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Extended tulip cervical reduction screws to restore alignment in traumatic atlantoaxial dislocation after type 3 odontoid fracture: illustrative case

Christopher F. Dibble, MD, PhD, Saad Javeed, MBBS, Justin K. Zhang, BS, Brenton Pennicooke, MD, MS, Wilson Z. Ray, MD, and Camilo Molina, MD

Department of Neurological Surgery, Washington University, St. Louis, Missouri

BACKGROUND Traumatic atlantoaxial rotatory subluxation after type 3 odontoid fracture is an uncommon presentation that may require complex intraoperative reduction maneuvers and presents challenges to successful instrumentation and fusion.

OBSERVATIONS The authors report a case of a 39-year-old female patient who sustained a type 3 odontoid fracture. She was neurologically intact and managed in a rigid collar. Four months later, she presented again after a second trauma with acute torticollis and type 2 atlantoaxial subluxation, again neurologically intact. Serial cervical traction was placed with minimal radiographic reduction. Ultimately, she underwent intraoperative reduction, instrumentation, and fusion. Freehand C1 lateral mass reduction screws were placed, then C2 translaminar screws, and finally lateral mass screws at C3 and C4. The C2–4 instrumentation was used as bilateral rod anchors to reduce the C1 lateral mass reduction screws engaged onto the subluxated atlantodental complex. As a final step, cortical allograft spacers were inserted at C1–2 under compression to facilitate long-term stability and fusion.

LESSONS This is the first description of a technique using extended tulip cervical reduction screws to correct traction-irreducible atlantoaxial subluxation. This case is a demonstration of using intraoperative tools available for the spine surgeon managing complex cervical injuries requiring intraoperative reduction that is resistant to traction reduction.

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KEYWORDS atlantoaxial dislocation; cervical deformity; cervical reduction screws; spine trauma; type 3 odontoid fracture; translaminar screws

Traumatic atlantoaxial (AA) dislocation in the setting of odontoid fracture is a rare presentation in both adults and children, often caused by high-energy mechanisms associated with significant morbidity and mortality.[1,2] In one epidemiological review, only 2 of 784 cervical spine fractures were combined AA dislocation and osseus odontoid injury. There are only a few published cases of AA dislocation associated with type III odontoid fracture.[2–9] These injuries can be complex, involving bony, ligamentous, and vascular structures, as well as spinal cord injury.[10]

Nondisplaced type III odontoid fractures are generally treated nonoperatively but can progress to nonunion and AA instability.[11–13] Niemeier et al. reviewed 125 patients with type III odontoid fracture and found that conservative management, with cervical collar or halo orthosis, had a 21% failure rate, and most patients in whom the treatment failed displayed progressive anterolisthesis and angulation.[13] Posterior cervical fixation is an effective treatment for AA instability that can be accomplished by a variety of strategies, including the C1 lateral mass/C2 transpedicular method of Goel and Harms, the transarticular method of Magerl, and the translaminar method of Wright.[14–17] Alternative strategies are important in situations with destruction of anatomy leading to loss of structures that normally provide rigid instrumented fixation, such as the pedicle or pars of C2.[18,19]

In this report, we present a case of a patient with a chronic, nondisplaced type III odontoid fracture who sustained a high-force cervical trauma resulting in AA dislocation and traction-irreducible kyphotic rotatory subluxation. We then describe a technique for performing intraoperative open reduction using newly available long tulip reduction cervical screws and the challenges of obtaining alignment and fusion using a variety of intraoperative maneuvers in the

ABBREVIATIONS 3D = three-dimensional; AA = atlantoaxial; CT = computed tomography; VA = vertebral artery.

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setting of type III odontoid fracture. Finally, we discuss reduction management strategies for complex AA injuries with kyphotic rotatory subluxation.

