A Cadaveric Study Comparing Standard Fluoroscopy With Fluoroscopy-Based Computer Navigation for Screw Fixation of the Odontoid

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Although direct osteosynthesis of certain types of odontoid fractures may increase union and decrease the need for prolonged immobilization, screw fixation remains a technically demanding procedure. This study compares radiation exposure, surgical time, and accuracy of hardware placement using standard fluoroscopy versus computer-assisted fluoroscopy-based navigation ("virtual fluoroscopy") to assist with the placement of odontoid screws. Twenty-two cadavers were divided into two groups and underwent placement of a single odontoid screw using either standard fluoroscopic or virtual fluoroscopic guidance. Following screw placement, dissection of the C1–C2 segments was performed to assess accuracy of screw placement. A significant reduction in fluoroscopy time was noted with the computer-based fluoroscopy technique, whereas the surgical time was not found to differ significantly between the techniques. No critical breaches (those risking neurovascular injury) were noted in either group, and the rate of noncritical breaches did not differ. It was concluded that fluoroscopy-based virtual navigation appears to have a safety profile similar to standard fluoroscopy while allowing a reduction in radiation exposure. (Journal of Surgical Orthopaedic Advances 14(4):1–6, 2005)

Key words: accuracy, cervical spine, fluoroscopy, internal fixation, odontoid fracture, osteosynthesis, virtual fluoroscopy

Fractures of the odontoid process are among the most common fractures affecting the upper cervical spine. These fractures often occur in young polytrauma patients or in elderly patients as an isolated injury (1–10). Type II fractures, as originally described by Anderson and D'Alonzo (2), and the shallow type III (IIIa), as described by Aebi et al. (1), are the most common fracture patterns seen and also present the highest risk of nonunion, which has been observed in 24–90% of such cases (1, 11–16).

Direct screw osteosynthesis has been described for treating these odontoid fractures and has the theoretical advantages of limiting the need for halo immobilization, avoiding motion loss associated with arthrodesis and enhancing the rate of successful healing (10, 13–20). Indeed, improved healing rates have been reported by a number of authors following screw osteosynthesis of acute odontoid fractures (1, 18, 21–26). Complications of direct osteosynthesis of the odontoid process, however, include the inability to place the screw because of patient body habitus; screw cutout; and vascular, visceral, or neurologic injuries (2, 4, 13, 16, 17, 27–29). Many complications are technical in nature and can be minimized by proper patient positioning, fracture reduction, and accurate screw placement. To assist with screw trajectory, radiographic image guidance is mandatory during screw placement. The traditional means of placing an odontoid screw involves the use of a C-arm fluoroscopy unit (30). Other techniques, including the use of biplanar fluoroscopy or computer-assisted image guidance, have also been reported.

Virtual fluoroscopy is an image-guided technique that uses standard two-dimensional C-arm images in conjunction with an optical tracking system and a computer to allow real-time visual tracking of calibrated instruments relative to preacquired images. Fluoroscopic images are acquired in multiple planes (e.g., anteroposterior [AP] and lateral) and stored prior to beginning surgical navigation.

Investigation was performed at the University of Virginia Health Sciences Center, Charlottesville, VA.

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A camera interfaced with the computer then tracks patient position and the position of special surgical instruments during the procedure (31). The predicted positions of instruments are displayed on the screen relative to the previously stored images and are updated several times per second, allowing real-time feedback as the surgeon moves and positions the instruments. Fluoroscopic navigation systems also allow the computer to project lines of a specific width and length from the tip of any navigated instrument, thus assisting with instrument targeting and proper implant selection. Virtual fluoroscopy has been successfully used for complex fracture fixation (32–34), arthroplasty (35), ligament reconstruction (36, 37), and nonorthopaedic procedures (4, 24, 33, 34). This study compared odontoid screw fixation in cadaveric spines using either standard fluoroscopy or virtual fluoroscopy to determine the differences in relevant surgical variables and accuracy between the two techniques.

Materials and Methods

Twenty-two cadavers were randomly divided into two groups of 11 and subjected to odontoid screw fixation using either a standard fluoroscopy or a virtual fluoroscopy technique. A single screw was placed in each cadaver simulating the technique for internal fixation of a type II odontoid fracture. Prior to screw placement, each cadaver was placed in a supine position on a standard operating room table with the skull secured using a Mayfield three-pin head holder (Ohio Medical Instrument Company, Inc., Cincinnati, OH). Each cadaver underwent surgical exposure of the anterior spine using a left-sided anterior approach performed at the C4–C5 level. The starting point for odontoid screw placement was identified visually and confirmed with lateral fluoroscopy at the anteroinferior corner of the C2 vertebral body.

