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Accuracy of the freehand technique for 3 fixation methods in the C-2 vertebrae

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Object. Intraoperative imaging often does not provide adequate visualization to ensure safe placement of screws. Therefore, the authors investigated the accuracy of a freehand technique for placement of pars, pedicle, and intralaminar screws in C-2.

Methods. Sixteen cadaveric specimens were instrumented freehand by 2 experienced cervical spine surgeons with either a pars or pedicle screw, and bilateral intralaminar screws. The technique was based on anatomical starting points and published screw trajectories. A pedicle finder was used to establish the trajectory, followed by tapping, palpation, and screw placement. After placement of all screws (16 pars screws, 16 pedicle screws, and 32 intralaminar screws), the C-2 segments were disarticulated, radiographed in anteroposterior, lateral, and axial planes, and meticulously inspected by another spine surgeon to determine the nature and presence of any defects.

Results. A total of 64 screws were evaluated in this study. Pars screws exhibited 2 critical defects (1 in the foramen transversarium and 1 in the C2–3 facet) and an insignificant dorsal cortex breech, for an overall accuracy rate of 81.3%. Pedicle screws demonstrated only 1 insignificant violation (inferior facet/medial cortex intrusion of 1 mm) with an accuracy rate of 93.8%, and intralaminar screws demonstrated 3 insignificant violations (2 in the ventral canal, 1 in the caudad lamina breech) for an accuracy rate of 90.6%. Pars screws had significantly more critical violations than intralaminar screws ($p = 0.041$).

Conclusions. Instrumentation of the C-2 vertebrae using the freehand technique for insertion of pedicle and intralaminar screws showed a high success rate with no critical violations. Pars screw insertion was not as reliable, with 2 critical violations from a total of 16 placements. The freehand technique appears to be a safe and reliable method for insertion of C-2 pedicle and intralaminar screws. *(DOI: 10.3171/2011.6.FOCUS1167)*

Key Words • **intralaminar screw** • **pedicle screw** • **pars screw** • **freehand technique** • **cervical spine** • **fixation**

Recently, C-1 and C-2 screws in the pedicle, pars/isthmus, and lamina with various rod and/or plate constructs have become popular because of their decreased risk of injuring the vertebral artery compared with previously described techniques.[2,8,9,11,13,14,18,25] C-2 pedicle and pars screws require thorough preoperative planning with CT because of the potential injury to the vertebral artery at the foramen transversarium (Fig. 1).[6] Pars/isthmus screws are typically reserved for salvage operations in patients in which other techniques are not feasible because the C-2 pars screw provides inferior biomechanical stabilization compared with pedicle and transarticular screws.[20] Intralaminar screws avoid the vertebral artery and provide effective stabilization, but there is an increased risk of a ventral cortical breech with intrusion into the canal.[10,12]

Although these screw-rod constructs are promising in addressing atlantoaxial instability, they are technically demanding and require extensive preoperative planning to ensure accurate placement of the screws. Additionally, there is limited literature on the use of the freehand technique for placement of C-2 pars, pedicle, and intralaminar screws, and intraoperative imaging often does not provide adequate visualization to ensure safe placement of each screw. Therefore, the purpose of this study was to investigate the use of a freehand technique for placement of pars, pedicle, and intralaminar screws in C-2.

Methods

Study Material

Following approval from the Institutional Review Board at Walter Reed Army Medical Center, 16 fresh-frozen human cadaveric spines (from the occiput to C1–T2) were obtained from the State Anatomy Board. All specimens underwent imaging prior to instrumentation

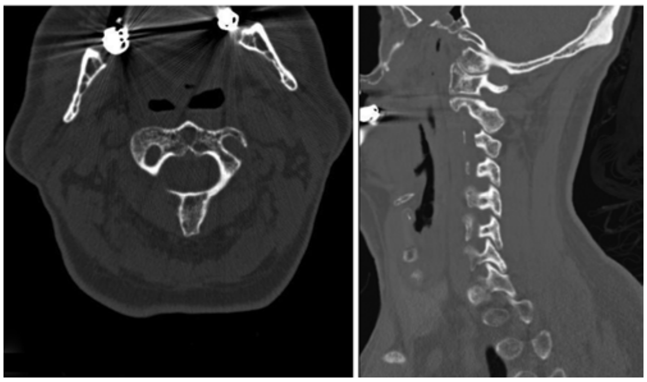

Fig. 1. Preoperative imaging is critical in evaluating the bone anatomy to determine if pedicle or pars screws are an option. Axial CT scans are the best images to evaluate the pedicle **(left)**, whereas sagittal images best demonstrate the pars interarticularis **(right)**.