Illustrative Case

History and Physical Examination

A 39-year-old homeless female with a past medical history significant for severe polytrauma as a pedestrian versus motor vehicle sustained 4 months prior, when she reportedly walked into traffic while intoxicated. Of note, she had a past medical history of polysubstance abuse, hepatitis C with cirrhosis, type 2 diabetes, and hypertension. At the time, she sustained numerous injuries, including a nondisplaced type III odontoid fracture (Fig. 1A–C), which was managed conservatively with a cervical collar, as well as separate three column/chance fractures at T3 and L4–5, which were managed with posterior percutaneous fixation. In addition, she had a small subdural hematoma managed nonoperatively and rib fractures with an associated pneumothorax managed with a chest tube. After an uncomplicated course in the intensive care unit, she recovered from her injuries. After completing a short course of inpatient rehabilitation, she was discharged with outpatient physical therapy with neurologically intact physical examination findings. A close neurosurgical follow-up was planned; however, the patient did not adhere to follow-up visits. After 4 months, she presented to the clinic complaining of new-onset severe neck pain and inability to lift her head.

On evaluation, her neck was flexed and rotated almost to her chest. The skin of her neck displayed visible bruising, and she endorsed that she had been assaulted several days before presentation, when she was strangled and thrown against a wall. She also endorsed that she had not been wearing her collar. Additional history and pertinent physical examination findings included intermittent bilateral hand paresthesias, with an otherwise intact neurological examination finding without long tract signs.

Radiological Work-Up

Initial computed tomography (CT) and magnetic resonance imaging showed displacement of the C2 fracture and severe AA complete rotatory subluxation of the right C1 on C2 lateral mass, with resulting severe spinal canal stenosis (Fig. 1D–F). A CT angiogram showed patency of the vertebral arteries (VAs), with left-sided dominance stable from her prior scan (Fig. 2).

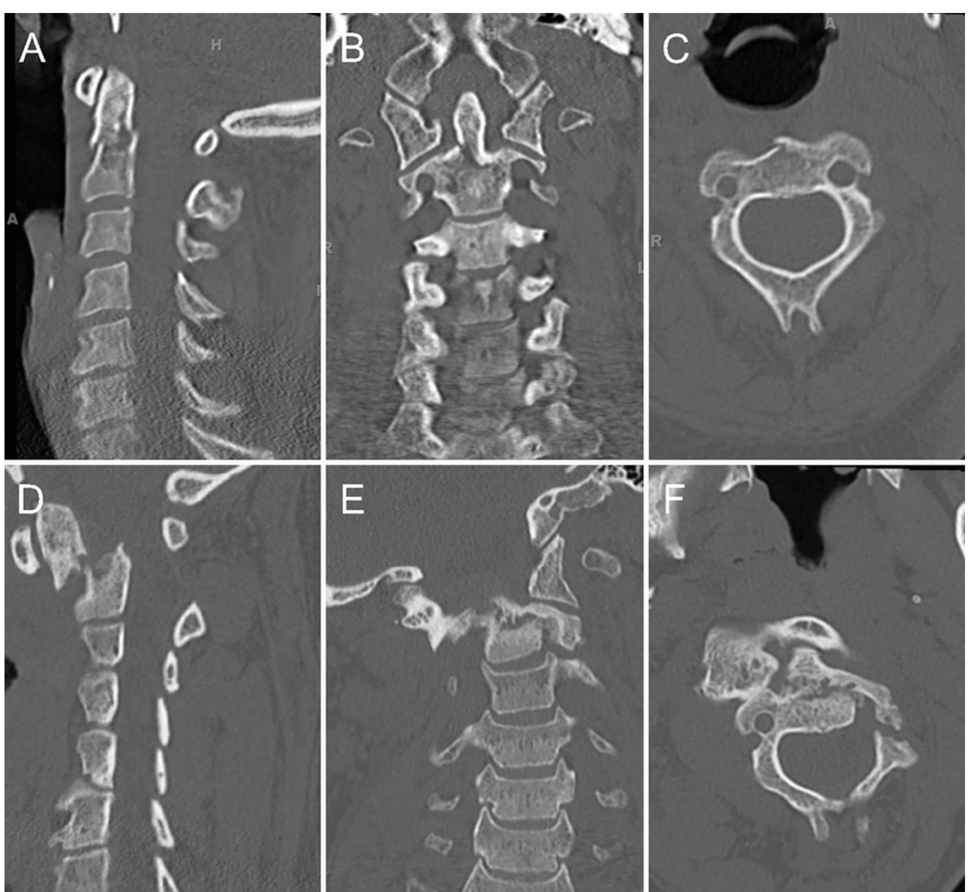

FIG. 1. Initial type III odontoid fracture managed with cervical collar. **A:** Sagittal view. **B:** Coronal view. **C:** Axial view. Subsequent type II AA dislocation after second injury leading to complete rotatory subluxation of right C1 on C2 lateral mass. **D:** Sagittal view. **E:** Coronal view. **F:** Axial view.

