

Robot-assisted atlantoaxial fixation: illustrative cases

*Amanda N. Sacino, MD, PhD, Joshua Materi, BS, A. Daniel Davidar, MBBS, Brendan Judy, MD, Ann Liu, MD, Brian Hwang, MD, and Nicholas Theodore, MS, MD

Department of Neurosurgery, Johns Hopkins School of Medicine, Baltimore, Maryland

BACKGROUND Placing screws in the high cervical spine can be challenging because of the vital anatomical structures located in that region. Precision and accuracy with screw placement is needed. The use of robotics in the cervical spine has been described before; however, here the authors describe the use of a new robotic setup.

OBSERVATIONS The authors describe 2 cases of robot-assisted placement of C2 pars screws and C1–2 transarticular screws. The operative plans for each patient were as follows: placement of C2 pars screws with C2–4 fusion for hangman's fracture and placement of C1–2 transarticular screws for degenerative disease. Intraoperative computed tomography (CT) was used to plan and navigate the screws. Postoperative CT showed excellent placement of hardware. Both patients presented for initial postoperative clinic visits with no recurrence of prior symptoms.

LESSONS Intraoperative robotic assistance with instrumentation of the high cervical spine, particularly C2 pars and C1–2 transarticular screws, may ensure proper screw placement and help avoid injury.

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KEYWORDS pars screw; robotics; transarticular screw

The use of robotics in spine surgery has rapidly expanded over the past few years, with an increase in the number of systems available as well as advancements in intraoperative navigation and instrumentation. The predominant use of robotic navigation with instrumentation in spine surgery until this point has been in the thoracic and lumbar spine. Initial studies have reported successful lumbar pedicle screw placement rates ranging from 97.4% (339 of 348)¹ to 99% (555 of 562).²

The surgical approach for high cervical spine pathology varies, with the main concern being accurate screw placement due to the proximity of the cervical spinal cord and vertebral and carotid arteries. Because instrumentation in this region of the spine arguably requires the highest degree of accuracy, it is a natural progression for the use of robotics for navigation. Here, we describe the use of robotic assistance for C2 pars screw fixation for hangman's fracture and C1–2 transarticular screw fixation for stabilization of atlantoaxial degenerative instability. Although transarticular C1–2 fixation and C1–2 pars instrumentation with robotic

assistance have been described before,^{3–7} these are the first cases detailing the use of a new robotic setup.

Illustrative Cases

The ExcelsiusGPS robot (Globus Medical, Inc.) was used for instrumentation assistance in both cases.

Clinical History

The patient in case 1 was a 61-year-old man who presented with acute-onset neck pain after a head strike during a surfing accident. He had no neurological deficits on physical examination. Computed tomography (CT) of his head and cervical spine showed a displaced, vertically oriented, transverse fracture that extended into the transverse foramina bilaterally (Fig. 1A), also referred to as a "hangman's fracture." Magnetic resonance imaging (MRI) showed retropulsion of a posterior fracture fragment with T2 hyperintensity consistent with epidural blood products, ultimately causing circumferential spinal canal stenosis (Fig. 1B). A posterior C2–4 decompression and fusion was recommended.

ABBREVIATIONS CT = computed tomography; MRI = magnetic resonance imaging.

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* A.N.S. and J.M. contributed equally to this work.

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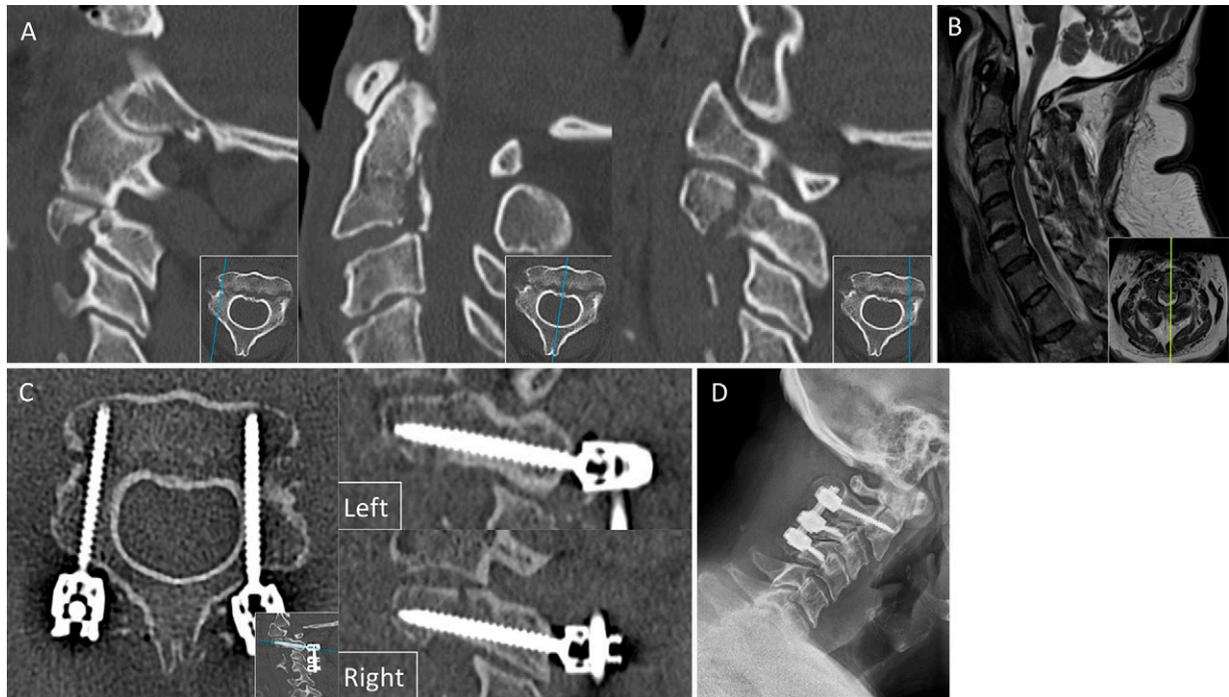


