



## Minimally invasive atlantoaxial fusion: cadaveric study and report of 5 clinical cases

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**OBJECTIVE** Minimally invasive techniques are being increasingly used to treat disorders of the cervical spine. They have a potential to reduce the postoperative neck discomfort subsequent to extensive muscle dissection associated with conventional atlantoaxial fusion procedures. The aim of this paper was to elaborate on the technique and results of minimally invasive atlantoaxial fusion.

**MATERIALS** Minimally invasive atlantoaxial fusion was done initially in 4 fresh-frozen cadavers and subsequently in 5 clinical cases. Clinical cases included patients with reducible atlantoaxial instability and undisplaced or minimally displaced odontoid fractures. The surgical technique is illustrated in detail.

**RESULTS** Among the cadaveric specimens, all C-1 lateral mass screws were in the correct position and 2 of the 8 C-2 screws had a vertebral canal breach. Among clinical cases, all C-1 lateral mass screws were in the correct position. Only one C-2 screw had a Grade 2 vertebral canal breach, which was clinically insignificant. None of the patients experienced neurological worsening or implant-related complications at follow-up. Evidence of rib graft fusion or C1–2 joint fusion was successfully demonstrated in 4 cases, and flexion-extension radiographs done at follow-up did not show mobility in any case.

**CONCLUSIONS** Minimally invasive atlantoaxial fusion is a safe and effective alternative to the conventional approach in selected cases. Larger series with direct comparison to the conventional approach will be required to demonstrate clinical benefit presumed to be associated with a minimally invasive approach.

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**KEY WORDS** atlantoaxial fusion; C1–2 fusion; minimal access; minimally invasive spine surgery; tubular retractor; cervical

POSTERIOR atlantoaxial fixation was first described in 1910 by Mixter and Osgood, who used a braided silk thread.<sup>20</sup> This concept has gradually evolved into more biomechanically stable modifications to the present day polyaxial screw-rod constructs.

Conventional C-1 lateral mass screw and C-2 pedicle screw placement, as initially described by Goel and Lahiri,<sup>7</sup> and later modified by Harms and Melcher,<sup>8</sup> requires midline exposure from the occiput to C3–4 to enable sufficient lateral retraction of the posterior neck muscles and visualize the described entry points for screw placement.

This extensive muscular dissection causes disruption of the posterior musculoligamentous tension band, resulting in impaired postoperative neck muscle function, and may be responsible for persistent neck discomfort.<sup>2,6,9,12,25</sup>

Minimally invasive muscle splitting approaches, introduced for the lumbar spine, have the potential to significantly reduce muscle injury and preserve the posterior tension band.<sup>13,19</sup> Their superiority in minimizing blood loss, reducing the duration of hospital stay, enabling earlier return to work, and improving functional outcomes compared with conventional procedures has been shown

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in several studies.<sup>5,26</sup> Recently, several reports of extension of this technique to the cervical spine have appeared in the literature and have shown promising outcomes.<sup>6,16,21,28</sup>

The present study elaborates minimally invasive C1–2 fusion performed using an expandable tubular retractor in 4 cadaver specimens and subsequently in 5 clinical cases.

## Methods

Four fresh-frozen cadavers with an intact skull base and cervical spine and good visualization of the bony anatomy on fluoroscopy were selected for this study. Preoperative CT scanning was performed in all cadavers to note the dimensions and integrity of the C-1 lateral mass and C-2 pedicles. The C-1 lateral mass and C-2 pedicles in all cadavers were found suitable for placing a standard 3.5-mm polyaxial screw. The same technique was then applied in a selected cohort of 5 clinical cases.

## Surgical Technique

Similar steps were followed while performing the procedure in cadavers and clinical cases (Videos 1 and 2).

**VIDEO 1.** Surgical technique of minimally invasive atlantoaxial fusion being done on left side with preservation of the C-2 ganglion, intraarticular drilling, and graft placement within the C1–2 joint. Copyright Umesh Srikantha. Published with permission. Click here to view.

