Comprehensive drilling of the C1–2 facets to achieve direct posterior reduction in irreducible atlantoaxial dislocation

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OBJECT The cause of irreducibility in irreducible atlantoaxial dislocation (AAD) appears to be the orientation of the C1–2 facets. The current management strategies for irreducible AAD are directed at removing the cause of irreducibility followed by fusion, rather than transoral decompression and posterior fusion. The technique described in this paper addresses C1–2 facet mobilization by facetectomies to aid intraoperative manipulation.

METHODS Using this technique, reduction was achieved in 19 patients with congenital irreducible AAD treated between January 2011 and December 2013. The C1–2 joints were studied preoperatively, and particular attention was paid to the facet orientation. Intraoperatively, oblique C1–2 joints were opened widely, and extensive drilling of the facets was performed to make them close to flat and parallel to each other, converting an irreducible AAD to a reducible one. Anomalous vertebral arteries (VAs) were addressed appropriately. Further reduction was then achieved after vertical distraction and joint manipulation.

RESULTS Adequate facet drilling was achieved in all but 2 patients, due to VA injury in 1 patient and an acute sagittal angle operated on 2 years previously in the other patient. Complete reduction could be achieved in 17 patients and partial in the remaining 2. All patients showed clinical improvement. Two patients showed partial redislocation due to graft subsidence. The fusion rates were excellent.

CONCLUSIONS Comprehensive drilling of the C1–2 facets appears to be a logical and effective technique for achieving direct posterior reduction in irreducible AAD. The extensive drilling makes large surfaces raw, increasing fusion rates.


KEY WORDS irreducible atlantoaxial dislocation; facetectomy; reduction; realignment; technique; facets; C1–2 joints

The management of atlantoaxial dislocation (AAD) is challenging due to the neural structures the craniovertebral junction (CVJ) houses and the proximity of the vertebral arteries (VAs). The dislocation may be reducible or irreducible. The reducible AAD can be defined as C1–2 alignment on extension or application of cervical traction. If the dislocation cannot be reduced despite cervical traction, it is labeled as an irreducible AAD. Management becomes difficult with irreducibility of the dislocation. Currently, the focus in treating such patients has shifted to the dislocated C1–2 facets rather than the dens. Since Goel’s description of C1–2 distraction, intraoperative joint manipulation has been the preferred method of treatment for irreducible AAD.1,2 In the recent past, various techniques of joint manipulation have been described to achieve reduction.3–8 However, little has been described about C1–2 facet mobilization using facet osteotomies. We have focused on treating the cause of irreducibility and joint mobilization by facet osteotomy apart from joint manipulation, and described the technique thereof.

The cause of irreducibility is likely to be the orientation of the C1–2 facets.5 In congenital irreducible AAD,
the C1–2 joints are deformed. The angulation of the facets gives rise to progressive slippage of C-1 over C-2, until at some point it becomes irreducible (Fig. 1A–F). Facetectomy is likely to address the cause of irreducibility and help in mobilizing the dislocated/deformed joint (Fig. 1G and H). In this paper we describe a technique of comprehensive drilling of the C1–2 facets (facetectomy) to eliminate the cause of irreducibility, and report our experiences with this technique.

Methods
Patient Population
Nineteen patients with congenital irreducible AAD were admitted to the Postgraduate Institute of Medical Education and Research, in Chandigarh, India, between January 2011 and December 2013. Irreducibility was defined as nonalignment of C1–2 (determined on lateral CVJ radiography) after extension (neck movement) or application of cervical traction (for 48 hours). Crutchfield cervical traction was applied, starting with 7%–8% of body weight (2–5 kg depending on age and weight). The head of the bed was elevated to provide counter traction. The weight was increased every 4 hours by 0.5 to 1 kg, to a maximum of 12%–13% of body weight. Serial radiographs were assessed for reduction. Those patients who demonstrated a reduction were excluded from the study. The patients who underwent operations in the 1st year were studied retrospectively and the remaining patients were evaluated prospectively. Proper informed consent was obtained from all patients.

