

An anatomical study comparing standard fluoroscopy and virtual fluoroscopy for the placement of C1–2 transarticular screws

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Object. The authors sought to compare radiation exposure, surgical time, and accuracy of screw placement when using either standard fluoroscopy or virtual fluoroscopy for the placement of C1–2 transarticular screws.

Methods. Twenty-two C1–2 transarticular screws were placed in 11 cadavers in a randomized and alternating order by using either standard fluoroscopy or virtual fluoroscopy (fluoronavigation). The radiation time, procedure time, and accuracy of screw placement were recorded and statistically compared. A small but statistically significant reduction in fluoroscopy time was noted with the virtual fluoroscopy technique but the surgical times were similar between the two techniques. The incidence of noncritical and critical breaches (those at risk of causing a neurovascular injury) was not significantly different between the two groups. Careful analysis of the C1–2 anatomy in these specimens underscored the importance of placing the screw path in a maximally dorsal and medial portion of the C-2 isthmus to avoid injury to the vertebral artery and to maximize the bone purchase of the C-1 lateral mass.

Conclusions. Although virtual fluoroscopy may represent a useful tool for transarticular screw placement, it does not supplant traditional surgical techniques and does not appear to lower the incidence of bone breaches that can occur when performing this demanding procedure.

KEY WORDS • atlantoaxial • internal fixation • cervical spine • transarticular screw • virtual fluoroscopy • fluoronavigation

VIRTUAL fluoroscopy is a system in which fluoroscopic images are used in conjunction with a computer and optical tracking system to allow real-time tracking of calibrated instruments within the surgical field. Virtual fluoroscopy has been successfully applied in performing procedures for complex fractures, arthroplasty, ligament reconstruction, and neurosurgical procedures.^{2,6,11,19,22,28}

Image-guided surgery has the potential to improve the accuracy of implant placement during complex surgical procedures such as C1–2 transarticular screw placement because image guidance can be used to track the position of surgical instruments in multiple planes continuously during the procedure. In addition, virtual fluoroscopy allows virtual “projections” (lines on the computer image projecting from the tracked instrument) to be created, which can simulate the trajectory, width, and length of the drill path or final implant. These projections can assist with proper implant selection (width and length) and facilitate aiming of the drill guide during pilot hole preparation. Despite these theoretical advantages, virtual fluoro-

scopy has not been validated for the placement of C1–2 transarticular screws.

The purpose of this study was to determine the accuracy and utility of virtual fluoroscopy for C1–2 transarticular screw placement by comparing this technique with traditional fluoroscopy in a cadaver study.

Materials and Methods

The surgical setup involved placing the cadavers prone on a standard operating table with the skull firmly attached to a Mayfield three-pin headholder (Ohio Medical Instrument Co., Inc., Cincinnati, OH). The operating table was placed in an approximately 20° reverse Trendelenburg position, simulating the position used for posterior cervical surgery. A C-arm fluoroscopy unit (GE Series 9800; OEC Medical Systems, Salt Lake City, UT) was used to obtain anteroposterior and lateral views of the upper cervical spine.

Virtual Fluoroscopy Setup

The virtual fluoroscopy system has several components including the following: a calibration target, which attaches to the C-arm; an optical tracking camera; a reference array; tracked instruments, which can include drill guides, awls, and screwdrivers; and a computer with software to acquire images and superimpose the position of the tracked instrument on preacquired C-arm images by using a large-screen monitor.

Abbreviations used in this paper: CT = computerized tomography; VA = vertebral artery.

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Setup of the virtual fluoroscopy system involves several steps. 1) A calibration target is attached to a compatible C-arm fluoroscopy unit. 2) The digital tracking camera is positioned so that the reference array and referenced instruments target can be tracked in the surgical field. 3) The C-arm calibration target and the digital camera are attached to a computer. 4) The reference array is attached to a fixed point close to the surgical site. 5) The tracked instrument is attached to the system and calibrated to the reference array. Fluoroscopic images are then obtained with the C-arm and transferred to the computer monitor. At this point, surgical navigation can commence with the computer monitor showing the position of the tracked surgical instrument superimposed on preacquired fluoroscopic images.

Our operating suite setup for this study is shown in Fig. 1 *upper*. The reference array was attached to the machined attachment site on the Mayfield tong headholder (opposite the table attachment to the Mayfield tongs) and positioned over the occipital portion of the skull, as shown in Fig. 1 *lower*. Anteroposterior and lateral C-arm images of the upper cervical region were captured and transferred to the computer monitor. No further C-arm images were used in the virtual fluoroscopy group until the final images were obtained after screw placement.