**VIDEO 2.** Surgical technique of minimally invasive atlantoaxial fusion being done on the right side with transection of the C-2 ganglion, intraarticular drilling, and graft placement within the C1–2 joint. A portion of the video also shows the placement of an overlay split rib autograft between the C-2 and C-1 laminae and anchoring it with a titanium miniscrew. The access track through the muscle closing, once the tube is removed, and the skin wound are also shown toward the end. Copyright Umesh Srikantha. Published with permission. Click here to view.

A vertical 2.5-cm incision was placed on either side 2.5 cm off the midline (Fig. 1A), and blunt soft-tissue dissection was done with artery forceps and a finger to palpate the inferior facet of C-2. The smallest dilator was introduced through the dissected plane and docked on the highest point of the C-2 facet (Fig. 1B). No effort was made at this point to palpate the posterior arch of C-1, and care was taken not to dip the smallest dilator toward the C1–2 joint or medially into the gap between the C-1 posterior arch and C-2 lamina. Sequential dilation was then done (Fig. 1C) to finally place a 22-mm expandable tubular retractor (Quadrant system, Medtronic Sofamor Danek) overlying the C-2 lateral mass (Fig. 1D). The retractor was then angled superiorly, and the blades were expanded so as to cover the area between the posterior arch of C-1 and C-2 lateral mass, between the superior and inferior blades of the retractor. The inferior oblique muscle, which runs transversely in the C1–2 interlaminar space, was transected using cautery to expose the C-1 posterior arch, posterior atlantoaxial membrane, and C-2 pars. The posterior atlantoaxial membrane was then divided using sharp dissection to expose the underlying venous plexus. Further dissection was done in between the C-1 and C-2 lateral masses to expose the exiting C-2 nerve root, C1–2 joint

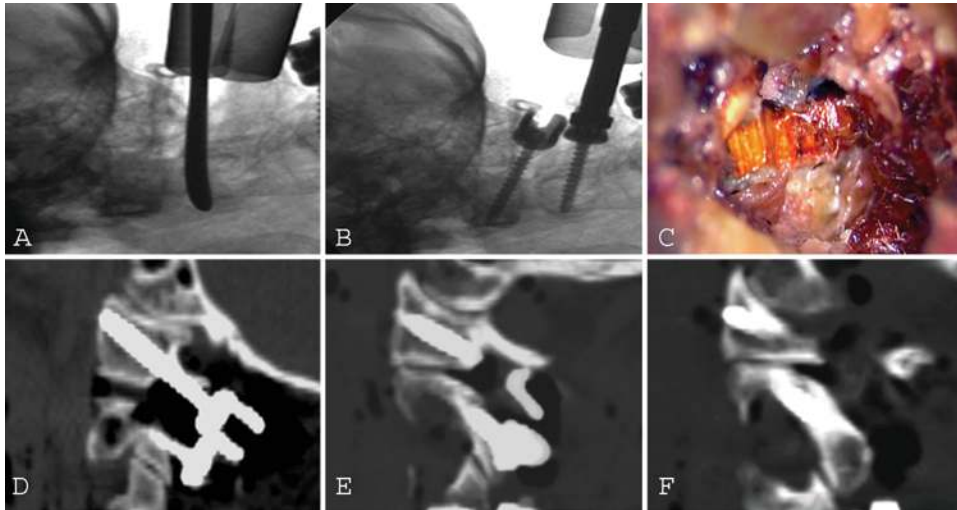


**FIG. 1.** A: Image showing the skin marking and stretch ability of the skin in the cervical region, allowing for a smaller incision. B–E: Intraoperative fluoroscopy images showing initial docking over the C-2 facet (B), after sequential dilation (C), placement of an expandable retractor (D), the C-1 lateral mass drill hole being prepared (E), and the final construct (F). Figure is available in color online only.