FIG. 1. Case 1. Sagittal CT scan (A) and T2-weighted MRI scan (B) show a C2 hangman's fracture with severe spinal canal stenosis at C2–3 and C3–4. Postoperative axial (left) and sagittal (upper and lower right) CT scans (C) showing excellent screw placement in the C2 pars through the fracture line. Cervical radiograph (D) at 7 weeks after surgery.

The patient in case 2 was a 68-year-old woman who presented with a 2-year history of progressive right-sided occipital neuralgia, for which conservative treatment with physical therapy, epidural steroid injections, and pain management had failed. She had no neurological deficits on physical examination. CT demonstrated right C1–2 joint arthritis. MRI showed severe degeneration of the joint causing right C2 nerve impingement, as well as evidence of instability with lateral displacement of the dens and pannus formation (Fig. 2A). In addition, the patient had high-riding vertebral arteries, particularly on the left, which could affect hardware placement. A C1–2 fixation with right C2 nerve root sacrifice was recommended to help control the patient's pain. Of note, nerve root sacrifice was not required for instrumentation.

Intraoperative Workflow

For these procedures, patients were positioned prone on a Jackson table. The head was fixated in a neutral position with a Mayfield clamp. A minimal midline surgical incision was planned to accommodate the Globus spinous process clamp as well as the angle of the robot arm for the operative spine levels (Supplemental Fig. 1A and B). Bony exposure of the screw entry sites was performed for both patients with the wand tool to help confirm accuracy because these were the initial operations using robot guidance. For case 1, the clamp was placed on the spinous process of C5 and angled toward the feet; for case 2, the spinous process clamp was placed on C2 and angled toward the head. After the patient reference and registration arrays were placed, the O-arm (Medtronic) was used for intraoperative CT. Once the data were transferred to the robot, the robot was draped and brought into the field. The accuracy of registration was determined by using bony landmarks, and, once confirmed, the registration array overlying the surgical wound was removed.

Screws were then planned and navigated: for case 1, bilateral pars interarticularis screws through the fracture (Supplemental Fig. 2A and B); for case 2, through the C1–2 joint (Supplemental Fig. 3A and B). Screw placement using power tools followed three steps: (1) drilling of the pilot hole, (2) cannulating of the hole, and (3) placement of the screw. Each surgical procedure was then completed as planned. The C3 and C4 lateral mass screws for case 1 were placed freehand. The C1–2 transarticular screws in the patient in case 2 were connected by a horizontal rod and buttressed by a fibular strut allograft wired under the C1 lamina. There were no operative complications for either patient. Time of surgery for each case was approximately 2 hours.

Postoperative Course and Follow-Up

The patient in case 1 had an uncomplicated postoperative course and was discharged home on postoperative day 5. Postoperative CT confirmed excellent hardware placement (Fig. 1B). He followed up in the clinic 7 weeks after surgery and was doing well, with minimal pain. Follow-up radiographs showed early evidence of arthrodesis across the C2 hangman's fracture (Fig. 1C and D), although it is still early to fully assess.

The patient in case 2 likewise had an uncomplicated postoperative course, with immediate relief of her right occipital neuralgia. Postoperative CT confirmed excellent hardware placement (Fig. 2B). She was discharged home on postoperative day 3. She followed up in the clinic 7 weeks after surgery and reported complete resolution of her pain. Follow-up radiographs showed excellent hardware positioning (Fig. 2D). We were unable to fully assess arthrodesis across the C1–2 joint at this early follow-up.