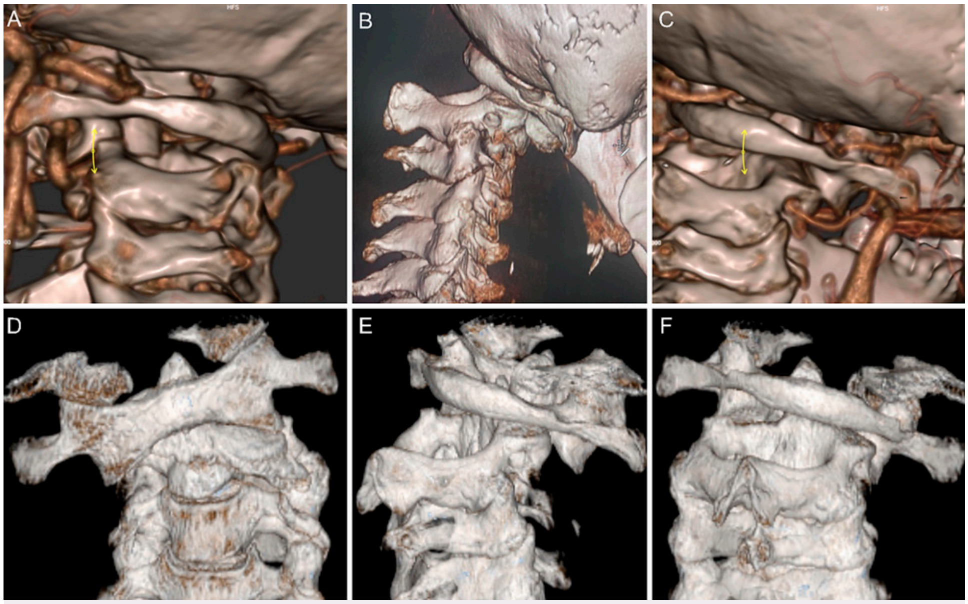

FIG. 2. 3D reconstruction of cervical CT angiography. **A:** Patent right vertebral artery. **B:** Severe fixed kyphotic deformity. **C:** Patent left and dominant vertebral artery. **D–F:** Severe rotatory subluxation on 3D bony reconstruction. *Yellow arrows* indicate rostral/caudal views.

Surgical Technique

Preoperative neuromonitoring data revealed excellent motor and somatosensory evoked potentials. A careful flip was performed, and the patient was positioned prone on an OSI Jackson frame with the head in 15 lb. of univector traction. A meticulous midline exposure was made. We placed bilateral (4.35 mm × 28 mm) freehand C2 translaminar screws (Fig. 3).[16,20] Although it is the authors' preference to achieve three-column C2 pedicle screw fixation, the narrow isthmus pedicles and bilateral pedicle fractures extending onto the oblique odontoid fracture made C2 pedicle screws not feasible. Due to the subluxation-induced aberrant course of the VA bilaterally, high-power magnification was used to fully expose the C2 lateral mass and pedicle course up to the deeper-seated bilateral C1 lateral masses and the C1–2 joints. The C2 nerve roots were sectioned bilaterally to secure ample access to the C1–2 joint. A laminar spreader across the posterior C1 arch and C2 lamina was employed to distract and partially reduce the subluxated C1–2 joint. Upon complete visualization of the C1 lateral masses, freehand C1 long tulip lateral mass screws were inserted using a modified Magerl technique (DePuy Synthes). Each was drilled to a depth of 20 mm, tapped, and then 5.0-mm × 30-mm screws were inserted to achieve bicortical purchase (Fig. 3).

