Placement of C2 laminar screws using three-dimensional fluoroscopy-based image guidance

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Abstract The use of C2 laminar screws in posterior cervical fusion is a relatively new technique that provides rigid fixation of the axis with minimal risk to the vertebral artery. The techniques of C2 laminar screw placement described in the literature rely solely on anatomical landmarks to guide screw insertion. The authors report on their experience with placement of C2 laminar screws using three-dimensional (3D) fluoroscopy-based image-guidance in eight patients undergoing posterior cervical fusion. Overall, fifteen C2 laminar screws were placed. There were no complications in any of the patients. Average follow-up was 10 months (range 3–14 months). Postoperative computed tomographic (CT) scanning was available for seven patients allowing evaluation of placement of thirteen C2 laminar screws, all of which were in good position with no spinal canal violation. The intraoperative planning function of the image-guided system allowed for 4-mm diameter screws to be placed in all cases. Using modified Odom's criteria, excellent or good relief of preoperative symptoms was noted in all patients at final follow-up.

Keywords C2 laminar screw · Atlantoaxial fusion · Image-guidance · Computer-assisted · Isocentric C-arm

Introduction

Originally described by Wright in 2004 [21], C2 laminar screws are appealing due to the large size of the C2 lamina, rigid fixation of the axis, and the reduced risk of injury to the vertebral artery. Limited case series have shown good clinical results with this technique [21, 22] and biomechanical studies of C2 laminar screws have recently been published [6, 13].

The use of image-guidance for spinal surgery made its advent in 1996 and has been shown to increase the safety and accuracy of spinal instrumentation placement [2–5, 11, 12, 15–17, 20, 23]. Spinal instrumentation placement using three-dimensional (3D) image-guidance has traditionally involved registering the spine with a paired points or surface matching algorithm. Point registration can prove challenging at the C1–C2 junction due to the decreased surface area and lack of focal anatomic landmarks on the C1 and C2 dorsal elements. Additionally, with paired points and surface matching algorithms only one vertebral level at a time can typically be registered.

The advent of 3D fluoroscopy using an isocentric C-arm has allowed for registration of multiple levels of the spine without the need for paired points or surface matching algorithm. The C-arm rotates 190° isocentrically around the area of the spine to be instrumented while acquiring multiple fluoroscopic images. A reference arc is attached to the C-arm allowing it to be tracked by an image-guidance system. The obtained images are then reconstituted into a CT data set that is automatically registered to the image-guidance system.

Safe and accurate spinal instrumentation placement from the C1 to S1 vertebral levels has been reported with 3D fluoroscopy-based image-guidance [1, 7–9, 18]. At the C2 level, the placement of screws into the odontoid, pars,

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pedicle and C1–C2 transarticular junction using 3D fluoroscopy-based image-guidance has been described [7, 9, 10, 18]. The authors report on the use of 3D fluoroscopy-based image-guidance for placement of C2 laminar screws, which has not been reported in the literature.

Material and methods

Between June 2005 and August 2006, eight patients (seven females, one male) undergoing posterior cervical fusion incorporating the axis underwent placement of C2 laminar screws using the BrainLAB (BrainLAB, Westchester, IL) image-guided system in conjunction with the Arcadis Orbic Isocentric C-arm (Siemens Medical Solutions, Erlangen, Germany). The average patient age was 72.2 years. The charts of these patients were reviewed retrospectively. Additionally, postoperative CT scans were reviewed for accuracy of screw placement.

In each case, the patient was positioned prone on a radiolucent spine table with the head fixated neutrally in a rigid, radiolucent headholder using skullpins. The base for the image-guided reference arc was attached to the radiolucent headholder using a clamp prior to prepping the patient. In cases in which C2 laminar screws are used, the author does not attach the reference arc to the spine itself because it would overly the entry points of the C2 laminar screws if attached to the C2 spinous process and the anatomy of the C1 posterior arch does not allow proper attachment of the reference arc to this level. After the posterior elements of the upper cervical spine were exposed, the image-guided reference arc was fixated to its base in sterile fashion. The isocentric C-arm was then

positioned so that the C1–C2 junction was in the center of the fluoroscopic field in the anterior-posterior (AP) and lateral plane. An isocentric spin of the C-arm was then accomplished and the obtained images were reconstituted into a CT data set, which was automatically registered to the BrainLAB image-guided system.