Surgical Technique

A subperiosteal exposure of the posterior elements of the upper two vertebral segments was performed. The starting point for each screw was identified using anatomical landmarks as previously described.^{7,15,16,25} Briefly, a small pilot hole was made at the juncture of a transverse line 3 mm superior to the caudal aspect of the inferior articular process of C-2 and a vertical line through the central portion of the C-2 isthmus, which was identified by palpating the superior and medial aspect of the C-2 isthmus with a Penfield No. 4 instrument. No attempt was made to visualize directly the C1–2 facet joint. The drill was angled in the transverse plane so as to pass through the central region of the palpated C-2 isthmus. The cephalad–caudad angulation of the drill was adjusted according to the standard fluoroscopy or virtual fluoroscopy images, depending on the technique used for a given screw. The angulation was adjusted so that the drill appeared to pass through the C1–2 facet joint aiming toward the middle third of the dens at the level of the C-1 arch on the lateral image. The orientation of the drill could be followed virtually in real time when using virtual fluoroscopy, but periodic C-arm images were obtained during drilling in the standard fluoroscopy group to ensure accurate angulation of the drill. The accuracy of instrument calibration was tested at the end of each navigation procedure by using anatomical landmarks to ensure accuracy of the navigation. When the anterior cortex of C-1 was perforated, the length of the tunnel was measured and tapped. Cortical 3.5-mm fully threaded screws (Synthes USA, Paoli, PA), corresponding to the measured length, were then placed across the joint. Finally, anteroposterior and lateral images were obtained with the C-arm for both groups to evaluate the final screw position. None of the fluoroscopic images obtained after screw placement was interpreted as showing a malpositioned or overly long screw.

Statistical Analysis

Total fluoroscopy time and total procedure time were recorded for each of the two techniques. Total fluoroscopy time, in both groups, was obtained from the C-arm display and included the total fluoroscopy time required to acquire all images before, during, and after screw placement, including the registration of the fluoronavigation equipment as well as the final anteroposterior and lateral images. Total procedure time included the time from start of screw preparation to the completion of screw placement, including the time to acquire the final fluoroscopic images. Cadaver positioning and surgical exposure were not included in the calculations of surgical time; however, the time to set up and calibrate the virtual fluoroscopy equipment was included in the total procedure time for screws placed with virtual fluoroscopy.

Following screw placement, each of the C1–2 segments were removed en bloc with a cuff of surrounding soft tissues and subjected to careful dissection to determine if any breach of the osseous cortex was present or any anatomical structures including the VA, du-