to rule out any osseous abnormality, with anteroposterior and lateral radiographs serving as guides for screw placement. Specimens were cleaned of soft tissue posteriorly to expose the posterior spinous process and lamina of C-2. Two experienced cervical spine surgeons (K.D.R. and R.C.S.) using pedicle, pars, and intralaminar screws instrumented the 16 cadaveric spines. Half of the 16 specimens received bilateral pedicle screws (16 total), and the remaining specimens received bilateral pars screws (16 total). All specimens received bilateral intralaminar screws (32 total).

Pedicle Screws

For the pedicle screws, a 4.0 × 20–mm polyaxial screw (VertexMax; Medtronic, Inc.) was placed using the Harms technique, with the anatomical starting point in the cranial and medial quadrant of the isthmus of C-2, and a trajectory of 20–30° in a convergent and cephalad direction in reference to the superior and medial surface of the C-2 isthmus (Fig. 2).[11]

Pars Screws

The pars screws were either 4.0 × 16– or 4 × 18–mm polyaxial screws. The starting point for the pars screw placement was 2–3 mm lateral and 2–3 mm above the medial aspect of the C2–3 facet (similar to a C1–2 transarticular screw), with a trajectory directed toward the C1–2 facet (Fig. 2).

Intralaminar Screws

A 4.0 × 20–mm polyaxial screw was placed into the lamina according to the technique described by Wright.[25] The starting point was the junction of the lamina and spinous process with the path directed contralaterally and the trajectory slightly less than the downward slope of the lamina. For all techniques, a pedicle finder was used to determine the path for the intralaminar screw; the pedicle was then tapped and palpated, and the screw was placed. Following placement of all the screws, the C-2 segments were disarticulated and radiographed in anteroposterior, lateral, and axial planes. Another spine surgeon determined the presence and nature of any defects by meticulously inspecting the segments.