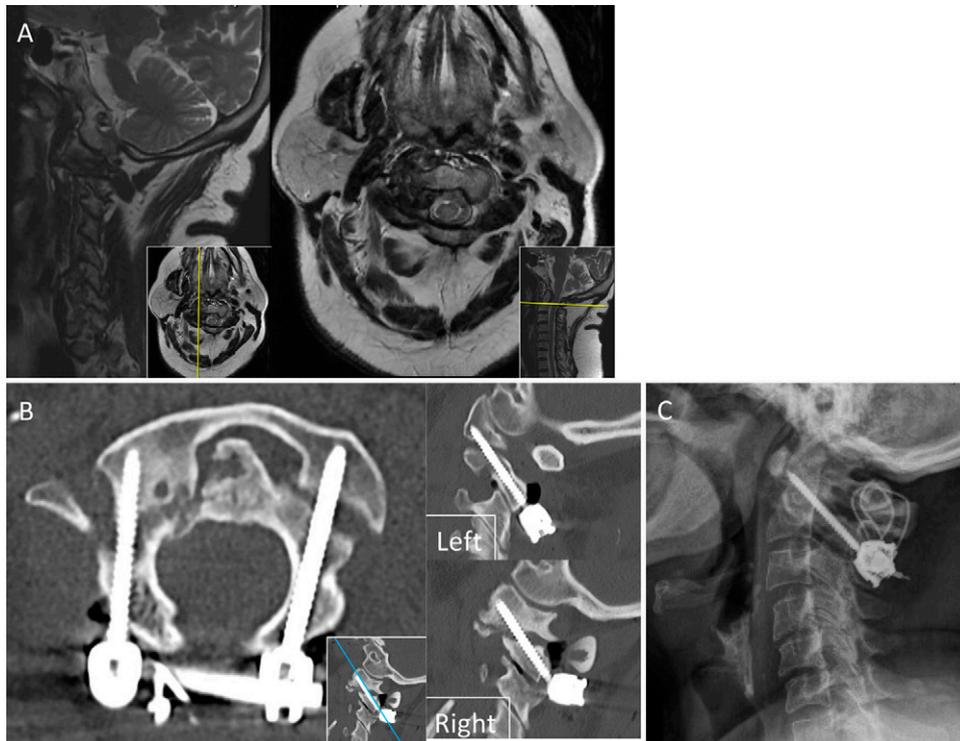


FIG. 2. Case 2. **A:** Sagittal (*left*) and axial (*right*) T2-weighted MRI scans show severe degenerative disease of the right C1–2 joint as well as pannus formation. **B:** Postoperative axial (*left*) and sagittal (*upper and lower right*) CT scans showing excellent placement of C1–2 transarticular screws attached by a horizontal rod. The fibular strut allograft with wiring can also be seen. **C:** Cervical radiograph at 7 weeks after surgery.

Discussion

Observations

High cervical fixation involving C1 and C2 is a complex surgical procedure associated with potentially severe complications, including screw malposition causing damage to neural and/or vascular structures. Prior studies evaluating the accuracy of the freehand technique of C2 pars screw and C1–2 transarticular screw placement without intraoperative radiographic guidance have shown that 11% and 7% of screws were mispositioned according to the cortical breach grading system.^{8,9} The real-time instrument/implant trajectory offered by this robotic system mitigates mispositioned screws. Increased accuracy of screw placement also decreases the risk of pseudoarthrosis.¹⁰ At C1–2, revision surgery would require extension of fusion to the occipital skull, which would significantly reduce mobility and the patient's quality of life.^{11,12}

Prior robotic systems for atlantoaxial fixation have failed due to translational error.¹³ Although we have shown here that the robot is accurate, landmark checks should still be completed using the stand-alone navigation with a wand tool. In addition to image-guided instrumentation, the fixed robotic arm incorporates a guide tube to interface with navigated instruments. Serving as a placeholder for instrumentation, the fixed robotic arm is advantageous because it allows the surgeon to follow the same path for all the steps of instrumentation instead of reorienting between steps. Coupling this arm with the use of power tools reduces wobble (deviation of the screw from its intended trajectory), which leads to increased screw purchase and pullout strength.¹⁴ The use of power tools also limits

the force applied to this highly mobile area of the spine, which has limited prior use of navigated instrumentation. The decreased movement of the bony elements during instrumentation improves accuracy. In addition, the surveillance software alerts the surgeon of possible instrument deflection (i.e., skiving) secondary to irregular bony surface or narrow trajectory.¹⁵

As described above, instrumentation is streamlined to three steps once the robotic arm is in place, with each tool passing through the fixed arm. This allows less chance for injury from passing instruments and less chance of inaccuracy due to micromovements of the patient and equipment. Each of the three tools used for instrumentation has its own array, which is close to the surgical site and improves accuracy.¹⁶ In addition, one of the logistical challenges of the case was positioning the robot so that the arm could achieve the degree of movement at the joints needed for the screw trajectory. With the base of the robot being mobile instead of attached to the surgical table, it is easier to achieve the correct position. An independent base may also be more stable than one attached to the surgical table.

