Vertical atlantoaxial distraction injuries: radiological criteria and clinical implications

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Object. The authors sought to establish radiological criteria for the diagnosis of C1–2 vertical distraction injuries.

Methods. Conventional radiography, computerized tomography (CT), and magnetic resonance (MR) imaging findings in five patients with a C1–2 vertical distraction injury were correlated with their clinical history, operative findings, and autopsy findings. The basion–dens interval (BDI) and the C-1 and C-2 lateral mass interval (LMI) were measured in 93 control patients who underwent CT angiography; these measurements were used to define the normal BDI and LMI. The MR imaging results obtained in 30 healthy individuals were used to characterize the normal signal intensity of the C1–2 joint. The MR imaging results were compared with MR images obtained in five patients with distraction injuries.

In the 93 patients, the BDI averaged 4.7 mm (standard deviation [SD] 1.7 mm, range 0.6–9 mm) and the LMI averaged 1.7 mm (SD 0.48 mm, range 0.7–3.3 mm). Based on CT scanning in the five patients with distraction injuries, the BDIs (mean 11.9 mm, SD 3.2 mm; p < 0.001) and LMIs (mean 5.5 mm, SD 2.2 mm; p < 0.0001) were significantly greater than in the control group. Fast–spin echo inversion-recovery MR images obtained in these five patients revealed markedly increased signal distributed throughout the C1–2 lateral mass articulations bilaterally.

Conclusions. In 95% of healthy individuals, the LMI ranged between 0.7 and 2.6 mm. An LMI greater than 2.6 mm indicates the possibility of a distraction injury, which can be confirmed using MR imaging. Patients with a suspected C1–2 distraction injury may be candidates for surgical fusion of C1–2.

Key Words • craniovertebral junction • C1–2 distraction injury • occipitoatlantal dislocation • C1–2 fixation

The C1–2 joint is susceptible to trauma resulting from exaggerated movement in any of the normal intrinsic directions of motion: vertical, anteroposterior, and rotatory. Subluxation of the C1–2 complex in the horizontal plane can be caused by trauma and by various degenerative, inflammatory (for example, rheumatoid arthritis), and congenital (such as, Down syndrome) conditions.1 Rotatory instability has also been well described.12 Radiological criteria have been established to identify horizontal and rotatory injuries of the C1–2 articulation, and therapeutic algorithms have been established for their management. In contrast, there are few reports in the literature in which vertical subluxation of the C1–2 articulation has been described.2,3,8,13–17 No radiological criterion has been established to define the normal relationship between the lateral masses of C-1 and C-2 in the vertical plane, and the appropriate surgical management of patients with this condition has not been established.

Clinical Material and Methods

Control Patient Group

During a 4-month study, 93 consecutive patients (49 males and 44 females; mean age 54.7 years, range 2–95 years) who had undergone CT angiography for other reasons served as the control group. Four patients were younger than 10 years of age. Patients with a history of trauma were excluded.

Technique of CT Scanning. All CT examinations were performed using a Lightspeed Scanner (General Electric Medical Systems, Milwaukee, WI) and included images of the C1–2 junction and skull base. Helically acquired axial images were reconstructed in three dimensions (2-mm thick, 2-mm intervals) in the coronal and sagittal planes.

The reconstructed images were analyzed on a Dominator unit (DR Systems, Inc., San Diego, CA). On coronal images, the widest distance between the lateral masses of
C-1 and C-2 was measured in a plane perpendicular to the joint space on the right and left sides, respectively, and defined as the LMI (Fig. 1 upper and lower left). Three measurements were performed in each patient, and the mean left and right LMI values were calculated. On sagittal images of the skull base, the narrowest distance between the basis of the odontoid process of C-2 was defined as the BDI. This distance was measured three times in each patient, and the mean was calculated. The configuration of the C1–2 lateral mass articulation was also evaluated qualitatively.

**Technique of MR Imaging.** Thirty patients (18 males and 12 females; mean age 45.3 years, range 3–89 years) with no history of acute trauma who had undergone MR imaging examinations of the soft tissues of the neck were identified from an existing MR imaging database, and MR images were reviewed by the neuroradiologists (D.F., R.C.W.). The signal from the C1–2 articulation was characterized on coronal FSE inversion-recovery images, which are best for demonstrating the joint space (Fig. 1 lower right). The signal intensity within the 60 slices of C1–2 articulations was graded as hypo-, iso-, or hyperintense compared with that of the normal cortical gray matter.

**Patients With C1–2 Vertical Distraction Injury**

From June 2001 to June 2002, we treated six patients (five males and one female; mean age 29 years, range 6–40 years) with distraction injuries at C1–2 (Table 1). Follow-up results were available in four patients by examination or telephone interview. One patient was lost to follow up after surgery. One patient died after arrival; an autopsy revealed a laceration at the pontomedullary junction and significant subluxation of C-2 onto C-1.