Screw placement was performed according to the technique described by Bohler (38) and Aebi et al. (1). Briefly, a 2.5-mm drill was used to create the screw pilot hole. The drill trajectory was directed according to the images on either the standard fluoroscopy monitor or the navigation system computer screen depending on the technique used for a given cadaveric specimen. The ideal trajectory on the AP projection was considered to be directly up the center of the dens. On the lateral projection, the ideal trajectory began at the anteroinferior corner of the C2 body and traversed the midportion of the dens ending at the superior, posterior tip of the dens.

After drilling, the hole depth was measured with a depth gauge and tapped with a 4.0-mm cancellous threaded tap. A partially threaded 4.0-mm cancellous screw (Synthes USA, Paoli, PA) corresponding to the measured length was placed. Following placement of the screw, final AP and lateral fluoroscopic images were taken to confirm screw position. In no case were the final images deemed to show an unacceptable screw position.

Standard Fluoroscopic Technique

Screw placement in the standard fluoroscopy group was performed using multiple C-arm AP and lateral images as needed to ensure the accuracy of screw placement. A single C-arm (GE Series 9800, OEC Medical Systems, Salt Lake City, UT) was adjusted multiple times during screw placement from the AP to lateral plane and back as needed to accurately guide the procedure. Using these images, the drill and screw were directed along the ideal trajectory as previously described. After the screw was placed, final AP and lateral images were obtained to ensure satisfactory implant position.

Virtual Fluoroscopy Technique

Procedures in the virtual fluoroscopy limb utilized the FluoroNav® fluoroscopy system (Surgical Navigation Technologies, Medtronic Sofamor Danek, Inc., Memphis, TN) (Figs. 1 and 2). To begin, a reference frame was attached to the Mayfield head holder, positioning the array within 10–15 cm of the surgical field as recommended by the manufacturer's guidelines. Single acceptable anteroposterior and lateral scout images of the upper cervical spine were then captured from the C-arm (GE Series 9800) and transferred to the computer and workstation. No further C-arm images were taken throughout the procedure until after the screw was inserted. The FluoroNav drill guide was calibrated and then tracked during the

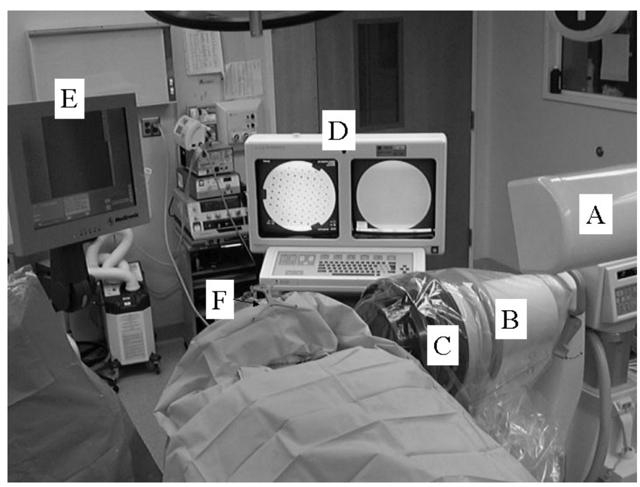

FIGURE 1 View of the operating room setup for fluoroscopic navigation, including **(A)** laser-guided tracking camera, **(B)** fluoroscopy C-arm, **(C)** calibration target attached to the C-arm, **(D)** C-arm monitor, **(E)** computer workstation and monitor, and **(F)** the patient reference frame.