space, and entry points for the C-1 lateral mass and C-2 pedicle screws. Any bleeding in clinical cases was controlled using bipolar cautery and Gelfoam. While using a C1–2 joint spacer (a trimmed wooden block was used as joint spacer in cadavers [Fig. 2C]), the C-2 nerve root was sacrificed if necessary; the joint space was distracted with the aid of a blunt Penfield dissector (Fig. 2A), the endplates were drilled using a diamond bur, and the graft was placed within the joint space. The C-1 lateral mass and C-2 pedicle screws were then placed with standard technique and instruments (Figs. 1E and F and 2B). The retractor had to be angled more superiorly to obtain the required trajectory for the C-2 pedicle screw. A connecting rod was placed under direct visualization. In some cases, a split rib graft was placed medial to the screw-rod construct (overlying the drilled cortical surfaces of the C-1 posterior arch and C-2 lamina), and was anchored with a miniscrew (Video 2). The retractor was removed, and similar steps were repeated on the other side.

## Results

Placement of the screws was assessed in the 4 cadaveric specimens using postprocedural CT scanning (Fig. 2D–F). All 8 C-1 lateral mass screws were found to be in the correct position, with no breach into the medial or lateral cortices or into the adjacent joint spaces. Although not intentional, bicortical purchase was seen in 2 screws.



**FIG. 2.** Lateral fluoroscopy images obtained in a cadaver, showing a Penfield dissector within the C1–2 joint space (A) and final construct after placing C-1 and C-2 screws (B). A fashioned wooden block is positioned as a joint spacer (C). Postprocedural sagittal paramedian CT scans in the cadaver showing the position of the C-1 and C-2 screws (D–F). Figure is available in color online only.

Vertebral canal breach was seen in 2 of the 8 C-2 screws, one a Grade 1 breach and the other a Grade 2 breach. Both breaches were seen on the inferior aspect of the screw, possibly due to insufficient superior angulation.

Details of the clinical cases are given in Table 1. All C-1 lateral mass screws were in the correct position. Only one C-2 screw had a Grade 2 vertebral canal breach (among the 6 screws assessed using postoperative CT scans). In the remaining 2 cases, in which only a plain radiograph was obtained at follow-up, the position of the screws appeared satisfactory based on radiographic parameters in the assessment of the vertebral canal<sup>4</sup> (Fig. 3). None of the patients had neurological worsening or implant-related complications at follow-up. Direct evidence of rib graft fusion or C1–2 joint fusion was successfully demonstrated in 4 cases (Fig. 4A and B); flexion-extension radiographs obtained at follow-up did not show mobility in any case (Fig. 4C and D).

## Discussion

With the aim of reducing approach-related morbidity, minimally invasive spine surgeries have been gaining increasing importance over the last decade.<sup>2</sup> Their role in reducing retraction-related devascularization and denervation of muscles and preserving the posterior midline tension band in both cervical and lumbar surgery has been emphasized in several studies.<sup>5,10,14,22,23</sup> In terms of clinical benefit, this would translate into lesser postoperative pain and analgesic usage, shorter hospital stay, earlier return to work, and better postoperative extensor muscle strength.<sup>15,19,26</sup> Although minimally invasive techniques were initially popularized for the lumbar spine, these techniques are being increasingly applied in the cervical spine as well. Reports of minimally invasive techniques being used to treat common cervical procedures, such as laminoforaminotomy,<sup>3,29</sup> lateral mass fusion,<sup>6,28</sup> and stenosis decompression,<sup>21,24</sup> can be found in the literature.

Application of minimally invasive techniques to perform an atlantoaxial fusion seems reasonable, as the steps of atlantoaxial joint manipulation, C-1 lateral mass, and C-2 pedicle/pars screw placement are all done from a lateral-to-medial trajectory and do not require exposure of midline structures. Of importance, this preserves muscular attachments of the C-2 spinous process, which act as stabilizers of the craniocervical junction, thus preventing postoperative loss of lordosis.<sup>2</sup> This can be compared with transforaminal lumbar interbody fusion, in which a minimally invasive approach has shown considerable advantages over a conventional midline approach.<sup>17,18,26</sup> The only muscle band that needs to be transected in a minimally invasive atlantoaxial fusion procedure is the inferior oblique muscle due to its anatomical position where it runs horizontally between the C-1 posterior arch and C-2 lamina. Since its function is to stabilize and aid in rotatory movements at the atlantoaxial segment, the impact of transecting this muscle is unlikely to affect outcome when an atlantoaxial fusion is being performed. Minimizing injury to the suboccipital muscles is the main advantage of this technique. We did not find a significant reduction in blood loss compared with conventional cases, as the main step where blood loss occurs in these procedures is during dissection around the C-2 root and exposing the C1–2 joint space, which is no different from that of a conventional technique.