Magnetic resonance imaging was performed using a Signa 1.5-tesla magnet (General Electric Medical Systems). The LMIs and BDIs were measured in each patient in the same fashion as those in the control group. The CT data were correlated with MR imaging data in five patients and with operative findings in three patients.

**Statistical Analysis**

Repeated-measures analysis of variance (within group) was used to analyze the BDIs and the right and left LMIs. Analyses were two-tailed, and the significance level was set at a probability level of less than or equal to 0.05. Intraclass correlation estimates of reliability were also calculated (Table 2).
Vertical C1–2 instability

Results

Within each group, there were no significant differences in the BDIs or the right and left LMIs. Intraclass correlation estimates of reliability for the entire sample were adequate (Table 2).

Control Patient Group

Based on measurements from CT scans, the mean BDI was 4.7 mm (Table 3). The mean of both the right and left LMIs was 1.7 mm. There was no correlation between BDI and age. The mean BDI was larger in male (mean 5.2 mm) than in female patients (mean 4.1 mm; p < 0.001). Both right and left LMIs were significantly larger (p < 0.001) in male than in female patients. A weak inverse correlation between age and both right (r = −0.3) and left (r = −0.37) LMIs was statistically significant (p < 0.05).

Because age was significantly related to LMI, age was used as a covariate in all subsequent analyses.

In 177 of the 186 articulations, at least one of the surfaces of the lateral masses bordering the C1–2 articulation was parallel, that is, linear, to the joint space (Fig. 1 upper left). In nine of the 186 articulations, the surfaces of the C-1 and C-2 lateral masses bordering the C1–2 articulation were concave at the narrowest segment of the joint space, creating an elliptical cup-shaped joint space (Fig. 1 lower left).

In nine articulations, the mean LMI of the cup-shaped C1–2 joint spaces was 2.6 mm (range 2.1–3.3 mm), significantly wider than the mean LMI of the linear joint spaces (mean 1.6 mm, range 0.7–2.8 mm; p < 0.05). In five patients the LMIs were more than two SDs above the mean (> 2.6 mm). In one of these patients, the LMI was more than 2.6 mm bilaterally, yielding six of 186 LMIs that measured more than 2.6 mm. In four of these six patients, the C1–2 articulation was cup shaped.


In the 30 patients who were evaluated using FSE inversion-recovery, 21 C1–2 lateral mass articulations were found to be hypointense and 39 were isointense compared with cortical gray matter (Fig. 1 lower right). No articulation was hyperintense compared with cortical gray matter.

Patients With C1–2 Distraction Injury

Based on measurements made on lateral radiographs the width between the posterior elements of C-1 and C-2 varied in the five patients (Fig. 2). Anteroposterior radiographs, available in three patients, revealed evidence of inferosuperior widening between the lateral masses of C-1 and C-2. In both projections, visibility of the C1–2 interspace was partially obscured by overlying osseous structures, extraneous objects, and support equipment.

The C1–2 distraction injuries, indicated by marked vertical widening of the C1–2 articulation, were most evident on coronal and sagittal reformatted CT scans (Fig. 3). On the five available CT studies, the mean LMI was found to be 5.5 mm (SD 2 mm; mean z score 8; Table 1). The LMIs in these five patients were more than three SDs above the mean of the control group (> 3.1 mm; z score > 3; p < 0.001). The mean BDI was 12.1 mm (SD 3.4 mm; mean z score 4.4; Table 1), significantly wider than the BDIs in the control group (p < 0.001). In one patient with C1–2

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distraction, the BDI fell within two SDs of the mean BDI of the control group (7.7 mm; z score 1.8).

The anteroposterior alignment of the C1–2 articulation was normal in these five patients. In one patient, the inferior aspect of the anterior arch of C-1 was avulsed. The C-1 arch was otherwise intact, and the posterior elements of C-1 and C-2 were aligned normally. In three patients, the posterior surface of the anterior arch of C-1 was cephalad to the anterior articulating surface of the odontoid process.

Fast–spin echo inversion-recovery MR images obtained in all five patients demonstrated markedly increased bilateral signal intensity within the C1–2 lateral mass articulations (Fig. 4). Specialized sequences designed to aid in the evaluation of the integrity of the transverse ligament revealed that their ligaments were intact.5 In two patients, signal intensity within the atlantooccipital articulation was slightly increased bilaterally. In the other three patients, this articulation appeared normal.