Clinical Features
Patients presented with pyramidal tract involvement (n

![Fig. 1. Sketches of the C1–2 joint. A: A normal C1–2 joint viewed from a posterolateral aspect. B: Position of the C1–2 joint in cases of AAD. Note the obliquity of the C1–2 facets as compared with normal. The thin arrow shows the direction of progressive dislocation due to obliquity of the facets. C: Dynamic progression of AAD (thick arrow from B to C). D–F: Parasagittal section of the C1–2 facets in cases of congenital irreversible AAD. Due to the obliquity, the dislocation does not reduce on extension. The posteroinferior edge of C-2 acts as a ledge preventing reduction (red arrow in E). C-2 cannot be pushed anterior to C-1 due to the anteroinferior edge of C-1 (red arrow in F). Blue arrows represent the forces during flexion and extension that act on the C1–2 facets. G and H: The shaded areas show the portion of the C1–2 facets (congenital irreducible AAD) to be drilled to make the joint relatively flat, helping to achieve reduction, with respect to the hard palate represented by the line to the left of panel G. The correction of vertical dislocation would require a spacer/bone strut graft. Figure is available in color online only.](image-url)
The artery was then dissected along its course. The soft tissue was teased out to dissect the artery. To the anomalous artery. The ganglion was dissected and C-1 lateral mass screws. Orly to safeguard it while drilling the facets and inserting dissection could be gently retracted superiorly or inferiorly to protect the artery. The anterior capsule and soft tissue is visualized easily. In severe subluxation with oblique orientation of the facets, the joint space is not observed while dissecting the C-2 lamina and C-1 posterior arch. The drilling of the posterior-superior wedge of the C-2 facet was performed until the joint space and posterior surface of the C-1 facet could be seen. A thin osteotome was then inserted in the joint space to open the joint. The drilling then was continued more on the C-1 facet surface, especially the posterior portion. Intermittent insertion of an osteotome, or even applying suction and using it as a lever with the posterior edge of the C-2 facet as a fulcrum, improved the visibility of the anterior portion of the C-1 facet that required drilling. The visualization of the anterior joint capsule and soft tissue provides a rough idea of adequate drilling (Figs. 1G and H and 2). The entire edge of the facet from the medial to lateral aspect was drilled so that the facet surfaces became flat. Care was taken so that no bone ledge remained that would prevent reduction. The lateral wedge of the C-1 facet and medial wedge of C-2 were drilled to make the joint flat in the coronal plane (Figs. 1 and 2).

With this type of drilling, the C-1–2 joint is mobilized completely, converting an irreducible subluxation to a reducible one. Pressing the C-2 spinous process anteriorly should align the C-1–2 facets and is a simple maneuver to check for complete facet mobilization. Reduction was then maintained with the use of spacers (bone alone or metallic spacers packed with bone) and C-1–2 was fused using sublaminar wires or polyaxial screws. The bone graft was harvested from the seventh or eighth rib posteriorly and cut into small pieces and thin slices. The small pieces were packed into the drilled joint, followed by the spacer packed with these grafts. Next, the remaining pieces were again placed posterior to the spacers between the C-1–2 joint. The slices were placed between decorticated surfaces of the occiput/C-1 arch and C-2 lamina.

We switched to using polyaxial screws after using sublaminar wire in the first 3 patients. After insertion of spacers the vertical reduction can be achieved completely. In the last 1.5 years, C-1–2 polyaxial screws were inserted, and further anteroposterior and rotational alignment was achieved using modification of a technique described by Suh et al. A long rod holder holds the rod loosely fastened in C-1 and C-2 polyaxial screws. After tightening the rod over the C-2 screw and slightly distracting the C-1–2 screws, the rod holder was used as a lever and the C-2 screw tulip as a fulcrum. The rotation of the handle of the rod holder in various directions corrects anteroposterior, rotational, or lateral components of dislocation. Alignment of the midpoint of the C-1 posterior arch and C-2 spinous process suggested complete reduction. Final tight-
enlargement in the aligned position was performed after slightly compressing the C1–2 screws.

