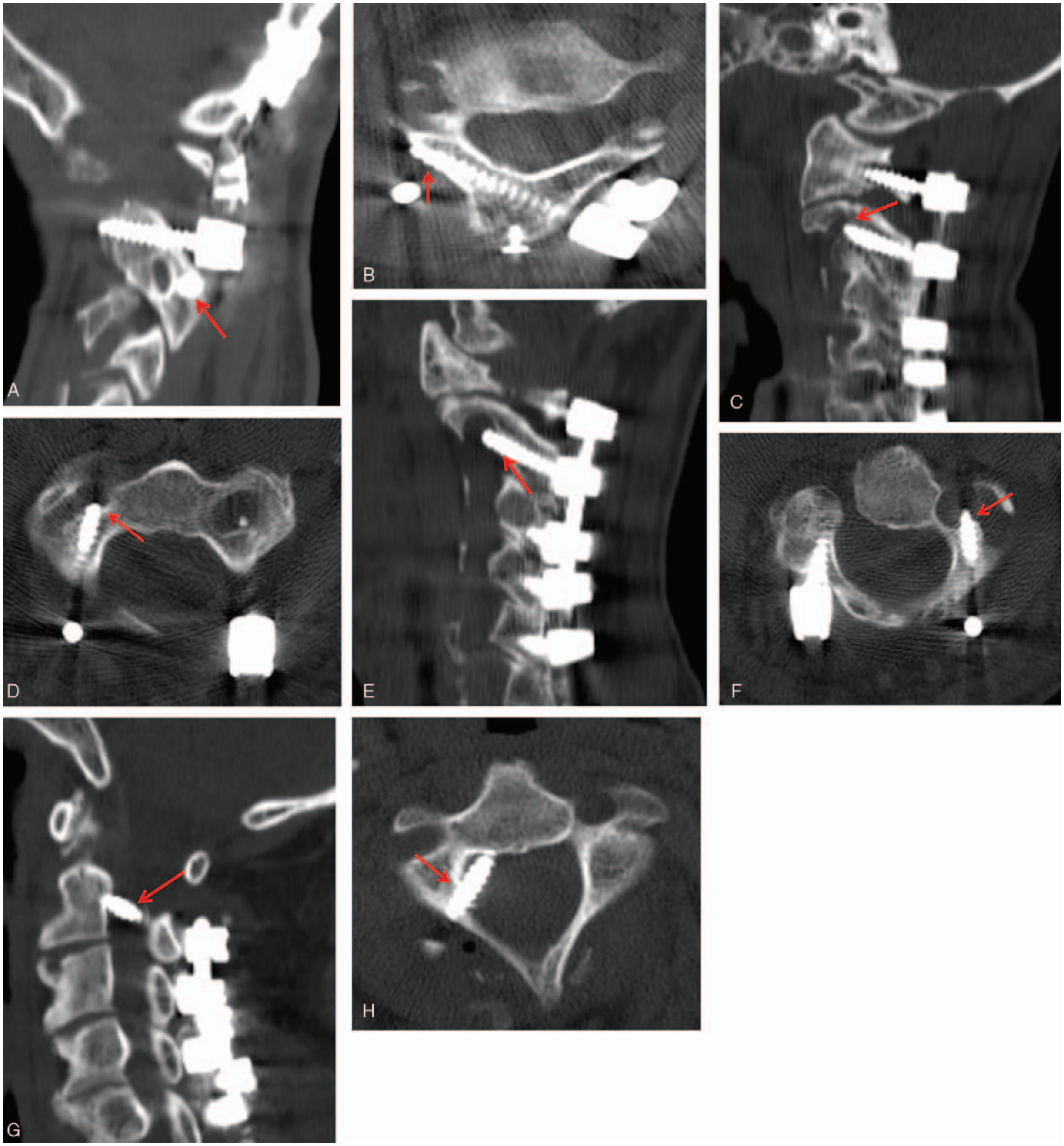

Figure 3. Types of cortical breaches as defined by the modification of the all India Institute of Medical Sciences outcomes classification for thoracic pedicle screws. The images of Type III breach are illustrative cases from different hospital. In the present study, Type III cortical breach did not occur during surgery. (A) and (B) Type IIa. (C) and (D) Type IIb. (E) and (F) Type IIc. (G) and (H) Type III.

Type IIc: Relatively unacceptable placement – screw violating ≥33% of the diameter of the C2 TF or ≥50% of diameter of screw violating surrounding cortex (Fig. 3E and F).
Type III: Unacceptable placement – clear violation of TF or spinal canal; regardless of clinical neurovascular complications (Fig. 3G and H).