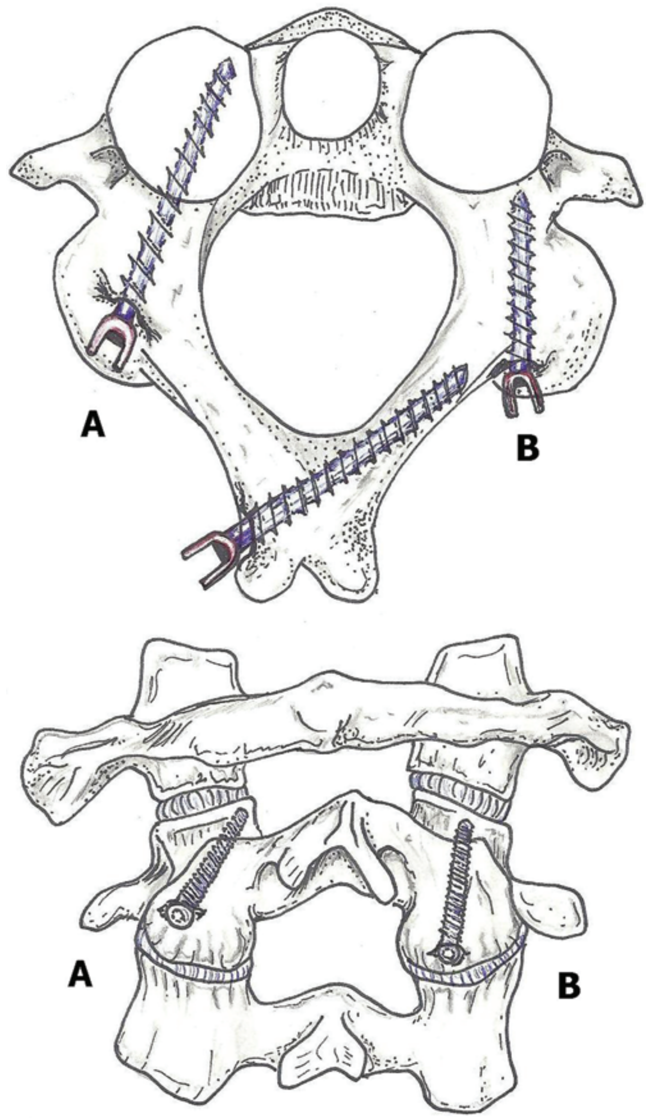

Fig. 2. Pedicle and pars screws differ slightly in their starting points and trajectory. The starting point for a pedicle screw **(A)** is more cephalad than the pars screw, whereas the pars screw **(B)** starts more caudal and aims more cephalad. The medial/lateral starting point is best determined intraoperatively using manual palpation of the medial border of the pedicle/pars using a nerve hook or Penfield 4 dissector.

Statistical Analysis

For statistical analysis, groups were compared using the Pearson chi-square test for categorical data. A probability value < 0.05 was considered statistically significant.

Results

A total of 16 pars, 16 pedicle, and 32 intralaminar screws (for a total of 64) were evaluated in this study. Anteroposterior and lateral radiographs obtained prior to instrumentation did not reveal any osseous abnormalities or anatomical variations. Following instrumentation and disarticulation, no additional anatomical variations in the osseous anatomy of C-2 were observed.

Pars Screws

Pars screws exhibited 2 critical defects: 1 foramen transversarium violation (Fig. 3) and 1 violation of the C2–3 facet. Subsequent radiographic evaluation and inspection following disarticulation of the C-2 vertebrae with the foramen transversarium violation revealed no anatomical abnormalities. The screw placed into the C2–3 facet appeared to have a trajectory not sufficiently cephalad to stay within the pars. In addition, 1 pars screw demonstrated an insignificant dorsal cortex breech. Upon radiographic evaluation, this screw appeared in an appropriate trajectory, but with visual inspection, the screw trajectory should have been less cephalad or a short screw placed. Thus, the freehand technique for pars screws placement demonstrated an accuracy rate of 87.5% (14/16) in avoiding a critical violation and a total accuracy rate of 81.3% (13/16).

Intralaminar Screws

Intralaminar screws demonstrated 3 insignificant violations: 2 ventral canal intrusions (Fig. 4) and 1 caudal lamina breech. The ventral canal violations were considered insignificant because the violation was less than 2 mm, a threshold extrapolated from a well-established level for the medial violation of pedicle screws. The overall accuracy rate of laminar screws was 90.6%, which was not significantly greater than the overall accuracy of pars screw insertion (p = 0.355); however, there were no critical violations, which was statistically significant (p = 0.041).

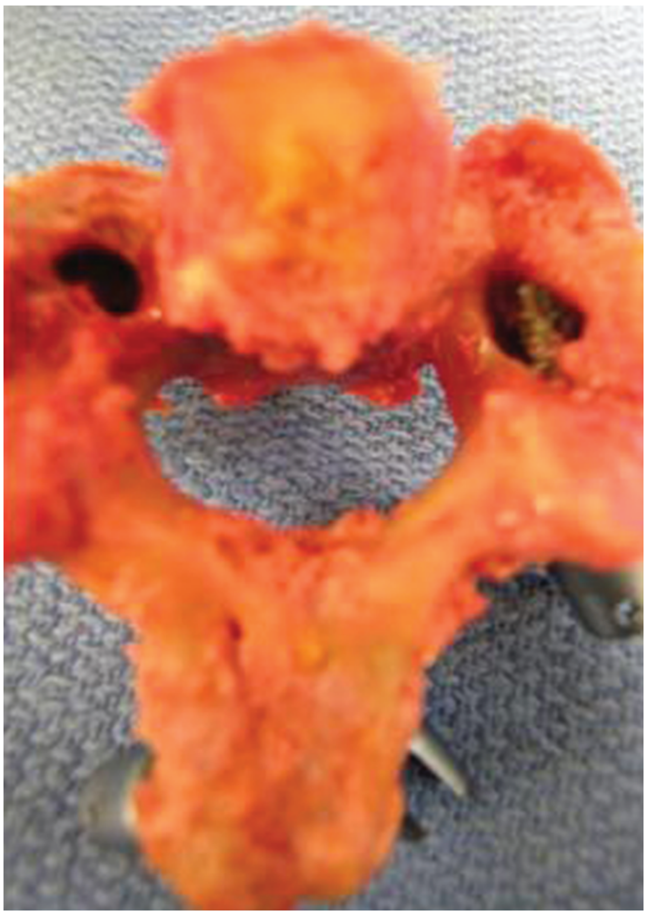

Fig. 3. Photograph showing critical violation of the foramen transversarium with the placement of a C-2 pars screw.