**Follow-Up**

Clinical and radiological evaluation was performed at regular intervals. The JOA scale score was compared with preoperative scores. Lateral radiographs of the CVJ in flexion and extension were obtained after 3 months. The inferior sagittal C-1 facet angle was calculated again using a postoperative CT scan. Bone fusion between the C1–2 facets was evaluated by both a radiologist and surgeon using a CT scan obtained 4–6 months after surgery. Thin reconstructed and reformatted (sagittal and coronal) CT scans were obtained to investigate fusion maturation and bone growth, as has been described for lumbar fusion. With thin CT scans, the scatter effect from newer metallic spacers is not an obstacle to interpretation. The entire construct was evaluated. Fusion was defined as bone trabeculae between the C1–2 facets or lamina and arch on CT without any gap in between (with no mobility on flexion-extension radiographs). In the presence of metallic spacers, particular attention was paid to the areas that were lateral, anterior, and posterior to the spacers. Cystic lucencies around the implants or along endplates and linear defects within the bridging trabeculae suggested nonfusion and required a repeat CT scan after 6 more months. An early CT scan at 4–6 months also showed subsidence or construct failure.

**Results**

The preoperative and postoperative modified JOA scale score, ADIs, and inferior C-1 sagittal facet angles for all patients are listed in Table 1. All patients improved postoperatively. Fourteen patients became independent (JOA score ≥15). Five patients improved from completely dependent to partially dependent (JOA score 11–14). Bone anomalies such as occipitalized arch of the atlas, C2–3 fusion, and central/vertical dislocation were noted in most of the patients with relatively acute inferior sagittal C-1 facet angles. The initial 3 patients in whom the technique was attempted were those who showed partial reduction after traction. Later, as the authors gained confidence, all patients with irreversible AAD underwent operations using this technique (Figs. 3 and 4). Vertebral artery injury (possibly anomalous) was encountered in 1 patient, in whom CT angiography was not obtained. A CT angiogram was obtained in the last 14 patients. Of the 28 VAs studied, 11 demonstrated an unusual and anomalous course, including fenestration in 1, persistent first intersegmental artery in 3, inverted VA (lateral variant of first intersegmental artery) in 3, and medial loop in 4. All of these arteries were dissected and safeguarded during the surgery as described above. There was no injury to any of these arteries. The facets were drilled flat to make the inferior sagittal C-1 facet angle more than 170°, except in 2 patients (1
### Table 1. Details of patients with irreducible AAD in whom C1–2 facets were comprehensively drilled to achieve reduction and fusion

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Associated Bone Anomalies</th>
<th>Anomalous VA</th>
<th>JOA Score Preop</th>
<th>Last FU</th>
<th>Rt</th>
<th>Lt</th>
<th>Rt</th>
<th>Lt</th>
<th>Preop</th>
<th>Postop</th>
<th>ADI (mm)</th>
<th>C1–2 Vertical Distraction</th>
<th>Bone Graft/Spacer</th>
<th>Fusion Technique</th>
<th>Intraop</th>
<th>Postop</th>
<th>Complications</th>
<th>Postop Interval (mos)/Fusion</th>
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<td>17</td>
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<td>150</td>
<td>172</td>
<td>170</td>
<td>8</td>
<td>3</td>
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<td>C1–2 transarticular screws</td>
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<td>11</td>
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<td>150</td>
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<td>160</td>
<td>9</td>
<td>5</td>
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<td>17</td>
<td>150</td>
<td>150</td>
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<td>170</td>
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<td>2</td>
<td>No</td>
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<td>145</td>
<td>145</td>
<td>175</td>
<td>175</td>
<td>8</td>
<td>3</td>
<td>Yes</td>
<td>Yes</td>
<td>Bone graft</td>
<td>O–C2 fusion (precurved rod &amp; C-2 PS)</td>
<td>Graft subsidence (partial vertical distraction)</td>
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<td>125</td>
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<td>3</td>
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<td>13</td>
<td>130</td>
<td>135</td>
<td>175</td>
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<td>10</td>
<td>3</td>
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<td>180</td>
<td>10</td>
<td>2</td>
<td>++</td>
<td>Yes</td>
<td>Bone graft</td>
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<td>120</td>
<td>180</td>
<td>180</td>
<td>11</td>
<td>5</td>
<td>++</td>
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<td>12/yes</td>
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(continued)
**TABLE 1.** Details of patients with irreducible AAD in whom C1–2 facets were comprehensively drilled to achieve reduction and fusion (continued)