Two lordotic cobalt chromium rods (Symphony; DePuy Synthes) were measured and cut. Using the C2 translaminar and C3–4

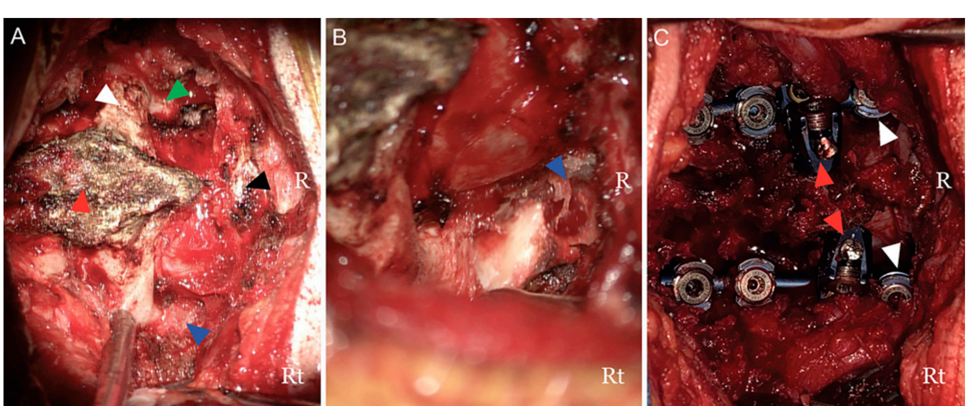

FIG. 3. Intraoperative photographs of C1–2 complex taken with microscope. R = rostral; Rt = right. *Arrowhead* colors are labeled parts. **A:** C1 arch (*black*), C1 lateral mass (*blue*), C2 spinous process (*red*), lamina (*white*), and pedicle (*green*). **B:** C1 lateral mass magnified (*blue*). **C:** After instrumentation with C1 screws (*white*) and C2 screws (*red*).

lateral mass screws as distal anchors, bilateral set screws were placed onto the C1 reduction tulip head and serially tightened to achieve the sagittal and rotatory reduction.

After reduction, we removed the rod on the left side while maintaining the contralateral rod firmly in place with final tightening to maintain the newly aligned C1–2 complex. This allowed full exposure of the left C1–2 joint, which was then decorticated and further mobilized via a series of facet spacer shavers and trials. In order to load the joint, maintain reduction, and achieve arthrodesis, we inserted a 4-mm facet spacer (Medtronic). The left-sided rod was then replaced/retightened, and the process was repeated on the right side. Decortication and preparation of the bilateral C1–2 joints facilitated further reduction of the subluxated atlantodental complex on retightening of the rods.

We used an intraoperative O-arm to confirm positioning and reduction, ensuring that the AA joints were appropriately aligned. We appreciated that the C1 screws were bicortical and the facet spacers were placed well to support and load the C1–2 joints (Fig. 4A–D). After ensuring well-placed hardware and accomplishing the reduction of fractures and rotatory subluxation, posterior arthrodesis was performed via decortication of all exposed bone surfaces and packed allograft.

Our intraoperative reduction technique allowed us to safely reduce and realign the type III odontoid fracture concurrent with traction-irreducible atlantoaxial subluxation. With the background of complex ligamentous and bony injuries, this reduction is challenging, and the long tulip cervical reduction screws enabled a reasonable purchase and lateral capture of the rods to achieve reduction and fusion with the distal anchors. The patient tolerated the procedure well. She was neurologically intact and transferred to the floor in a cervical collar. She was discharged with outpatient physical therapy on postoperative day 7, with exit upright radiographs demonstrating sustained reduction and good alignment (Fig. 4E and F). At 6-week follow-up, she was doing well, remaining neurologically intact with her pain greatly improved. Anteroposterior and lateral films demonstrated good alignment without any evidence of hardware failure (Fig. 4G and H). Our normal follow-up for patients undergoing complex posterior fusion procedures is 6 weeks, 3 months, 6 months, 12 months, and 2 years, with radiographs. This patient was instructed to stay in a hard collar (Miami J) for at least 3 months postoperatively. This patient relapsed into substance abuse and was lost to follow-up after 6 weeks, despite being discharged initially with outpatient resources set up.