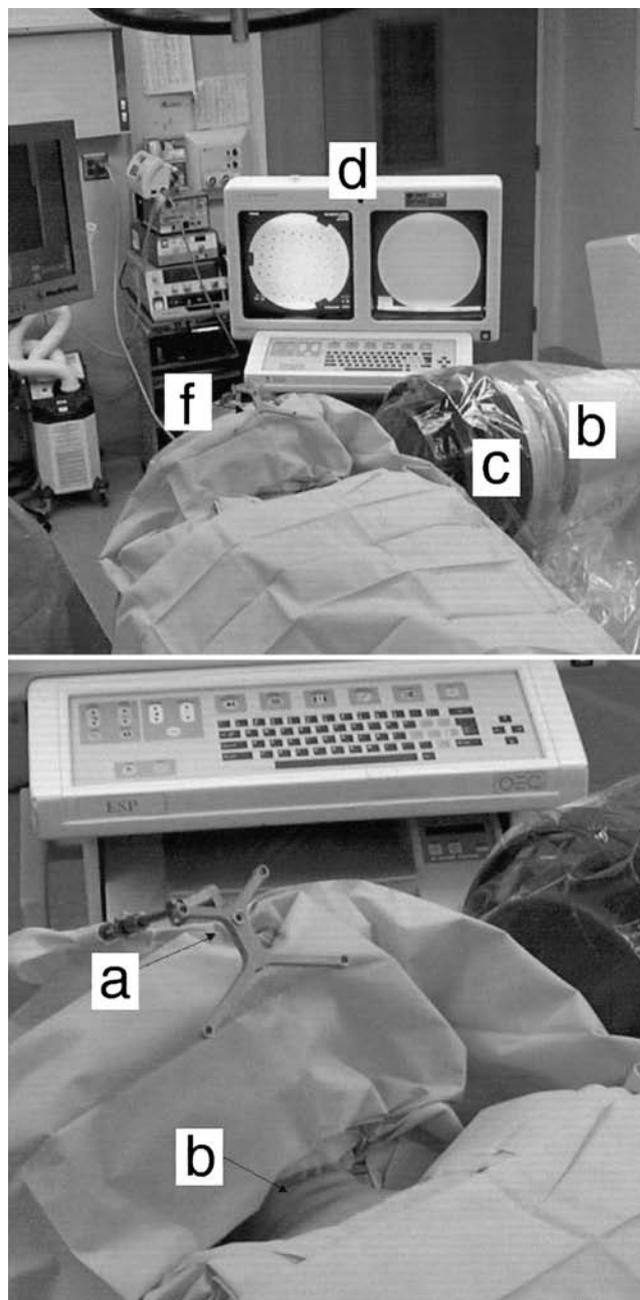


FIG. 1. *Upper*: Operating room setup for the study. The virtual fluoroscopy equipment includes the optical tracking camera (not shown) placed at the foot of the operating room table. The C-arm (b) has been fitted with the calibration target (c). The C-arm monitor (d) is placed at the head of the table. The reference array (f) is seen positioned over the occipital region of the skull and is attached directly to the Mayfield headholder attachment site. *Lower*: A closer view of the reference array (a) and posterior cervical region (b) of the cadaver is shown.

ra, carotid artery, hypoglossal nerve, or atlantooccipital joint were endangered or damaged. The number and site of any bone breach was recorded. Using fine calipers, the anterior–posterior and medial–lateral widths of the C-2 isthmus at the site of C1–2 screw passage were measured to ensure that the bone corridor was adequate for screw placement. Any isthmus with a minimum width less than 5 mm was considered inadequate for placement of a C1–2 screw

and was excluded from the breach rate calculation but was included for the calculation of the radiation exposure and procedure time.

The Fisher exact test was used to compare the breach rates. Fluoroscopy and procedure times were compared using a one-tailed Student t-test. Results were considered significant at a probability level less than 0.05.

Results

A summary of procedure time, fluoroscopy time, and accuracy of screws in the virtual fluoroscopy and standard fluoroscopy groups is shown in Table 1. Screws observed to breach the bone corridor were classified according to the location of the breach (medial, lateral, anterior, or posterior) and according to any structures that were contacted by a screw. Statistical significance for comparisons between the parameters of the virtual fluoroscopy and standard fluoroscopy groups are shown as probability values.

Fluoroscopy and Procedure Times

The total fluoroscopy time was significantly less in the virtual fluoroscopy group compared with the standard fluoroscopy group (3.18 seconds compared with 5.73 seconds, respectively; $p = 0.046$). This difference represents an average reduction in radiation exposure in the virtual fluoroscopy group of approximately 0.2 mGy.

The total procedure times did not differ significantly between the two groups. The mean procedure time was 510 seconds in the virtual fluoroscopy group and 458 seconds in the standard fluoroscopy group ($p = 0.184$).

Breach Rate

In the standard fluoroscopy group, with the exception of the one specimen that was not suitable for screw placement because of an overly narrow C-2 isthmus (see Table 1), all screws were perfectly placed within the isthmus of C-2. One screw, however, was noted to enter the atlantooccipital joint by 2 mm because of an overly steep angle in the sagittal plane.

In the virtual fluoroscopy group, two specimens were excluded due to overly narrow C-2 isthmus regions. Two screws were found to breach the bone corridor of the C-2 isthmus. One screw slightly breached the posterior bone corridor by less than 2 mm and did not place any anatomical structures at risk. Another screw violated the transverse foramen and contacted, but did not disrupt, the VA and was considered a critical breach. An additional screw was found to enter the atlantooccipital joint by 1.5 mm because of an overly steep angle in the sagittal plane.

The breach rate was not significantly different between the fluoronavigation group compared with the standard fluoroscopy group ($p = 0.3$). Only one of the 22 screws placed in this study was noted to cause a critical breach (placing an anatomic structure at risk); the other breaches were clinically insignificant or involved the atlantooccipital joint and would likely go undetected in the clinical setting.