<table>
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<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Associated Bone Anomalies</th>
<th>Anomalous VA</th>
<th>JOA Score Preop</th>
<th>Last FU</th>
<th>Postop ADI (mm)</th>
<th>C1–2 Vertical Distraction</th>
<th>Bone Graft/Spacer Fusion Technique</th>
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<td>Facet Fx Wound infection</td>
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<td>17</td>
<td>145 145 180 180</td>
<td>9 2 Yes Yes</td>
<td>Spacer + bone graft</td>
<td>C1–LMS &amp; C-2 PS</td>
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<td>16</td>
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BI = basilar invagination (telescoping); CTA = CT angiogram; FU = follow-up; Fx = fracture; LMS = lateral mass screw; NA = not applicable; PS = pedicle screw; SLW = sublaminar wire; ++, +++ = increasing severity of vertical distraction or telescoping.
in whom a VA injury occurred and another with an acute sagittal angle operated on 2 years previously). Satisfactory reduction was achieved in all patients. The alignment was more optimal in the last year and a half of the study (ADI $\leq 2$ mm).

All patients showed clinical improvement. CT scans obtained before discharge showed good reduction (ADI $\leq 3$ mm) in 17 patients (Fig. 3). In the remaining 2 patients in whom partial reduction was achieved, the cause was incomplete drilling in 1 patient due to VA injury.

The sublaminar wires were used in the initial days when direct reduction was attempted in patients with rela-
tively less-acute facet angles. With more-acute angles, the degree of drilling increased significantly. We feared substantial instability with the use of sublaminar wires alone, following such extensive drilling. Therefore we switched over to lateral mass and pedicle screws.

Two patients developed graft (bone only) subsidence with partial vertical redislocation, with ADI progressing from < 3 mm in the immediate postoperative period to 5 mm, which was observed on the CT scan obtained at 4 months. Both patients did not worsen clinically (with minimal dependence on others, JOA score 14) and did not undergo another operation. They continue to remain at the same clinical status. The CT scan at 9 months showed fusion in the same partially dislocated position. To avoid the complication of bone graft subsidence (due to possible resorption) leading to loss of height and redislocation, we switched to using metallic spacers in the last 1.5 years. We noted no dislodgements or redislocations since the use of metallic spacers. Fusion was observed in most patients 4–6 months after surgery and in all patients on CT performed 9–12 months postoperatively (Fig. 5).

Discussion

The atlantoaxial joints provide maximum mobility. This mobility, however, comes at the cost of stability. The neural structures and adjoining VAs make dislocation at this level dangerous. Atlantoaxial dislocations can be due to congenital bone anomalies, laxity of ligaments, or trauma. AADs are likely to reduce on extension. Currently the treatment of AAD is C1–2 arthrodesis in reduction. Certain AADs do not reduce on extension and even after application of traction. These types are referred to as irreducible AADs. It is important to know the cause of irreducibility so that the focus of treatment can be directed toward correcting it.