A few reports of minimally invasive atlantoaxial fusion published over the last decade can be found in the literature.<sup>2,9,12,25</sup> Using 12 fresh-frozen cadavers, Bodon et al.<sup>2</sup> described the muscle splitting approach to the atlantoaxial joint in detail and were able to reach and identify the entry points for the C-1 lateral mass and C-2 pars screws in all the cadavers bilaterally. Joseffer et al.<sup>12</sup> initially reported a case of os odontoideum that was successfully treated with a minimally invasive technique using an expandable tubular retractor, and later Holly et al.,<sup>9</sup> from the same group, described the technique being used to treat 5 cases

**TABLE 1. Details of the clinical cases**

| Variable                   | Case 1   | Case 2  | Case 3  | Case 4   | Case 5   |
|----------------------------|--|---|---|--|--|
| Age/Sex                    | 46/M   | 68/F  | 22/M  | 37/F   | 52/M   |
| Clinical history           | Known case of RA for 15 yrs; neck pain for 5 yrs; progressive myelopathy for 4 mos | History of RTA 2 mos earlier w/ back injury; treated for head & chest injuries; neck pain | History of RTA; severe neck pain                                    | Underwent MRI for back pain that revealed T12–L1 PIVD. Incidentally detected unstable AAI w/ cord signal changes | Neck pain for 1 yr; progressive myelopathy for 1 yr        |
| Diagnosis                  | AAI (reducible)  | Type III odontoid fracture  | Type II odontoid fracture   | AAI (reducible)  | AAI (reducible)  |
| Neurological status        | Nurick Grade 3   | Nurick Grade 2  | Nurick Grade 2  | Nurick Grade 1   | Nurick Grade 3   |
| mJOA score                 | 12   | 13  | 15  | 17   | 11   |
| Details of procedure       | C-1 lateral mass/C-2 pars fixation; rib graft (joint+interlaminar)                 | C-1 lateral mass/C-2 pars fixation; rib graft (interlaminar)                              | C-1 lateral mass/C-2 pars fixation; rib graft (interlaminar)        | C-1 lateral mass/C-2 pars fixation; (joint bone substitute)  | C-1 lateral mass/C-2 pars fixation (joint bone substitute) |
| Duration of surgery (mins) | 230  | 170   | 210   | 160  | 190  |
| Blood loss (ml)            | 400  | 250   | 300   | 150  | 200  |
| Duration of hospital stay  | 7 days   | 5 days  | 12 days   | 7 days   | 6 days   |
| FU duration (mos)          | 24   | 15  | 26  | 16   | 14   |
| Nurick grade at FU         | 0  | 1   | 0   | 0  | 1  |
| mJOA score at FU           | 18   | 16  | 18  | 18   | 15   |
| Imaging findings at FU     | CT: screws in correct position; rib graft fusion                                   | CT: screws in correct position; rib graft fusion  | CT: screws in correct position; fusion at fracture site & rib graft | X-ray: screws in situ; C1–2 joint space fusion   | X-ray: screws in situ; C1–2 joint space fusion             |
| FU status                  | Asymptomatic; working  | Asymptomatic  | Occasional neck pain; working                                       | Asymptomatic; working  | Asymptomatic; working                                      |

AAI = atlantoaxial instability; FU = follow-up; mJOA = modified Japanese Orthopaedic Association; PIVD = prolapsed intervertebral disc; RA = rheumatoid arthritis; RTA = road traffic accident.

of odontoid fracture with good results in all cases. Taghva et al.<sup>25</sup> performed the procedure initially in 4 fresh-frozen cadavers and subsequently in 2 patients with odontoid fracture and described that the correct entry point for obtaining a lateral trajectory for placing screws was 3.5 cm lateral to midline. We followed a similar protocol in undertaking a cadaveric study prior to clinical application but found that an incision 2.5 cm lateral to the midline is more beneficial as it gives a more direct view of the C1–2 joint, prevents lateral placement of the tubular retractor, and also provides sufficient lateral angulation for placement of the screws.