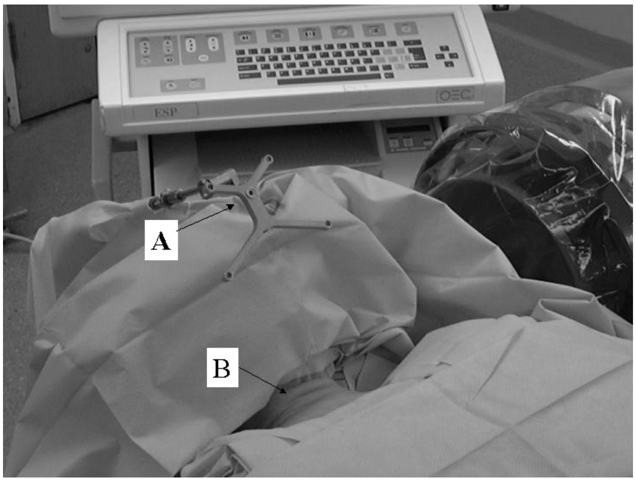

FIGURE 2 Closer view of **(A)** the FluoroNav reference frame attached to the head holder in relation to **(B)** the operative site.

procedure, allowing the position and trajectory of the drill to be displayed and followed (virtually) relative to the preacquired fluoroscopic images. The FluoroNav monitor provides simultaneous visualization of the drill position on both AP and lateral images during drilling and allows continuous adjustments to be observed in both planes simultaneously on the monitor. After drilling, the screw hole was measured and tapped and the screw of appropriate length was placed. Following screw placement, final AP and lateral C-arm images were taken to assess the final position of the implant.

Anatomic Dissection

Following screw placement, the C1–C2 segment was removed en bloc from each cadaver with a surrounding cuff of intact tissue. The C2 vertebrae and dens were carefully dissected to identify any breach of the screw outside the bony corridor. If any breach was identified, the location and amount of any screw outside the bone were recorded and the proximity to neurovascular structures was noted. Breaches were defined as "noncritical" if a portion of the screw violated the odontoid outer cortex but did not place any neurologic or vascular structures at risk (i.e., breaches into the anterior atlantodens interval), whereas those breaches that occurred in the vicinity to the spinal cord or vertebral arteries were classified as "critical."

Data Analysis

Total fluoroscopy time was recorded from the C-arm in seconds for all images required to perform each screw insertion. This included the registration images required in the fluoroscopic navigation group and the final images in both groups. Total procedure time was recorded in minutes, from the beginning of the screw insertion portion of the procedure until after acquisition of the final AP and lateral C-arm images. Time needed for surgical exposure of the C2 body in each specimen was excluded. For the fluoroscopic navigation group, procedure time included the time necessary to attach and calibrate the FluoroNav equipment and acquire the necessary C-arm scout images.

Fluoroscopy time and procedure time were compared between groups using a one-tailed Student t test, whereas breach rates were compared using Fisher's exact test. A cutoff level of $p < .05$ was used for statistical significance.

Results

Fluoroscopy time, procedure time, and number of observed breaches are summarized in Table 1.

Radiation Exposure and Procedure Times

Significantly less fluoroscopy time was required in the virtual navigation group when compared with the standard fluoroscopy group (mean = 8.3 s vs. 20.8 s; $p < .001$). Total procedure time was not found to differ significantly between the virtual and standard fluoroscopy groups (mean = 8.6 min vs. 11.6 min; $p > .05$).

Screw Accuracy

One specimen in each group was found to contain a screw breach. In each case, the screw threads were visible in the atlantodens interval between the anterior portion of the odontoid process and the posterior portion of the anterior C1 ring. No critical screw breaches were observed in either group.

Discussion

Although technically demanding, osteosynthesis of type II odontoid fractures can reduce the need for prolonged halo vest immobilization, lower the rate of nonunion, and preserve C1–C2 motion (10, 13–20, 28, 29, 39, 40). Although two screws were described in the original techniques of fixation, a single odontoid screw fixation has been successfully used by several authors and is what we chose to test here (20, 33, 39, 41, 42). In this study, mean operating time was approximately 25% less using the fluoroscopic navigation method, although this difference did not reach statistical significance. A short learning curve exists for use of the computer system; the experimental

TABLE 1 Summary of procedure times, fluoroscopy times, and rate of screw cutout in standard fluoroscopy and virtual fluoroscopy groups

	Procedure Time (min)		Fluoroscopy Time (s)		Presence of Screw Breach	
Specimen	SF	VF	SF	VF	SF	VF
1	20	6	23	12	No	No
2	16	14	25	10	No	No
3	13	15	38	27	No	No
4	18	5.5	13	11	No	Yes
5	7	7.5	24	5	No	No
6	6	9	27	9	No	No
7	7	8.5	21	9	No	No
8	8	5.5	14	6	No	No
9	7	7	20	9	Yes	No
10	8	9	23	9	No	No
11	17.5	8	24	8	No	No
Mean (±SD)	11.6 (±5.4)	8.6 (±3.2)	20.8 (±4.9)	8.3 (±1.9)	—	—
p value	.132		.0001		—	