Surgical Outcomes. The patients in Cases 2, 3, and 5 underwent spinal fusion and fixation. Because distraction was minimal in Case 4 compared with the normative data and his neurological course was stable, he was treated only with a halo brace. The patient in Case 1 sustained a severe systemic injury and was extremely unstable for a few days. His poor neurological status was complicated by dissection of the VA between C-1 and C-2, which caused a posterior inferior cerebellar artery infarct. Once stabilized, his neurological status caused him to be restricted to bed, and no further intervention was attempted. In Cases 3 and 5, C-1 lateral mass and C-2 pedicle screws were used as anchorage points for fixation, with posterior sublaminar wiring and autograft placement for fusion (Fig. 5). In the patient in Case 2, the course of the VA was revealed to be abnormal on CT scanning; therefore, C-3 was included in the same construct, leaving C-2 with a pedicle screw on one side. There were no surgical complications.

Follow-Up Review. Follow up (Table 1) was available in four patients (mean 10.25 months, range 3–15 months) and was based on the patients’ GOS scores as judged by their treating physicians. The results of radiography studies were used to confirm adequate alignment. There was no motion on flexion–extension radiographs in Cases 1

### TABLE 2

<table>
<thead>
<tr>
<th>Group</th>
<th>BDI</th>
<th>Rt LMI</th>
<th>Lt LMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>entire sample</td>
<td>0.99</td>
<td>0.96</td>
<td>0.98</td>
</tr>
<tr>
<td>control group (90 patients)</td>
<td>0.97</td>
<td>0.86</td>
<td>0.88</td>
</tr>
<tr>
<td>distraction group (5 patients)</td>
<td>0.99</td>
<td>0.96</td>
<td>0.99</td>
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</table>

### TABLE 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (mm)</th>
<th>Range (mm)</th>
<th>95% Confidence Interval</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>BDI</td>
<td>4.7</td>
<td>0.6–0.9</td>
<td>4.3–5.0</td>
<td>1.7</td>
</tr>
<tr>
<td>rt LMI</td>
<td>1.7</td>
<td>0.8–3.3</td>
<td>1.6–1.8</td>
<td>0.46</td>
</tr>
<tr>
<td>lt LMI</td>
<td>1.7</td>
<td>0.7–3.1</td>
<td>1.6–1.8</td>
<td>0.45</td>
</tr>
<tr>
<td>both LMIs</td>
<td>1.7</td>
<td>0.7–3.3</td>
<td>0.16–0.17</td>
<td>0.48</td>
</tr>
</tbody>
</table>

FIG. 2. Cross-table lateral cervical radiograph revealing a vertical distraction injury in a patient who died soon after the radiographs were obtained. The C-1 ring and skull base are markedly displaced cephalad with respect to C-2. The BDI is widened (Line A), and the atlantodens distance is increased (Line B). The distance between the posterior elements of C-1 and C-2 is grossly increased (Line C).

FIG. 3. Case 3. This 34-year-old man was a pedestrian involved in a collision with a motor vehicle. Coronal (left) and sagittal (right) reconstructions demonstrating marked widening of the C1–2 LMI, compatible with a vertical distraction injury.

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Vertical C1–2 instability

In vertical distraction injuries of C1–2, which are intimately related to OAD, the transverse ligament is undamaged. Based on the position and function of the cruciate ligament, damage to its vertical portion is unavoidable in a vertical distraction injury (Fig. 6).

Neuroimaging Studies

The clinical need to diagnose C1–2 vertical instability is underscored by the complications documented in patients with unrecognized injuries who have undergone cervical traction for other injuries. Axial CT scanning of the C1–2 interspace is insensitive in the evaluation of vertical distraction; coronal and sagittal reconstructions of axial CT images are necessary. On coronal CT scanning, the widening of the distance between the C-1 and C-2 lateral masses characteristic of vertical distraction is often bilateral and symmetrical and can obscure the underlying pathological entity. The most reproducible rostrocaudal characterization of the C1–2 articulation is the perpendicular distance between the surfaces of the lateral masses/articulating facets of C-1 and C-2 at the narrowest portion of the joint in the coronal plane.

When recognized, the cup-shaped joint space (Fig. 1 lower left) is rarely confused with a pathological condition. The close apposition (and sometimes contact) of the medial and lateral aspects of the lateral masses (defining the ends of the ellipse) verifies the normalcy of the observations. If this configuration is not recognized as normal, distraction injuries will be overdiagnosed and the incidence of false-positive results will be high.

Because only four patients younger than the age of 10 years were included in the study, the normative data are not necessarily applicable to children. Although the C1–2 interspace narrows with age, the change is still relatively small in proportion to the width of the interspace. In the absence of other data, however, we apply the same LMI threshold of 2.6 mm as an indication for MR imaging of the cervical spine of pediatric patients with significant traumatic injury associated with neck pain. Because the C1–2 joint may appear normal on MR imaging in children, it is important to recognize ligamentous laxity that might contribute to overdistraction that is demonstrated on radiography or CT studies.