Discussion

Observations

Treatment of fixed kyphotic AA dislocation is challenging, with goals being to achieve reduction and then rigid bracing progressing to achieve fusion. There is a paucity of high-level evidence to guide decision making, and surgeons must weigh individual patient factors and the morphology of the injury. Initial attempts at reduction through external traction are warranted, although with great caution to avoid causing neurological injury in the setting of significant bony and ligamentous instability.[21] Operative planning requires high-quality images to understand bony, vascular, and neuroanatomy of the axial and subaxial cervical spine and the atlanto-occipital junction. The course of the VA must be determined and protected during reduction. Intraoperative reduction techniques must be employed, such as articular release, distraction, instrumentation, and threaded lever rod reduction.

Historically, anterior or transoral approaches reinforced with posterior fusion have been used to treat AA dislocation, along with posterior wiring, with many modern strategies taking advantage of the powerful purchase and high fusion rates afforded by modern implants.[15,22,23] Strong purchase with instrumentation allows satisfactory rod reduction, with the principle that the long tulip allows significant set screw drive distance. Reduction screws are used in the thoracolumbar spine in instances of trauma and spondylolisthesis for both open and minimally invasive surgical applications.[24,25] Until recently, reduction screws have not been available for the cervical spine, which changed in 2019 with the approval of the Symphony

FIG. 4. Intraoperative CT showing C1 lateral mass tulip reduction screws. **A:** Axial view. **B:** Sagittal view. **C:** Coronal view. C1/C2 loading with the facet spacer (B). **D:** C2 translaminar screws, axial view. Postoperative radiographs show good alignment with intact hardware. **E and F:** One-week (E) anteroposterior (AP) and (F) lateral films. **G and H:** Six-week (G) AP and (H) lateral films.

OCT system (DePuy Synthes) by the Food and Drug Administration. These are polyaxial screws that allow 10 mm of threaded reduction over the length of the tulip head. They incorporate 3.5- to 4.0-mm rods and a variety of compatible hooks and cross-connectors. We also found that they allow easier lateral capture of the rod, given the long tulip.

As with any rod reduction, understanding the sequence of rod locking is important. When reducing the rostral level, screws should be driven down bilaterally slowly and in unison. A unilateral temporary rod to maintain reduction can be employed for changing implants on the contralateral side. Engagement of the rod in the screw head generates recoil forces, and, importantly, both the bone and caudal anchor interface must be of sufficient quality to withstand reduction forces.[22] We believe that the forces applied by the pistol reducers used more commonly in the thoracolumbar spine would have potentially led to fracture or screw pullout due to the high forces required to reduce this rotatory subluxation. It also would have been technically difficult to mount multiple reduction towers on our C1–2 construct, although tower and pistol reducers, along with manual reduction, remain viable options in skilled hands. The technique we report represents another option due to a technological innovation in a screw system, not a novel principle of reduction. Although there are no other published clinical data regarding the use of these screws, we reasoned that using a large-diameter screw bicortical purchase at C1 in combination with multiple caudal anchor points would reduce the chance of such failure. In high-energy trauma where the pedicles of C2 are damaged and unable to accommodate true three-column fixation via a pedicle screw, alternate strategies are necessary, in our case, large translaminar screws with domino connectors. A three-dimensional (3D) model of the patient's cervical spine demonstrates the instrumentation and reduction with C1 long tulip screws (Fig. 5).

Instrumentation may be technically feasible, but maintaining alignment and then achieving fusion are difficult with complex