$N = 11$ for each group. *SD*, standard deviation; SF, standard fluoroscopy; VF, virtual fluoroscopy.

team was fairly inexperienced with the system, but once setup and navigation became familiar, we found drilling and screw placement were consistently more expedient using this technique. The biggest limitation of standard fluoroscopy using a single C-arm is that imaging is available in only one plane at a time. The surgeon must position the tool or implant in one view, then obtain additional images in other orthogonal views for trial-and-error placement (31). This expends significant operating time while the technician changes the C-arm position during and after implant placement, and is avoidable only through the use of virtual fluoroscopy or the use of biplanar standard fluoroscopy. It should be noted, however, that a number of surgeons do, in fact, use two standard perpendicular fluoroscopy units simultaneously, which may reduce operative times significantly. As we did not compare fluoroscopic navigation with biplanar fluoroscopy in this study, we are unable to evaluate whether any significant differences in operative time exist between these techniques.

An improvement in radiation exposure was noted with the use of virtual fluoroscopy. In real patient surgery, it is possible that the magnitude of radiation savings with virtual fluoroscopy would be even greater because the number of traditional fluoroscopy images taken in a living patient to ensure clinical safety would likely exceed the number of images taken in the standard fluoroscopy limb of this study. Although the differences demonstrated here are relatively small, this corresponds to a real and statistically significant reduction in radiation exposure to the surgeon. One minute of intraoperative fluoroscopy is equivalent to as much as 4 Rads (40 mSv, 4,000 mRem) of radiation (43). The average savings of 12 s in fluoroscopy here thus represents a mean reduction of approximately 0.8 Rad, or the equivalent of 50 chest radiographs (43). Unfortunately, this single small additional radiation dose approximates the total dose experienced annually by high-altitude pilots, a concerning fact considering that career pilots have a three- to fivefold increase in myeloid and skin malignancies when compared with the general population (44). Although the careful surgeon may experience little direct body exposure to this radiation, he or she is still subject to scatter and often direct exposure to the hands during implant positioning and placement.

Certain limitations of the study should be noted. First, the reference array was attached to the Mayfield head holder. When possible, it is desirable to attach the reference array to the anatomic structure being addressed (here, the C2 vertebrae). This is because any shift in position of the reference frame relative to the position of the patient will introduce errors in navigation and potentially lead to a misplaced implant. The Mayfield frame was chosen as the attachment site because of the difficulty encountered with attaching the array to the C2 vertebrae and still keeping the array out of the surgeon's way during the procedure. One goal of this study, therefore, was to explore the appropriateness of the Mayfield attachment site. We suggest that a Mayfield attachment site may be safely used during fluoroscopic navigation for odontoid osteosynthesis; however, great care should always be employed on the part of the surgeon to ensure that the skull and upper cervical spine are rigidly fixed during the procedure to avoid inaccuracies with image navigation.

Second, the type of breach observed in this study involved the anterior atlantodens articulation. Although not widely described, this type of violation involves the synovial articulation of the C1–C2 joint and theoretically could place a patient at risk for pain or degenerative changes involving this joint. In neither case was the breach suspected on the basis of the postprocedural fluoroscopic images, making it possible that this type of breach is more common that previously reported. Further study of this type of implant breach appears warranted.

Finally, these cadavers had intact odontoid processes rather than fractures. This was deemed acceptable because it simulated the anatomic fracture reduction that is necessary prior to odontoid osteosynthesis. However, because fluoroscopic navigation systems do not allow "virtual" imaging of fracture reduction, scout images must be obtained and stored only after all reduction has been completed. More importantly, virtual fluoroscopy does not allow intraoperative feedback of any positional shifts of the patient or fracture. Our use of intact odontoids precludes comment on any effects of intraoperative fracture displacement that might occur after registry of the initial fluoroscopy images. Before clinical use of the computer system, it will be important to repeat this study using an odontoid fracture model to ensure that the lack of intraoperative fluoroscopic feedback during the computer-guided procedures does not add morbidity to the procedure. It may ultimately prove most effective to use limited intraoperative imaging to ensure maintenance of fracture reduction, combined with virtual fluoroscopy for the majority of the procedure, allowing the significant savings in radiation exposure and the ability to view the position of the navigated instruments in both the AP and lateral planes simultaneously as described here.

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