The C1–2 joints in congenital AADs are oblique (Fig. 1A–C). Due to the obliquity in the sagittal plane, C-1 tends to slip anteriorly and inferiorly over C-2.5 Also, the joints are vertical in the coronal planes, leading to vertical slipping of C-2 within C-1 (central or vertical dislocation).5 This obliquity can be measured objectively in the parasagittal and coronal planes as C-1 inferior sagittal and coronal facet angles.6 The degree of joint obliquity determines the rate of slipping and the age at which the person is likely to present due to canal compromise. It appears that every congenital AAD is reducible to begin with and is a dynamic process.5 Additionally, C2–3 fusion and an oc-cipitalized atlas is often observed with congenital AAD. Such anomalies add to the stress at the C1–2 joints. Due to the acute angulation of facets, the reduction becomes difficult on extension and dislocation progresses until it becomes irreducible.5 At this point, the C-1 facet has slipped significantly anteriorly and inferiorly relative to C-2. The posterosuperior edge of the C-2 facet itself acts like a ledge that prevents anteroposterior reduction on extension or even on minimal distraction provided by cervical traction (Fig. 1D–F). These abnormal movements should be labeled as translation and subsidence rather than dislocation. However, traditionally they have been referred to dislocation.

The focus in management of irreversible AAD has shifted from the compression (odontoid) to the cause of AAD. The pathology lies in the joints. Hence, the present treatment protocols have been directed toward reducing the joints by their intraoperative manipulation followed by fusion.1,2,5,6,8 Various techniques have been described to achieve intraoperative reduction. Goel’s C1–2 joint distraction followed by placement of a spacer is a popular technique.1,2 Making the facet surfaces raw is important to aid fusion. The present technique emphasizes comprehensive drilling of the facets apart from making the surfaces raw. Drilling the posterior-superior wedge of C-2 and anterior inferior wedge of C-1 in congenital AAD makes the surfaces relatively flat and more like normal (Fig. IG and H). Drilling of the facets to nearly flat would convert an irreducible dislocation to a reducible one. Following this, the joints can be fused. Theoretically, such a facetectomy would avoid the tendency of C-1 slipping over C-2 until actual bone fusion occurs. The present technique also has an advantage of bone fusion due to extensive drilling.

There are certain disadvantages to this technique. The sectioning of the bilateral C-2 nerve root ganglion may cause occipital neuralgias, dysesthesias, or numbness. Interestingly, none of our patients complained of these in the postoperative period. Furthermore, sectioning of the C-2 root ganglion provides a panoramic view to the narrow corridor, and acts as a landmark for an anomalous VA; sectioning it under vision helps to mobilize the artery needed for safeguarding during joint manipulation. In addition, there is a theoretical possibility that stretching the C-2 nerve root ganglion during drilling and placement of spacers may injure the cord indirectly due to traction. The advantages of C-2 root ganglion sectioning appear to outweigh the disadvantages. The anomalous VA needs to be

FIG. 5. Postoperative parasagittal CT scans of various patients showing good bone fusion of the C1–2 joint. Note the bony trabeculae between the C1–2 facets without any gap (red arrows). With metallic spacers, the trabeculae are observed anterior and posterior to the spacers, suggesting bone fusion. The drilled endplates (smaller; open arrows) and the periscrew region (area adjacent to the screws) show no lucencies, suggesting good fusion. Figure is available in color online only.
dissected and safeguarded. A large exposure is required for such extensive drilling and the venous ooze can be bothersome at times. There is a potential danger of injuring the surrounding vital structures due to inadvertent slipping of the drill. Excessive drilling leads to loss of height, making placement of metallic spacers essential to avoid settling and reappearance of (central) vertical dislocation. The bone graft alone may not maintain the height until fusion due to graft subsidence (resorption), as was observed in 2 of our patients who underwent previous operations (see Table 1). Additionally, excessive drilling of C-2 may reduce the purchase for pedicle screws.

Conclusions

Comprehensive drilling of the C1–2 facets appears to be a logical and effective technique for achieving direct posterior reduction in irreversible AAD. The extensive drilling makes large surfaces raw, increasing the fusion rates.

References


Author Contributions

Conception and design: Salunke. Acquisition of data: all authors. Analysis and interpretation of data: Salunke. Drafting the article: Salunke, Sahoo. Critically revising the article: Salunke.

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