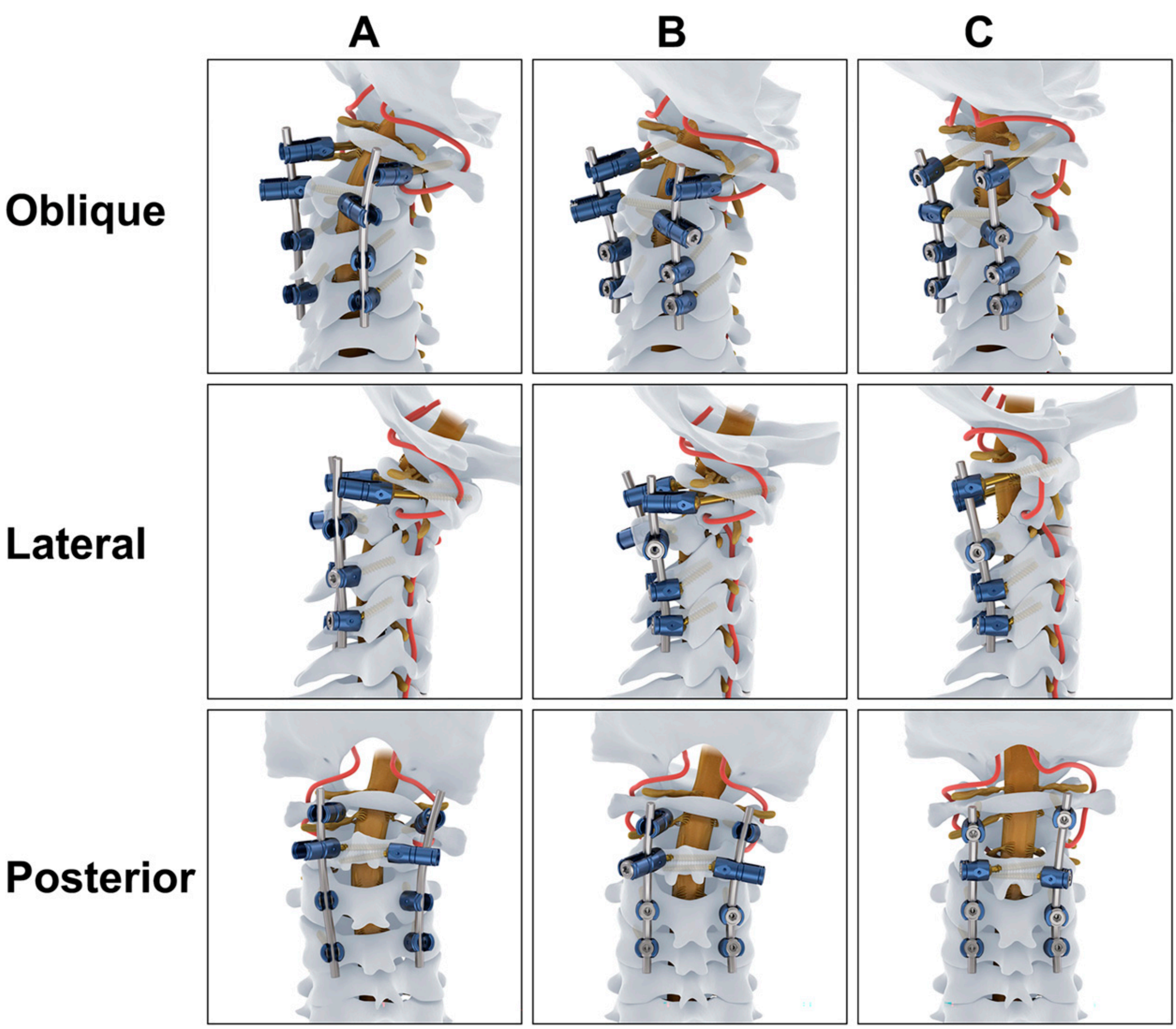

FIG. 5. 3D model of the patient's cervical spine demonstrating the final reduction using long tulip C1–2 screws. **A:** The model shows the fracture after instrumentation and initial reduction maneuvers. **B:** There was mild further reduction after driving the set screws down on the C2 translaminar screws. **C:** Reduction on the C1 long tulip provides powerful final reduction of the subluxated C1–2 complex.

ligamentous and bony injuries. We believe this case is also of interest because of the use of cervical bone allograft spacers at C1–2 to help achieve lasting reduction and fusion, which would be the first time this has been demonstrated in concurrent AA dislocation and type III odontoid fracture.[26] Goel first described use of intraarticular spacers to achieve distraction, reduction, and fusion over the mobile AA joint in 2007,[27] and Aryan et al. followed this with the first use of commercial allograft spacers at C1–2 in 2008.[28] Most pertinent to this case, Turel et al. reviewed 19 patients who underwent posterior fusion of C1–2 for AA instability using cervical interfacet allograft spacers, reporting a 95% fusion rate.[26] In our patient, we undertook a wide lateral release of the C1–2 joint to facilitate reduction, so we had anterolateral exposure of the joints and were able to decorticate extensively. We were then able place large facet shims to achieve better purchase and facilitate fusion with compressed bone graft in the joint for better long-term stability of the construct. This strategy is supported by biomechanical analysis suggesting that C1–2 interfacet spacers combined with screw/rod construct results in additional construct rigidity and appears to be more useful in cases with instability.[26,29] We thought that a longer distal construct with a larger-diameter rod would allow better force distribution. However, it may be reasonable to opt for a short segment construct or a more powerful proximal construct via extending to the occiput to cantilever down to correct kyphosis. Nevertheless, given this patient had an intact craniocervical junction, occipital fusion would be highly morbid due to significant restriction in range of motion.