Discussion

Background for C1–2 Transarticular Fixation

Other authors have studied the rate of malpositioned screws following transarticular screw placement. Grob, et

TABLE 1

Summary of procedure and fluoroscopy time and accuracy of screw placement in virtual and standard fluoroscopy groups

Group/Specimen	Procedure Time (sec)	Fluoroscopia Time (sec)	Breach	Location of Breach
virtual				
fluoroscopy				
1	430	8	no	
2	521	6	no	
3	550	5	no	
4	432	3	no	
5	746	4	no	
6*	475	1	yes	lat
7	544	1	no	
8	490	1	yes	atlantooccipital joint
9	395	2	yes	foramen transversarium
10*	534	2	yes	medial
11	494	2	yes	posterior
mean	510	3.18		
standard				
fluoroscopy				
1	318	9	no	
2*	632	13	yes	ant
3	516	5	yes	atlantooccipital joint
4	411	7	no	
5	495	4	no	
6	465	6	no	
7	436	2	no	
8	475	4	no	
9	401	3	no	
10	510	7	no	
11	381	3	no	
mean	458	5.72		
p value	0.183	0.046		

* These specimens were unsuitable for screw placement because of a small isthmus measuring less than 5 mm in width. These specimens were excluded from breach rate statistical analysis but included in the calculations of procedure and fluoroscopy time.

al.,¹⁵ studied 161 patients following transarticular screw placement and they noted radiographic malposition of 15% of the screws but no neurovascular injuries. Madawi, et al.,²⁰ reported a 14% incidence of malpositioned screws in 61 patients and observed an 8% incidence of VA injury and one case of a cranial nerve palsy. In a survey of the active members of the American Association of Neurological Surgeons and Congress of Neurological Surgeons, Wright and Laurysen³⁰ identified 54 definite or suspicious VA injuries in 1318 patients who underwent C1–2 transarticular screw placement—a clinical injury rate of 4.1%.

Screw violations of the atlantooccipital joint have not been widely discussed in the literature but have been recognized by other authors.¹⁴ In our study, two screws, one from each group, were found to enter this articulation but did not violate the occipital condyle cartilage surface due to the minimal nature of the breach and the obliquity of the screws. Unfortunately, the postprocedure fluoroscopic images failed to indicate either violation due to the shape of the atlantooccipital joint, which has a deeply cupped fossa along the medial portion of the joint with a taller lateral wall that obscures the breach on lateral images. Penetration of this joint is caused by an overly steep screw

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path. As suggested by other authors, the clinical significance of this type of malposition is uncertain.^{14,15}

Our technique of dissection to detect any breach of the bone corridor is more stringent than the techniques used in most other studies to determine the accuracy of screw placement.^{4,10,12,14,16,26} Therefore, minor breaches without clinical significance were observed. In addition, we chose not to use intraoperative fluoroscopy to “spotcheck” the accuracy of virtual fluoroscopy during the screw placement procedure so as to test this technique under stringent conditions. In the clinical setting, however, intraoperative fluoroscopy could easily be used during the procedure to confirm the accuracy of the virtual fluoroscopy and perhaps improve the comfort of the surgeon with the navigation technique being used.

Of the various structures at risk during screw placement, the VA is the most clinically concerning.^{5,23} To diminish the odds of a VA injury, patients with unsuitable anatomy for C1–2 transarticular screw placement, as determined by preoperative CT scanning, should be treated using alternative techniques.^{4,9,14,17,20,21,25} An isthmus measuring less than 5 mm or the presence of an ectatic and medial positioned transverse foramen has been argued as an indication to avoid C1–2 transarticular screw placement and use an alternative method of fixation.^{1,9} Paramore, et al.,²⁰ studied CT scans and found that the C-2 isthmus was unsuitable for screw placement in 18% of their patient population and was risky on at least one side in an additional 5% of patients. Similar results were reported by Solanki and Crockard²⁵ who found that 22% of patients in their study were unsuitable for transarticular screw fixation.²¹ In this study, we excluded three of the C-2 isthmus corridors from inclusion in the calculation of the breach rate because of an overly narrow isthmus at these levels. In clinical practice, these levels would also have been excluded from C1–2 transarticular fixation by using preoperative CT measurements.