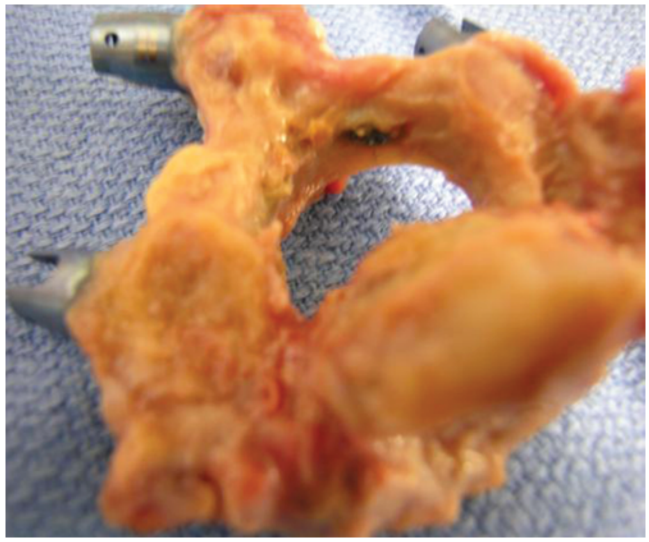

Fig. 4. Photograph showing a less than 2-mm violation of the ventral cortex with a C-2 lamina screw.

Pedicle Screws

Pedicle screws exhibited a single, insignificant, inferior facet medial cortex intrusion of 1 mm, for an accuracy rate of 93.8%. Similar to intralaminar screws, this was not statistically significant compared with pars screws (p = 0.285). There were no critical violations compared with 2 violations with the pars screws, but this was not significant (p = 0.144), likely due to the small sample size.

Discussion

Although transarticular screws provide higher fusion rates than posterior wiring techniques, the procedure is technically demanding, and the procedure is contraindicated due to screw trajectory endangering the vertebral artery in as many as 20% of patients.[1] Additionally, screw placement in C-2 poses risks to the surrounding neurovascular structures, especially the vertebral artery. Intraoperative fluoroscopy aids the surgeon in evaluating correct screw placement, but it is often inadequate in ensuring safe placement of all screws. Therefore, the goal of this study was to evaluate the use of a freehand technique in placing pars, pedicle, and intralaminar screws in the C-2 vertebra.

Overall the pedicle and intralaminar screws had the highest success rate, with 1 and 3 insignificant violations, respectively. The pars screws were not as reliable and demonstrated 2 critical violations (1 in the foramen transversarium and 1 in the C2–3 facet) and 1 insignificant dorsal cortex breech, for an accuracy rate of 81.3%.

Initially, pedicle screw placement was believed to pose substantially less of a risk to the vertebral artery than transarticular screws, but the literature now suggests that the anatomical risk to the vertebral artery between the 2 techniques may be similar.[26] Although the trajectory of the pedicle screw should theoretically avoid injuring the vertebral artery, anatomical reports of the presence of a high-riding C-2 transverse foramen in 18% of patients, vertebral artery erosion of the lateral mass and pedicle, and an anomalous vertebral artery increase the risk of injuring the artery.[5,6,13,17,21,24] However, the technique described by Harms and others, utilizing a lateral-to-medial trajectory and oriented in the cephalad direction, has been reported to provide satisfactory stabilization with minimal complications.[11,16] The use of intraoperative fluoroscopy for screw placement was reported to have an overall 2.7% complication rate in a report of 79 patients, with 1 case of injury to the vertebral artery without any neurological complications.[16] The freehand pedicle screw technique had 1 insignificant breech of the inferior facet/medial cortex, which has been reported as one of the more common complications with pedicle screw placement.[16] This complication is likely the result of the medial/cephalad trajectory advocated by Harms and others to avoid injury to the vertebral artery, in addition to the narrow isthmus of C-2.[11,19] Thus, the results of this study suggest that the freehand method is a viable technique for safely and efficiently placing pedicle screws, although further clinical evaluation is warranted.