Types I, IIa, and IIb were categorized as acceptable placement, and Types IIc and III as unacceptable placement.

2.4. Morphometric measurements of C2

Morphometric features of C2 were analyzed alongside HRVAs. C2 superior pars height/length, inferior pars length, and laminar thickness/length were measured on CT scans using PACS and a digital caliper (Fig. 4).

2.5. Statistical analysis

The student's t test, the paired t test, and ANOVA were used as appropriate to analyze continuous and ordinal variables.

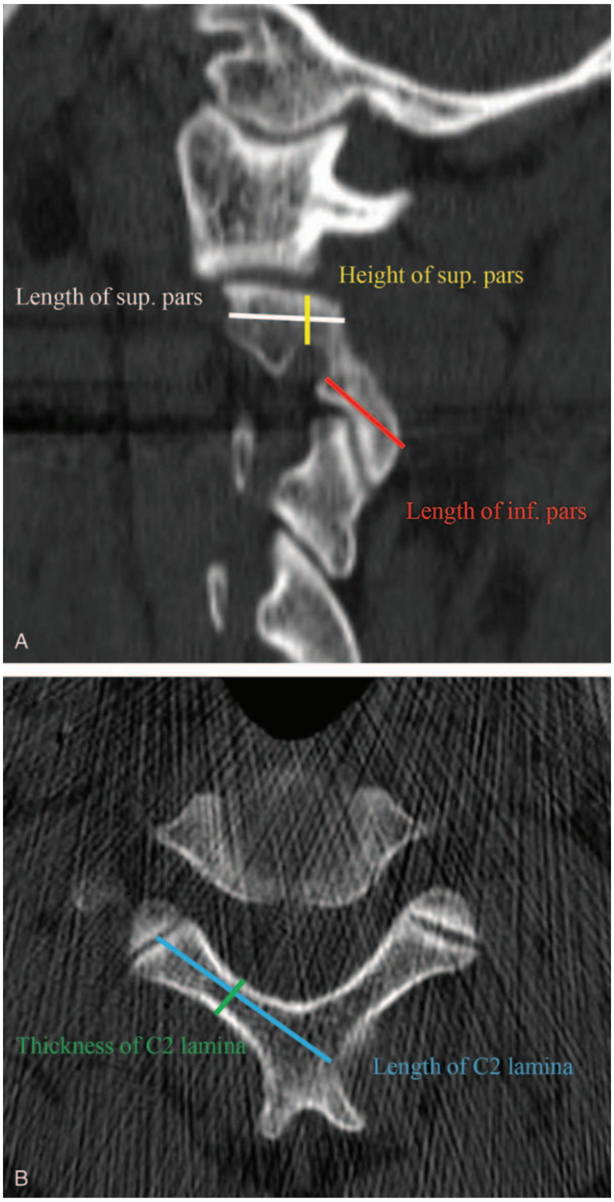

Figure 4. The five C2 morphometric variables on sagittal and axial CT images. (A) Length (white) and height (yellow) of superior pars and length (red) of inferior pars. (B) Length (light blue) and thickness (green) of C2 lamina.

P-values of <.05 (two-tailed) were considered statistically significant, and the analysis was conducted using commercial software (IBM SPSS Statistics, version 23; IBM Corp., Armonk, NY).

Table 1

Clinical information of the 90 patients with a high riding vertebral artery.

Characteristics	Number
Male: female (%)	31 (34.4): 59 (65.6)
Age (years, mean±SD)	62.4±14.5
Pathology (%)	
Spondylosis	25 (27.8)
Trauma	21 (23.3)
Rheumatoid arthritis	24 (26.7)
Congenital anomaly	17 (18.9)
OPLL	2 (2.2)
Tumor	1 (1.1)
Unilateral: bilateral HRVA (%)	57 (63.3): 33 (36.7)
C2 instrumentation (%)	174 (96.7)
Pedicle screws	57 (32.8)
Translaminar screws	41 (23.6)
Superior pars screws	7 (4)
Inferior pars screws	69 (39.6)
Skip the screw (%)	6 (3.3)
Cortical breaches of alternative C2 screws (%)	
Type I	86 (73.5)
Type IIa	7 (6)
Type IIb	22 (18.8)
Type IIc	2 (1.7)
Type III	0
Neurovascular injury	0

HRVA=high riding vertebral artery, MD=mean deviation, OPLL=ossification of the posterior longitudinal ligament, SD=standard deviation.