Screws with polyaxial heads were used in all cases. After accuracy of navigation was confirmed by the surgeon, the entry points and trajectories of the C1 lateral mass screws were ascertained using the image-guided probe. The entry points were then decorticated with a high-speed drill and the holes for the C1 lateral mass screws were drilled using a 2.6-mm navigated drillguide (Fig. 1). Prior to tapping these holes and placing the C1 lateral mass screws, accuracy of navigation was confirmed on the C2 lamina and the entry point and trajectory of the C2 laminar screws was ascertained using the image-guided probe (Fig. 2). Pilot holes were made with a high-speed drill and the navigated drillguide was then used to drill the holes for the crossing C2 laminar screws. Care was taken to carefully plan the entry points of the holes so the crossing C2 laminar screws did not collide in the midline when being placed. After the holes were drilled, they were probed with a small ball-probe to verify there was no bony breach. The holes were then tapped and after no bony breach was again confirmed, the screws were placed. Typically, a 4-mm diameter screw could be placed usually of a length varying from 22 to 30 mm, depending on the patient's anatomy. Tapping of the C1 lateral mass holes and placement of the C1 lateral mass screws can result in some minor movement of the C1–C2 junction thereby resulting in navigation inaccuracy. Because of this, these steps were done last. If fusion was going to be

Fig. 1 Image from the BrainLAB platform showing the navigated drill guide being used to drill the holes for the C1 lateral mass screws. The CT images in this figure were obtained using the isocentric C-arm

Fig. 2 Three-dimensional image-guidance used to ascertain entry point and trajectory of a C2 laminar screw

carried down to the subaxial spine, then lateral mass screws were placed below the C2 level without image-guidance. The interarticular surfaces of the C1–C2 joints, as well as the dorsal spinal elements, were decorticated with a high-speed drill and grafting material was then placed in these areas. Grafting material consisted of bone morphogenetic protein supplemented with morcellized allograft in four patients and iliac crest autograft in the other four patients. Rods were then connected to the polyaxial screws with locking caps. Offset connectors were used to incorporate the C2 laminar screws into the construct in cases that the fusion extended down to the subaxial spine (Fig. 3). After all of the instrumentation was inserted, an intraoperative lateral radiograph was obtained to confirm adequate placement. To conserve operating room time, another isocentric spin of the C-arm was typically not done to check instrumentation placement. However, in one case the evoked potentials did drop shortly after placement of the C2 laminar screws. An isocentric spin of the C-arm was done, which revealed no spinal canal violation by the instrumentation. The evoked potentials did come back to baseline spontaneously and the drop was eventually discovered to be secondary to anesthetic effect. Postoperatively, all patients were maintained in a cervical collar for 3 months. Serial radiographs and CT scans were used to assess fusion status (Fig. 4).

Results

There were no complications in this series. Overall, fifteen C2 laminar screws were placed in eight patients (Table 1). Five patients underwent solitary C1–C2 fusion, two patients had the axis incorporated as part of a multilevel posterior fusion construct and one patient underwent anterior removal of a failed odontoid screw with subsequent posterior C1–C3 fusion done in a single stage. Mean operating time for all patients was 310 min. In the five patients undergoing solitary C1–C2 fusion, mean operating time was 275 min. Average follow-up was 10 months (range 3–14 months). In one patient the anatomy only allowed placement of one C2 laminar screw; therefore, a short Magerl screw was placed in the C2 pars contralaterally. One patient was lost to physical follow-up after 6 weeks, however, she was contacted via telephone 12 months after her surgery and stated her preoperative cervical pain had completely abated and she was doing fine. She refused further follow-up as well as a request for a CT scan. The other seven patients in this series did undergo postoperative CT scanning allowing for assessment of screw placement. Thirteen C2 laminar screws were placed in these patients, 12 of which showed excellent position with no bony breach (Fig. 5). One screw did have a minimal (<1 mm) posterior laminar cortex breach by the

Fig. 3 Illustration showing the final construct in a patient undergoing C1–C3 fusion. The C2 laminar screws are incorporated into the construct using offset connectors

distal tip of the screw. This breach was known at the time of surgery and expected given the patient's anatomy. This screw was purposely not backed out as the surgeon felt that purchase of the posterior laminar cortex by the distal tip of the screw only added to the strength of the screw. No spinal canal violation occurred with any screw. Using modified

Odom's criteria, excellent or good relief of preoperative symptoms was noted in all patients at final follow-up.