Virtual fluoroscopy is only one of the many tools that have been used to assist in the placement of C1–2 transarticular screws. Many authors have used standard fluoroscopy and have described a variety of fluoroscopic landmarks helpful with the placement of C1–2 implants.^{8,9,12–14,18,20,25} Others have studied the use of special guidance tools or jigs to assist in screw placement.^{14,18} Still others have advocated CT-based image guidance for the placement of C1–2 screws. Weidner, et al.,²⁹ used the StealthStation (Surgical Navigation Technologies; Medtronic Sofamor Danek, Inc., Memphis, TN) to assist in placement of the transarticular screws in 37 patients and noted one malpositioned screw that entered the transverse foramen without causing a clinically significant injury. Unfortunately, most CT-based image guidance techniques require intraoperative registration by identifying anatomical landmarks, which may lead to error during the registration process.^{3,27,29}

When using virtual fluoroscopy for C1–2 transarticular screw placement, one could theoretically attach the reference array (reference light-emitting diode frame) to the C-2 spinous process or to the Mayfield clamp. Although attachment to the C-2 spinous process should minimize the odds of movement between the clamp and the C-2 isthmus, placement of a bulky clamp on the spinous process of C-2 can crowd the operative field and obscure important anatomical landmarks. Therefore, in this study, we

chose to study the accuracy of the procedure with the reference array attached to the Mayfield clamp to determine if this operative strategy provided adequate accuracy for C1–2 transarticular screws placement. Careful consideration of the attachment site and surgical setup is recommended as the reader draws conclusions about the utility of virtual fluoroscopy for use in this demanding procedure.

Conclusions

In this anatomical cadaver study we found the surgical time, fluoroscopic exposure, and risk of neurovascular injury to be clinically similar between traditional and virtual fluoroscopy. If virtual fluoroscopy is to be applied in the clinical setting, the surgeon should not expect an improved accuracy over standard surgical techniques and thus should be intimately familiar with the topographical anatomy of the C1–2 region and with standard imaging landmarks. Our surgical dissection of the C1–2 complex underscored the importance of placing a C1–2 transarticular screw path in the dorsal and medial portion of the critical C-2 isthmus to avoid entering the transverse foramen and to maximize the bone purchase of the C-1 articular pillar. An overly steep screw path in the sagittal plane should be avoided to minimize the risk of penetration of the atlanto-occipital joint.

References

1. Abou Madawi A, Solanki G, Casey AT, Crockard HA: Variation of the groove in the axis vertebra for the vertebral artery. Implications for instrumentation. **J Bone Joint Surg Br** **79**: 820–823, 1997
2. Arand M, Schempff M, Kinzl L, Fleiter T, Pless D, Gebhard F: Präzision standardisierter Iso-C-Arm-basierter navigierter Bohrungen am proximalen Femur. **Unfallchirurg** **104**:1150–1156, 2001
3. Bloch O, Holly LT, Park J, Obasi C, Kim K, Johnson JP: Effect of frameless stereotaxy on the accuracy of C1–2 transarticular screw placement. **J Neurosurg (Spine 1)** **95**:74–79, 2001
4. Brockmeyer DL, York JE, Apfelbaum RI: Anatomical suitability of C1–2 transarticular screw placement in pediatric patients. **J Neurosurg (Spine 1)** **92**:7–11, 2000
5. Coric D, Branch CL Jr, Wilson JA, Robinson JC: Arteriovenous fistula as a complication of C1–2 transarticular screw fixation. Case report and review of the literature. **J Neurosurg** **85**: 340–343, 1996
6. Crowl AC, Kahler DM: Closed reduction and percutaneous fixation of anterior column acetabular fractures. **Comput Aided Surg** **7**:169–178, 2002
7. Dickman CA, Foley KT, Sonntag VK, Smith MM: Cannulated screws for odontoid screw fixation and atlantoaxial transarticular screw fixation. Technical note. **J Neurosurg** **83**:1095–1100, 1995
8. Ebraheim NA, Misson JR, Xu R, Yeasting RA: The optimal transarticular c1–2 screw length and the location of the hypoglossal nerve. **Surg Neurol** **53**:208–210, 2000
9. Ebraheim NA, Xu R, Ahmad M, Heck B: The quantitative anatomy of the vertebral artery groove of the atlas and its relation to the posterior atlantoaxial approach. **Spine** **23**:320–323, 1998
10. Eleraky MA, Masferrer R, Sonntag VKH: Posterior atlantoaxial facet screw fixation in rheumatoid arthritis. **J Neurosurg** **89**: 8–12, 1998
11. Foley KT, Simon DA, Rampersaud YR: Virtual fluoroscopy: computer-assisted fluoroscopic navigation. **Spine** **26**:347–351, 2001