3. Results

Ninety patients were included in the study, that is, 31 men and 59 women (Table 1). Mean patient age was 62.4±14.5 years. Patients underwent C2 instrumentation had pathologies such as spondylosis, trauma, rheumatoid arthritis, congenital anomaly, ossification of the posterior longitudinal ligament (OPLL), or a tumor. Thirty-three patients had bilateral HRVA and 57 had unilateral HRVA. A total of 117 alternative C2 screws were inserted; 41 translaminar screws (35.0%), 7 superior pars screws (6.0%), and 69 inferior pars screws (59.0%). Eighty-six (73.5%) screws were well placed, and 29 (24.8%) screws showed acceptable cortical breaches. Only two screws (1.7%) showed relatively unacceptable cortical breaches. There was no Type III cortical breach and no symptomatic neurovascular injury occurred after screw placement.

Table 2 summarizes information of cortical breach for each alternative screw type. Translaminar screws showed best accuracy. One of seven superior pars screws showed Type IIa cortical breach, and 27 of the 69 inferior pars screws showed Type II cortical breaches. The accuracy of placement of inferior

Table 2

Accuracies of C2 screw placement using a freehand technique determined by computed tomography (CT) images.

The grade of cortical breach	Translaminar screw (%)	Superior pars screw (%)	Inferior pars screw (%)	Total number of each type (%)
Type I	38 (92.7)	6 (85.7)	42 (60.9)	86 (73.5)
Type IIa	3 (7.3)	1 (14.3)	3 (4.3)	7 (6.0)
Type IIb	–	–	22 (31.9)	22 (18.8)
Type IIc	–	–	2 (2.9)	2 (1.7)
Type III	–	–	–	–
Total number of each screw	41	7	69	117

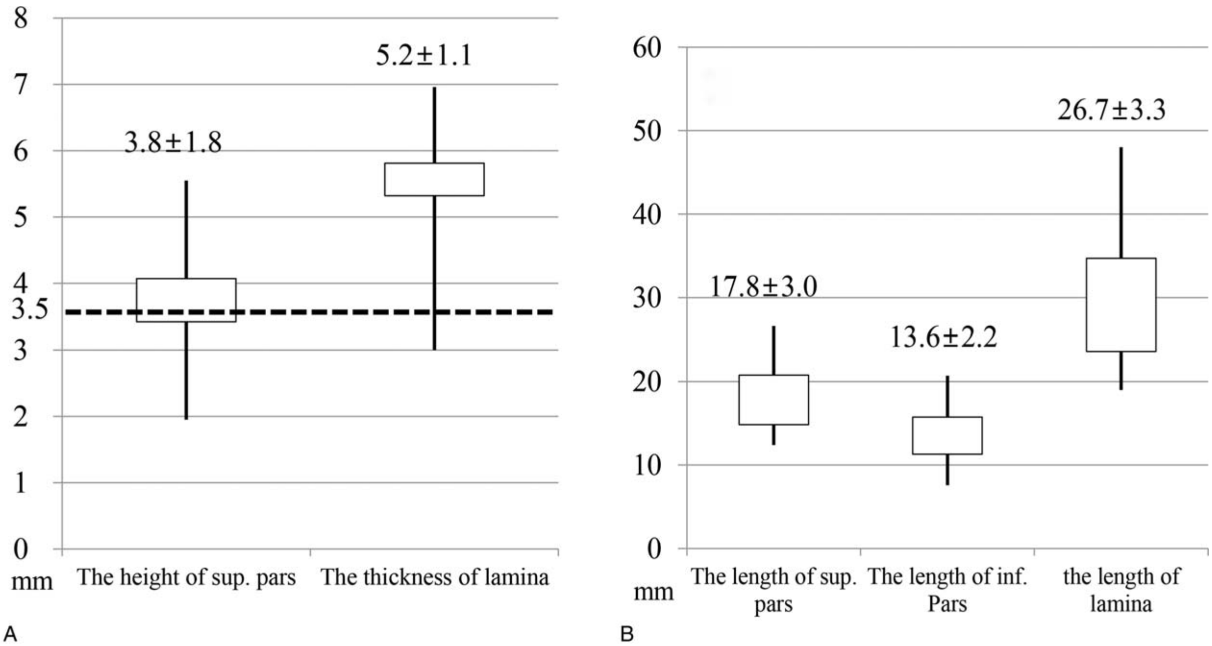

Figure 5. Values of the five C2 morphometric variables. (A) Mean superior pars height and laminar thicknesses (mean ± SD). (B) Mean lengths of the superior pars, inferior pars, and lamina (means ± SDs).

pars screw was significantly less than that of other alternative C2 screws. Cortical breaches of TFs by inferior pars screws were not uncommon, but most breaches (92.6%) were mild or acceptable. Two inferior pars screws showed Type IIc cortical breaches, but no neurovascular symptoms occurred.