As with all new procedures, setting up the workflow increases the timing of the procedure. For both patients in this study, the duration of the procedure was approximately 2 hours. This increased time was due to extra bony exposure to accommodate the spinous process clamp and to view the screw entry sites to ensure accuracy of the robot, given that this was the first time this procedure was being performed with robotic guidance. In addition, extra time was taken to try to position the robot so the angle of the arm could be

accommodated without having to open the incision further. In a systematic review, Joseph et al.¹⁷ analyzed the learning process associated with robotic-assisted spine surgery in 8 studies, and all demonstrated a notable reduction in per-screw time and fluoroscopy time. The advantages of decreased time have also been reported elsewhere.¹⁸ Anecdotally, our institution has seen significant increases in efficiency with the use of robotics for lumbar and thoracic screw placement since we first used it in 2017. Therefore, we predict that, over time, with refinement of the workflow and increased familiarity with usability and interdisciplinary setup, we will be able to reduce the operative time by more than half.

Ultimately, the combination of a fixed robotic arm with the use of navigated power tools reducing wobble for C1–2 transarticular screws will allow percutaneous fixation in future cases. Patients who have undergone open C1–2 transarticular fixation already have high rates of satisfaction when assessed on postoperative outcome surveys.¹⁹ Percutaneous fixation will be extremely beneficial in patients with favorable anatomy who need atlantoaxial stabilization and may not be able to medically withstand an open posterior cervical surgery. In lieu of the spinous process clamp used in our cases, there is a registration array that clamps directly to the Mayfield clamp, which will alleviate the need for an open midline incision (Supplemental Fig. 1A). Screws can be placed via two stab paramedian stab incisions; however, planning for the robot arm must consider the angle of screw placement and the body habitus (Supplemental Fig. 1B); that is, too steep of a screw angle may not be accommodated in a patient with a large body habitus. The transarticular screw also eliminates the technical steps involved with placement of C1 and C2 screws, such as the venous plexus between C1 and C2, and the C2 nerve roots, which are frequently covering the entry point for C1 screw placement. C1–2 transarticular screws have the highest lateral bending stability, followed by C1 lateral mass C2 pars screws, compared with other high cervical constructs.²⁰ In addition, a study of 2,000 cases of transarticular atlantoaxial fixation showed a 95% fusion rate and a low incidence of vertebral artery injury (3.1%).⁹ Therefore, robot-assisted percutaneous C1–2 transarticular fixation could become a highly beneficial surgical treatment in patients with atlantoaxial pathology.

Lessons

There are many complexities to consider when planning fixation of the high cervical spine, not only to help promote fusion but also to prevent catastrophic injury to the patient. Therefore, a high degree of accuracy in instrumentation is vital. Though traditional methods of freehand and fluoroscopic guidance during instrumentation provide relatively high rates of accuracy, there is still room for improvement that could be addressed with robotic assistance. Although the main point of this case illustration is to demonstrate successful robotic assistance with high cervical fixation, we have not shown definitive evidence of arthrodesis, which requires long-term follow-up. These cases show proof of concept for robotic-assisted high cervical fixation to serve as the foundation for a future study with long-term follow-up to fully assess arthrodesis. With sufficient training and refining of surgical technique, robotic assistance with high cervical fixation could become a mainstay of treatment for these complicated pathologies.

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Disclosures

Dr. Theodore reported personal fees from Globus Medical outside the submitted work; in addition, Dr. Theodore had a patent for Robotic platform with royalties paid from Globus Medical Globus Medical and a patent for Robotic platform issued Globus Medical. No other disclosures were reported.

Author Contributions

Conception and design: Theodore, Sacino, Materi, Hwang. Acquisition of data: Theodore, Sacino, Materi, Davidar, Judy, Hwang. Analysis and interpretation of data: Theodore, Sacino, Materi, Davidar, Hwang.

Drafting the article: Sacino, Materi, Davidar, Judy, Hwang. Critically revising the article: all authors. Reviewed submitted version of manuscript: Sacino, Materi, Davidar, Judy, Liu. Approved the final version of the manuscript on behalf of all authors: Theodore. Administrative/technical/material support: Davidar. Study supervision: Theodore, Davidar.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplemental Figs. 1–3. <https://thejns.org/doi/suppl/10.3171/CASE22114>.

Correspondence

Nicholas Theodore: Johns Hopkins Hospital, Baltimore, MD. theodore@jhmi.edu.