Discussion

The method of C2 laminar screw placement described in Wright's original study, as well as in all subsequent studies in the literature regarding this technique, relies solely on anatomical landmarks for screw placement [6, 13, 14, 19, 21, 22]. Two-dimensional (2D) fluoroscopy is of limited benefit in C2 laminar screw placement secondary to the oblique trajectory of the screw, which results in the inability to adequately determine spinal canal compromise by the screw in the AP or lateral plane.

Placement of C2 laminar screws using 3D image-guidance has not been described in the literature. An advantage of 3D fluoroscopy-based image-guidance in C2 laminar screw placement is real-time feedback of the proposed screw trajectory in the axial, coronal and sagittal plane. Additionally, with the BrainLAB image-guided platform an intraoperative planning function allows for a virtual screw of various lengths and diameters to be placed at the tip of the image-guided probe (Fig. 6). This enables the surgeon to determine exactly what size screw can be placed into the C2 lamina or whether the lamina is large enough to accommodate the smallest diameter screw available to the surgeon. In a study of 38 cadaveric spines, Wang reported that 37% of the specimens had at least one C2 lamina that could not accommodate a 3.5-mm diameter screw with a 1-mm bony margin and 47% of specimens could not

Fig. 4 Lateral plain radiograph and sagittal CT scan of a patient s/p C1–C3 fusion showing precise placement of instrumentation and solid fusion

Table 1 Summary of data in eight patients undergoing posterior cervical fusion with image-guided placement of C2 laminar screws

Case	Age (years), sex	Diagnosis	Operative procedure	FU (months)	Placement accuracy (postoperative CT)	Outcome
1	64, F	C1–C2 facet arthropathy	Posterior C1–C2 fusion	12	Minimal posterior laminar breach	Fusion, no complications, excellent relief of preoperative pain
2	78, F	C1–C2 facet arthropathy	Posterior C1–C2 fusion	9	No bony breach	Fusion, no complications, excellent relief of preoperative pain
3	72, F	Postoperative cervical deformity	Posterior C1–C5 fusion	12	NA	No complications, excellent relief of preoperative pain
4	81, F	Type 2 odontoid fx, s/p failed odontoid screw	Posterior C1–C3 fusion	9	No bony breach	Fusion, no complications, good relief of preoperative pain
5	75, M	C1–C2 facet arthropathy	Posterior C1–C2 fusion	14	No bony breach	Fusion, no complications, excellent relief of preoperative pain
6	57, F	Type 2 odontoid fx, non-union	Posterior C1–C2 fusion	14	No bony breach	Fusion, no complications, excellent relief of preoperative pain
7	75, F	C1–C2 facet arthropathy	Posterior C1–C2 fusion	3	No bony breach	Fusion, no complications, excellent relief of preoperative pain
8	76, F	C1–C3 facet arthropathy	Posterior C1–C3 fusion	10	No bony breach	Fusion, no complications, excellent relief of preoperative pain

NA not available, fx fracture, s/p status post, FU follow up

accommodate 4-mm diameter screws bilaterally [19]. In our series, all fifteen C2 laminar screws placed were 4 mm in diameter and the authors attribute this to the beneficial attributes of 3D image-guidance described above. One C2 lamina could not accommodate a screw in this series and this was determined intraoperatively with the aid of the

planning function on the image-guided platform. Postoperative CT evaluation was able to be used to assess placement of thirteen C2 laminar screws, none of which violated the anterior cortex of the C2 lamina.

Three-dimensional (3D) fluoroscopy using the isocentric C-arm has been a significant advance in the field of spinal image-guidance as it allows for multilevel vertebral

Fig. 5 Postoperative CT showing accurate placement of C2 laminar screws **Fig. 6** Intraoperative planning of a C2 laminar screw

registration without the need for point matching. At the atlantoaxial junction this technology is particularly beneficial due to the difficulty with paired points and surface matching on the C1 and C2 dorsal elements. In the authors' experience, the total amount of OR time required to position the isocentric C-arm, acquire the images and send the reconstructed 3D data set to the image-guided platform is approximately 4–5 min. The authors feel that the benefits of 3D fluoroscopy-based image-guidance far outweigh this small amount of added OR time.

Conclusion

C2 laminar screw placement is a recently described technique with considerable advantages over traditional fixation methods of the axis. In this study, it has been shown that C2 laminar screws can be safely and accurately placed using 3D fluoroscopy-based image-guidance. Advantages of this technology over traditional techniques include real-time 3D computerized feedback to the surgeon during placement, as well as the ability to size the screw to the patient's anatomy using intraoperative computerized planning.

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