Figure 5 shows the results of morphometric measurement of C2. Mean height of C2 superior pars was 3.8 ± 1.8 mm. Fifty-eight (49.6%) of the 117 cases had a C2 superior pars height of <3.5 mm, which was a minimal diameter of cervical screw. Mean thickness of C2 lamina was 5.2 ± 1.1 mm, and 8 (6.8%) cases also had a C2 lamina thickness of <3.5 mm. Mean thickness of C2 lamina was greater than mean height of C2 superior pars, which suggested a translaminar screw might be better than a superior pars screw in terms of safety margin.

Mean lengths of C2 superior pars, inferior pars, and lamina were significantly different (17.8 ± 3.0 mm, 13.6 ± 2.2 mm, and 26.7 ± 3.3 mm, respectively) ($P < .01$) (Fig. 5). Therefore, available lengths of alternative C2 screws could be in the following order; translaminar screw > superior pars screw > inferior pars screw.

4. Discussion

C2 pedicle screws are generally considered to be the best option in terms of biomechanical stability, but they introduce the risk of vertebral artery injury (VAI) during insertion, especially in the presence of a HRVA.[4] The risk of VAI after C2 pedicle screw placement has been reported to be 4% to 6%.[14] Therefore, alternative C2 screws are recommended in the presence of HRVA to avoid neurovascular injury. In the present study, HRVA was present in 35.8% of patients that underwent C2 instrumentation, which is higher than its prevalence in the normal population, which we ascribe to the high incidence of C1-2 facet joint pathologies (e.g., rheumatoid arthritis, osteoarthritis, and developmental anomalies) in our study cohort.

In the present study, the accuracies of alternative C2 screw placement using the freehand technique in descending order were translaminar, superior, and inferior pars screws. For the 117 alternative C2 screws, 26.5% exhibited a cortical breach, 73.5% were well placed, and 98.3% (115 screws) were acceptably placed. Although two inferior pars screws exhibited unacceptable placement, no symptomatic neurovascular complication occurred postoperatively. These findings indicate that alternative C2 screw placement using the freehand technique can be accurate and safe even in patients with a HRVA.

Some previous studies support our results. Sciubba et al reported the outcomes of 100 C2 pedicle/pars screws placed using the freehand technique.[22] Cortical breaches occurred in 15% (13% Type IIa, 1% Type IIc, and 1% Type III) according to our definition of cortical breach, but no symptomatic neurovascular injury occurred. Punyarat et al also reported outcomes for C2 pedicle/pars screws placed using the freehand technique in 76 of 198 patients with an available postoperative CT scan,[17] and found C2 pedicle and pars screws had cortical breach rates of 23% and 11%, respectively. They also encountered no symptomatic neurovascular injury. These studies show C2 screw placement using the freehand technique can be performed safely and effectively, and that mild cortical breaches do not result in clinical symptoms.

To reduce the risk of neurovascular injury, intraoperative fluoroscopy or navigation can be used during screw insertion. Bransford et al reported outcomes for 316 C2 pedicle screws and 56 inferior pars screws.[23] Postoperative CT revealed, ideal placement of 81.5% of the pedicle screws and of 85.7% of the pars screws; 0.6% of the pedicle screws caused VAI, and 3 (3.9%) Type III breaches and 5 (6.5%) Type II breaches of 77 short pars screws were detected. However, no clinical sequela occurred. Overall acceptable placements of pedicle and pars screws were 98.8% and 94.6%, respectively. Elliott et al reported that 3% to 8% of screws were malpositioned without a neurovascular complication.[24] Cortical breach rates of C2 screws placed under intraoperative fluoroscopy guidance were similar to those of C2 screws placed using the freehand technique. Lateral intraoperative fluoroscopy can prevent screw misplacements in the superior and inferior directions, but confirmation of appropriate medial and lateral screw directions in anteroposterior view may be compromised by the superimposition of bony structures. For this reason, we believe that meticulous dissection of C2 pars interarticularis to make anatomical orientations clearer is more important for improving the accuracy of C2 instrumentation than the use of intraoperative fluoroscopy or navigation. Furthermore, Hlubek et al reported the freehand technique was more accurate than CT-based navigation for C2 pedicle or pars screw placement.[25] Superior pars screw placement introduces the risk of occipital neuralgia because the entry point of the screw abuts on the C2 nerve root.[26] Therefore, superior pars screw might be useful, especially when the C2 nerve root has been resected. Translaminar screws were used only when pars screws were not available and when C2 laminectomy was unnecessary. Accordingly, the presence of C2 lamina and C2 nerve root are important considerations when selecting an optimal C2 screw.