The use of pars screws in stabilizing the atlantoaxial complex is typically reserved for salvage operations or when the patient's anatomy or pathology excludes other techniques as safe alternatives. Ebraheim et al.,[7] in their anatomical study, defined the par interarticularis as the narrow portion of the axis between the superior and inferior facets. In this study the use of freehand techniques to place pars screw resulted in the most significant complications. Therefore, given the 2 major complications associated with the freehand technique for placement of pars screws and significant variability in C-2 vertebral anatomy, placement of pars screws should be restricted to those patients in whom other techniques have failed. In addition, preoperative and intraoperative imaging should be used to the fullest extent to ensure proper placement of the pars screws.

Intralaminar screws in C-2 provide a unique platform for addressing atlantoaxial instability due to its application to a wide variety of patients and avoiding injury to the vertebral artery.[15,22,23,25] In addition, this technique is able to be performed without fluoroscopy and is less technically demanding than other rigid fixation techniques. Several biomechanical studies suggest that an intralaminar screw is a stable anchor that is equivalent to other rigid fixation techniques.[4,10,12] The lamina of C-2 is the largest cervical lamina and is able to accommodate 20-mm-long screws in 99% of patients, but several cadaveric studies indicate a larger variability in lamina diameter restricting screw diameter.[3,22,25] Wright[25] discussed one potential complication from C-2 intralaminar screw placement as the intrusion of a screw into the spinal canal; furthermore, he advised a trajectory less than the dorsal cortex of the lamina in an effort to avoid a ventral cortex breech. However, breech of the ventral canal intraoperatively is reported in the literature and was reproduced in this study, but no neurological complications have been reported in association with this complication to date.[23,25] The 2 ventral breeches observed in this study could have possibly been avoided by using a smaller diameter screw. The cadaveric study by Wang[22] reported that as many as 47% of C-2 lamina bilaterally are unable to accommodate a 4.0-mm screw at its thinnest diameter. Biomechanical data in the literature support the view that smaller screws are equivalent to pedicle screws in establishing rigid fixation. Thus, the freehand technique used in this study was associated with a breech in the ventral cortex, and although this complication has not been associated with any adverse complications, the use of smaller screws in appropriate patients could possibly reduce this complication.

Weaknesses of this study include its cadaveric design, in which additional intraoperative soft tissue and position could limit adequate screw placement. In addition, imaging was unable to adequately assess the vascular structures in the cadaveric specimens, which could have been useful in preoperative planning. Furthermore, the use of more specimens would have also increased reliability and yielded more accurate results. Nevertheless, the practical applications of this study support the use of freehand techniques in placement of pedicle and laminar screws, which reduces operative time and intraoperative radiation exposure.

Conclusions

Instrumentation of the C-2 vertebrae using the freehand technique for insertion of pedicle and intralaminar screws showed a high success rate with no critical violations. Pars screw insertion was not as reliable with 2 critical violations from a total of 16 screws placed. The freehand technique appears to be a safe and reliable method for insertion of C-2 pedicle and intralaminar screws.

Disclosure

Dr. Riew served as a consultant to Biomet, has direct stock ownership in Vertiflex, Benevenue Medica, Paradigm Spine, PSD, Osprey, Expanding Orthopedics, Spineology, Spinal Kinetics, Amedica, and Nexgen Spine. He has also received royalties from Biomet, Medtronic, and Osprey. Dr. Sasso is a patent holder with Medtronic.

Author contributions to the study and manuscript preparation include the following. Conception and design: Lehman, Helgeson, Sasso, Riew. Acquisition of data: Helgeson, Dmitriev. Analysis and interpretation of data: Lehman, Helgeson, Dmitriev, Sasso, Riew. Drafting the article: Helgeson. Critically revising the article: Lehman, Helgeson, Dmitriev, Kang. Administrative/technical/material support: Kang, Tannoury. Study supervision: Lehman, Sasso, Riew. Final revision and online submission: Kang. Illustrations: Tannoury.

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