The BDI has been used to identify OAD. The pres-
ent data confirm significant widening of the BDI in patients with a C1–2 vertical distraction injury; however, the BDI of one injured patient fell within two SDs of the normative value. Therefore, a normal BDI does not exclude C1–2 vertical dislocation. Nonetheless, an increased BDI indicates a craniovertebral junction injury and should direct attention to both the atlantooccipital and atlantoaxial articulations.

Based on cervical spine radiographs with no correction for magnification issues, Lee, et al.,11 reported that the normal BDI ranged between 2 and 15 mm in adults. This range is slightly greater than that observed in our normative population based on CT scans. Because CT scanning is more accurate than plain radiography, the current data may be more accurate than those previously reported. Consequently, BDI values greater than 9 mm (derived from sagittal CT reconstructions) likely indicate the possibility of traumatic disruption of the craniovertebral junction.

Isolated vertical C1–2 subluxation represents a pure distraction injury. Therefore, the ligaments that maintain the normal horizontal alignment tend to be intact, and dynamic flexion–extension radiographs do not contribute to the assessment of C1–2 vertical subluxation.

Magnetic resonance imaging is the gold standard with which to verify suspected C1–2 vertical distraction injuries revealed on CT scans. Fat-suppression sequences (STIR sequences, FSE inversion-recovery sequences, or long repetition time sequences with chemical fat saturation) are most useful in demonstrating blood and fluid distributed within the C1–2 joint space. The coronal plane best reveals the distribution of signal abnormalities throughout the C1–2 joint space. The normal C1–2 articulation is iso- or hypointense on FSE inversion-recovery images. The signal intensity of the interspace should never be similar to that of CSF. In this study, the signal from the 60 normal C1–2 articulations was hypointense compared with cortical gray matter. In the patients with distraction injuries, the intensity of long repetition time signals increased diffusely throughout the joint space and was equal to that of CSF.

The traumatic injury

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Therapeutic Implications

No real guidelines have been established for the treatment of these rare injuries. The 11 published cases2,3,8,13–17 may underrepresent the actual incidence of distraction injuries, which could increase if three-dimensional images and reconstructions become standard in the initial assessment of trauma patients.

Measures that reproduce the mechanism of C1–2 vertical distraction, such as cephalic traction and collars with extension, should be avoided to prevent neurological worsening or the appearance of new deficits. The logical treatment is compression and reduction of the distracted space. The patient’s head should be kept aligned with sandbags to prevent motion.

Vertical distraction associated with neurological deterioration6,13 (and even death) has been reported after the application of traction.2,9 The mechanism may be related to an undiagnosed initial combined injury (anteroposterior and vertical subluxation) that has been worsened by traction or to a new iatrogenic injury that has been caused by excessive traction. In such cases, cephalic traction with
standard loads should not have overdistacted the CVJ unless an additional ligamentous injury was present. Typically, early placement of a halo brace with axial loading or head compression during placement reduces distraction. Patients in whom cephalic traction is placed must be required to undergo periodic imaging to avoid eventual overdistraction.

Definitive treatment should be individualized (Fig. 7). We recommend C1–2 fusion for patients with isolated C1–2 subluxation. A halo brace may provide definitive treatment, especially in children with lax ligaments and in whom the results of MR imaging are negative; however, close follow up and progressive evaluation for delayed neck pain are mandatory. Because our normal sample included only four patients younger than 10 years of age, these results cannot be generalized to children. Treatment in children should be individualized and based on the mechanism of trauma, the presence of associated injuries, and the extent of distraction demonstrated on CT and MR imaging.

In severely injured patients, neck instability should be assessed once life-threatening issues are resolved and the patient’s general condition allows further intervention. Either transarticular screws or pedicle screws with inter-
spinous bone graft and wiring should be used. Chip fractures involving the anterior arch of C-1 (such as in our Case 3) may represent a C-1 extension teardrop fracture that occurs when the ligaments between C-1 and C-2 are torn and should not constitute additional instability.\(^\text{19}\)

Theoretically, C-1 lateral mass screws and C-2 pedicle screws connected with an adjustable rod can be used to correct the distraction. Insertion of screws in C-1 and C-2 facilitates posterior reduction of the wiring between distracted fragments. Transarticular screws provide a lag effect when the screw crosses the joint and brings the distal fragment (C-1 lateral mass) proximally toward the screw head. To our knowledge no biomechanical evidence indicates that one system is better than another for treating this particular injury.

Conclusions

Because clinicians have no quantitative guidelines by which to diagnose vertical C1–2 distraction injuries, they may go unrecognized and be more common than currently believed. An LMI greater than 2.6 mm (> two SDs above the mean) should arouse clinical suspicion of instability in this region. In particular, a high index of suspicion should be present in dealing with victims of high-velocity accidents. In the setting of acute trauma, CT scanning with multiplanar reconstruction facilitates evaluation of patients with suspected injuries at the CVJ.

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References


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