In previous studies, 11% to 23% of cortical breaches did not result in clinical sequelae.[15,17,23,24] In fact, the dominancy of the vertebral artery (VA) and the presence of the ipsilateral posterior communicating artery play important roles in the development of clinical sequelae arising from VAI. If bilateral high-grade cortical breaches do not occur, the contralateral VA could compensate blood flow and oxygen demand in the ipsilateral side, and thus, the risk of symptomatic neurovascular complications depends on bilaterality of VAI. If VAI is suspected during C2 screw placement, the contralateral side should be switched to an alternative C2 screw to avoid the risk of bilateral VAI. If C2 morphometry is unfavorable for screw placement, contralateral C2 instrumentation can be skipped and the level of fixation extended. In the present study, cortical breaches did not result in symptomatic neurovascular injury.

As for accuracy, translaminar screws were found to be far better than pars screws. However, Type IIa breaches were occurred for three translaminar screws; one violated the outer cortex of C2 lamina and two violated the inner cortex of C2 lamina and the spinal canal. Space around the spinal cord is capacious at C2, which probably permits low-grade inner cortical breaches to be clinically tolerated in this area. Superior pars screws showed one Type IIa cortical breach, that is, an inferior violation that penetrated the upper arch of the TF. However, this was also not symptomatic because this violation was trivial. Lastly, cortical breaches of inferior pars screws (39.1%) occurred more frequently than with other screws. Nevertheless, these breaches did not exceed 1/3 of the C2 TF diameter and the majority of these cortical breaches (81.5%) were of Type IIb, which is relatively acceptable. Only two inferior pars screw exhibited unacceptable placement without symptomatic sequelae. It should be noted the present study was performed in the presence of HRVA, and thus, inferior pars length was shorter than that in normal anatomies. Mean inferior pars length was 13.6 mm, which was slightly shorter than 14 mm length of inferior pars screws. Surgeons should measure the length of C2 inferior pars preoperatively to ensure optimal screw length and avoid VAI.

Reliance on tactile feedback when the freehand technique is used allows the surgeon to use anatomical landmarks to prevent high-grade cortical breaches. In addition, this technique reduces operative time and radiation exposure.[15,17,22,23,27,28]

We measured five morphometric variables alongside HRVAs. According to results of these measurements, 49.6% of superior pars and 6.8% of C2 lamina were not available for C2 instrumentation because they were smaller than the minimal diameter of cervical screws. Morphometric measurements of translaminar, superior, and inferior pars were significantly different. Possible lengths of C2 screws were in the order translaminar > superior pars > inferior pars screws. However, 6.8% (8/109) of superior pars length was shorter than inferior pars length and 6.8% (8/109) of laminar length was shorter than superior pars length. Morphometry of C2 is variable in patients with HRVA because the VA pathway varies on an individual basis,[29] and this probably increases the risk of cortical breach or screw misplacement. For this reason, preoperative evaluation of C2 morphometry should be conducted before C2 instrumentation. Preoperative radiologic assessments provide critical information regarding the pathway of the VA and enable the selection the optimal C2 screw types and sizes.

This study has several weaknesses that should be emphasized.

1. It is limited by its retrospective, single-center design, which may have caused selection bias;
2. The sample size was rather small;
3. Patient pathologies were heterogenous;
4. Distribution of each screw was not equal;
5. Long-term clinical and radiological outcomes were not evaluated.

5. Conclusions

The present study shows alternative C2 screws could be good option for the patients with HRVA and that the placement of these screws using the freehand technique is both accurate and safe in this special group of patients. Also, this study demonstrates preoperative measurements of C2 morphometry are essential for choosing proper alternative C2 screws and preventing neurovascular complications.

High accuracy of C2 screw placement using the freehand technique allows surgeons to tailor C2 fixation safely for individual patients.

Author contributions

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Validation: Jong-Hyeok Park, Jong Beom Lee, Jae Taek Hong.
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