12. Fountas KN, Smisson HF III, Robinson JS Jr: C1-C2 transarticular screw fixation for atlantoaxial instability: a 6-year experience. **Neurosurgery** **50**:672–673, 2002
13. Fuji T, Oda T, Kato Y, Fujita S, Tanaka M: Accuracy of atlantoaxial transarticular screw insertion. **Spine** **25**:1760–1764, 2000
14. Gebhard JS, Schimmer RC, Jeanneret B: Safety and accuracy of transarticular screw fixation C1-C2 using an aiming device: an anatomic study. **Spine** **23**:2185–2189, 1998
15. Grob D, Jeanneret B, Aebi M, Markwalder TM: Atlanto-axial fusion with transarticular screw fixation. **J Bone Joint Surg Br** **73**:972–976, 1991
16. Haid RW Jr, Subach BR, McLaughlin MR, Rodts GE Jr, Wahlig JB Jr: C1-C2 transarticular screw fixation for atlantoaxial instability: a 6-year experience. **Neurosurgery** **49**:65–70, 2001
17. Hanson PB, Montesano PX, Sharkey NA, Rauschnig W: Anatomic and biomechanical assessment of transarticular screw fixation for atlantoaxial instability. **Spine** **16**:1141–1145, 1991
18. Ito Y, Hasegawa Y, Toda K, Tanaka M, Nakahara S: The original hole-in-one guide for atlantoaxial transarticular screw fixation. **J Orthop Sci** **6**:16–21, 2001
19. Jane JA Jr, Thapar K, Alden TD, Laws ER Jr: Fluoroscopic frameless stereotaxy for transsphenoidal surgery. **Neurosurgery** **48**:1302–1308, 2001
20. Madawi AA, Casey AT, Solanki GA, Tuite G, Veres R, Crockard HA: Radiological and anatomical evaluation of the atlantoaxial transarticular screw fixation technique. **J Neurosurg** **86**:961–968, 1997
26. Marcotte P, Dickman CA, Sonntag VKH, Karahalios DG, Drabier J: Posterior atlantoaxial facet screw fixation. **J Neurosurg** **79**:234–237, 1993
21. Paramore CG, Dickman CA, Sonntag VKH: The anatomical suitability of the C1–2 complex for transarticular screw fixation. **J Neurosurg** **85**:221–224, 1996
22. Picard F, DiGioia AM, Moody J, Martinek V, Fu FH, Rytel M, et al: Accuracy in tunnel placement for ACL reconstruction. Comparison of traditional arthroscopic and computer-assisted navigation techniques. **Comput Aided Surg** **6**:279–289, 2001
23. Prabhu VC, France JC, Voelker JL, Zoarski GH: Vertebral artery pseudoaneurysm complicating posterior C1–2 transarticular screw fixation: case report. **Surg Neurol** **55**:29–33, 2001
24. Silveri CP, Vaccaro AR: Posterior atlantoaxial fixation: the Magerl screw technique. **Orthopedics** **21**:455–459, 1998
25. Solanki GA, Crockard HA: Peroperative determination of safe superior transarticular screw trajectory through the lateral mass. **Spine** **24**:1477–1482, 1999
26. Tokuhashi Y, Matsuzaki H, Shirasaki Y, Tateishi T: C1–C2 intra-articular screw fixation for atlantoaxial posterior stabilization. **Spine** **25**:337–341, 2000
27. Van Cleynenbreugel J, Schutyser F, Goffin J, Van Brussel K, Suetens P: Image-based planning and validation of C1–C2 transarticular screw fixation using personalized drill guides. **Comput Aided Surg** **7**:41–48, 2002
28. Varga PP, Hoffer Z, Bors I: Computer-assisted percutaneous transiliac approach to tumorous malformation of the sacrum. **Comput Aided Surg** **6**:212–216, 2001
29. Weidner A, Wahler M, Chiu ST, Ullrich CG: Modification of C1–C2 transarticular screw fixation by image-guided surgery. **Spine** **25**:2668–2674, 2000
30. Wright NM, Laurysen C: Vertebral artery injury in C1–2 transarticular screw fixation: results of a survey of the AANS/CNS section on disorders of the spine and peripheral nerves. American Association of Neurological Surgeons/Congress of Neurological Surgeons. **J Neurosurg** **88**:634–640, 1998

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