This case demonstrates the complex bony morphology that can result from multiple high-energy insults to the AA complex and the challenges in achieving reduction of an unstable kyphosis. Strategies such as upsizing implants and cortical allograft facet spacers can help achieve stability of the construct and lasting fusion. Although this is the first report of the use of cervical reduction screws, we believe they have applications in a number of upper cervical spine pathologies, including odontoid fractures and dislocations, nonunion, and congenital malalignment. Last, in cases where there is significant 3D displacement of unstable (i.e., highly mobile) anatomical structures, fluoroscopy and stereotactic computer navigation may be misleading. Thus, it is critical to perform an ample exposure and be experienced in freehand instrumentation of atlantoaxial structures to safely perform these procedures.

Limitations

Importantly, there are a number of limitations involving cervical AA reduction, including with the use of this new technology. These screws are the first with extended reduction capabilities in the screw head itself, but other technologies exist to achieve threaded reduction, such as pistol grip reducers or tower reducers. We believe these long head reduction screws have the promise of decreased forces applied to potentially unstable constructs during reduction compared with these techniques. Although this has not yet been demonstrated in the literature, we believe that serial set screw threading on the screw-integrated reduction tulips permits redistribution of the reduction forces along the entire construct rather than exerting these forces across a single implant. It is conceptually possible to use multiple reduction towers or pistons, but with the small working space between C1–2 screw heads, it is difficult to apply multiple reduction towers to the operative field at once.

It should also be noted that there are no long-term data for this screw system, and our follow-up here is limited due to this patient being lost to follow-up as a result of known substance abuse issues. Clearly, further biomechanical and human studies are needed, but we feel this represents an additional technical option for spine surgeons.

Lessons

Fixed AA rotatory subluxation presenting with displaced type III odontoid fracture is an uncommon pathology. A thorough preoperative work-up and understanding of the fracture morphology are critical. In this case, the odontoid fracture, bilateral pedicle fractures, and AA rotation prevented conventional C1 and C2 instrumentation techniques, necessitating alternative strategies such as translaminar C2 screws for reduction/fixation and C1–2 allograft spacers for long-term stability of the construct. When standard preoperative and intraoperative techniques such as traction and manual reduction and distraction fail, cervical reduction screws are a viable option to gain further realignment. This report describes the first case of the use of these screws, which offer a powerful new tool for managing fixed C1–2 deformity with type II AA dislocation and odontoid fracture. Cervical reduction screws are technically simple, because many spine surgeons are already familiar with the principles of threaded rod reduction in the thoracolumbar spine. No high-level evidence exists on their use, but we thought that using upsized C1 and C2 screws maximized our chances of successful reduction and minimized the chance of subsequent pullout or hardware failure. As experience with reduction screws in the cervical spine grows, we look forward to further refinements of this technique.

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Disclosures

Dr. Ray reported receiving personal fees from DePuy Synthes during the conduct of the study and personal fees from Globus Medical and personal fees from NuVasive outside the submitted work. Dr. Molina reported receiving nonfinancial support from DePuy Synthes during the conduct of the study and serving as an ad hoc consultant for DePuy Synthes. The other authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Molina. Acquisition of data: Molina. Analysis and interpretation of data: Molina, Dibble. Drafting the article: Molina, Dibble, Javeed. Critically revising the article: Molina, Dibble, Javeed, Ray. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Molina. Administrative/technical/material support: Zhang.

Correspondence

Camilo Molina: Washington University, St. Louis, MO. cmolina@wustl.edu.