As we have shown in the present series, in addition to placing C-1 and C-2 screws, minimal access to the C1–2 region does not limit routine methods used to achieve fusion. Intraarticular drilling, graft/spacer placement, and placement of an overlay interlaminar rib graft can all be performed with minimal access as well. These steps were adequately backed by the cadaver study done prior to the clinical series. With the availability of these steps, achieving fusion rates similar to those of conventional techniques should be possible even with minimally invasive techniques. In the present series, although direct evidence of fusion based on CT scanning findings was



**FIG. 3. A and B:** Postoperative anteroposterior (A) and lateral (B) radiographs showing the position of the screws. **C:** Appearance of the wound at follow-up. Figure is available in color online only.



**FIG. 4.** Follow-up images in illustrative cases showing fused rib graft in a CT scan image (A, arrow) and fusion mass within the C1–2 joint space on an anteroposterior fluoroscopy image (B, arrow). Flexion (C) and extension (D) lateral radiographs obtained in a representative case, showing no mobility.

demonstrated in 3 of the 5 cases, dynamic radiographs in all patients did not show any mobility. However, it should be emphasized that cases with complex craniovertebral junction abnormalities that require bilateral simultaneous joint manipulation or added decompression in the form of foramen magnum decompression or C-1 arch excision may not, in our opinion, be feasible for minimally invasive techniques. Similarly, posterior wiring techniques, which have been speculated to increase fusion rates, cannot be used in the minimal access route.<sup>27</sup> In the present series, only cases of posttraumatic odontoid fracture with no cord injury or compression and reducible atlantoaxial instability were selected for treatment using minimally invasive techniques. This is one of the reasons for a small study group, which is the main drawback of the present study.

Application of minimally invasive techniques for atlantoaxial fusion has now crossed the boundary of technical feasibility. Despite minimally invasive approaches being increasingly used for treating diseases of the cervical spine as well as convincing rationale and theoretical evidence of their benefit over conventional approaches, there is a striking paucity of randomized studies comparing minimally invasive with conventional methods. A few studies comparing outcome between the approaches in cervical laminoforaminotomy have shown a marginal benefit for a minimally invasive approach over a conventional approach,<sup>3,29</sup> which is more than one can say about a similar procedure in the lumbar spine, e.g., microlumbar discectomy.<sup>1,11</sup> Future studies comparing minimally invasive and conventional techniques for more invasive procedures in the cervical spine might reveal more convincing benefit for a minimally invasive technique. Such studies are lacking at present.

## Conclusions

The present study demonstrates the safety and efficacy in the application of a minimal access technique for

atlantoaxial fusion, initially performed in 4 fresh-frozen cadavers and then in a small group of 5 carefully selected clinical cases. Further studies with larger patient numbers and direct comparison with conventional techniques are necessary to demonstrate the clinical benefit associated with minimally invasive approaches.

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### Disclosures

The 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: Srikantha. Acquisition of data: Srikantha, Joshi. Analysis and interpretation of data: Srikantha, Jagannatha, Joshi. Drafting the article: Srikantha, Khanapure. Critically revising the article: Srikantha, Khanapure. Reviewed submitted version of manuscript: Srikantha, Varma, Hegde. Approved the final version of the manuscript on behalf of all authors: Srikantha. Administrative/technical/material support: Hegde. Study supervision: Varma, Hegde.

### Supplemental Information

#### Videos

*Video 1.* <https://vimeo.com/168047525>.

*Video 2.* <https://vimeo.com/168047657>.

#### Previous Presentations

Portions of this work were presented as proceedings during the 2nd annual meeting of Minimally Invasive Spine Surgeons of India (MISSICON-2015) held on October 24 and 25, 2015, in Mumbai, India.

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