In young children, the axis is divided by synchondroses between the VB, odontoid process, and neural arches. These cartilaginous plates do not ossify until approximately 5–7 years of age and are a potential source of biomechanical weakness. In addition to the weakness of the synchondrosis, children have disproportionately large heads, underdeveloped neck muscles, horizontally oriented facet joints, and physiological wedging of the VBs. All of these factors combine to make the axis the most commonly injured vertebra in children. Historically, fractures through the odontoid synchondrosis have been treated with traction, reduction, and external orthosis. This treatment plan has an extremely high rate of fusion and is recommended by most authors. However, there are reports of failure and progression of deformity despite halo treatment. In addition, conservative therapy with a halo orthosis introduces risks inherent with the device. There are imaging characteristics, such as severe angulation or displacement of the odontoid, that suggest a highly unstable odontoid synchondrosis fracture. We propose that surgical fixation may be considered in the initial management of these injuries.

Open reduction and internal fixation for angulated, unstable odontoid synchondrosis fractures in children: a safe alternative to halo fixation?

Report of 2 cases

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External orthosis is the accepted and historical management of odontoid synchondrosis fractures; however, this conservative therapy carries a significant complication and fracture nonunion rate among young children. The purpose of this study was to evaluate the authors’ own experience in the context of the literature, to explore surgical fixation as a primary treatment for unstable fractures. The authors retrospectively reviewed 2 cases of unstable odontoid synchondrosis fractures treated at their institution; both showed radiographic progression of deformity and subsequently underwent open surgical reduction and fusion. A literature review was conducted to compare the authors’ management strategy with those in published data. External orthosis for treatment of odontoid synchondrosis fractures has a strong history of success. However, in the literature, patients treated with a halo orthosis had a 43.3% rate of complications and an 11.4% risk of nonunion. There are radiographic findings that suggest instability, such as severe angulation and displacement of the odontoid process. Both patients in the present report underwent successful fusion without complication, as documented on CT scans obtained 3 months after surgery. Given the high rate of fusion attained with conservative therapy, it is recommended for most synchondrosis fractures. However, there is a recognized subgroup of synchondrosis fractures with severe angulation (> 30°) and displacement suggestive of significant ligamentous injury. In these patients, surgical fixation may be a safe and efficacious alternative to halo orthosis as the primary treatment.

Key Words: odontoid fracture, synchondrosis, pediatric spine, children, unstable spinal fracture, halo orthosis

Abbreviations used in this paper: LCH = Langerhans cell histiocytosis; VB = vertebral body.
Case Reports

Case 1

History and Physical Examination. This otherwise healthy 18-month-old girl was involved in a high-speed, head-on motor vehicle collision. The patient was stabilized at the referring facility and transferred to Texas Children’s Hospital after a diagnosis of a left humerus and C-2 fractures. Her neck was immobilized in a rigid cervical collar. She was neurologically intact.

Imaging Studies. Initial images from the referring facility demonstrated that the odontoid process was displaced anteriorly and angulated approximately 39° anteriorly (Fig. 1A). The patient underwent further imaging at our facility, including an MR imaging study and a repeat CT scan. The MR imaging study demonstrated disruption of the bilateral C-2 facet joints, with damage in the anterior longitudinal ligament and posterior ligamentous complex. The repeat CT scan showed a 45° increase in the anterior angulation of the ododontid process (Fig. 1B).

Operation. The fracture was considered unstable due to the severity of the ligamentous injury and the progression on imaging performed within 24 hours. The patient was taken to the operating room for open reduction and stabilization. We performed a posterior instrumented fusion from C-1 to C-2 by using off-labeled bone morphogenetic protein with bone matrix, and instrumentation consisting of bilateral C-1 lateral mass screws, a right C-2 pars screw, and a left C-2 translaminar screw. The patient was neurologically intact postoperatively. Her postoperative images showed anatomical reduction of the deformity (Fig. 1C).

Postoperative Course. The patient was kept in a hard cervical collar for 2 weeks and then placed in a soft collar for comfort only. She had transitioned out of the collar completely by 2 months after discharge. She was at full activity and was neurologically intact. One year after discharge, imaging showed maintenance of the reduction, with bone fusion (Fig. 1D). The patient was doing well after 18 months of follow-up.

Case 2

History and Physical Examination. This 21-month-old girl presented with a stiff neck that had lasted for 2 weeks and had progressed to torticollis. She was otherwise neurologically intact and had no history of trauma. The patient was evaluated with a CT scan, which suggested a retropharyngeal abscess. Further imaging showed multiple osseous lytic lesions in the skull, spine, ribs, and pelvis. A needle biopsy of a rib lesion suggested a diagnosis of LCH.

Imaging Studies. The initial CT evaluation demonstrated pathological involvement of the C-2 vertebrae, with intact alignment (Fig. 2A). The patient was placed in a rigid cervical collar. Imaging studies obtained 1 week later showed a pathological basilar synchondrosiis fracture, with anterior subluxation and 42° of angulation (Fig. 2B).

Discussion

Cervical spine injuries are relatively rare in children compared with adults. The injuries in children are predominantly upper cervical, with C-2 the most commonly involved vertebra. The unfused odontoid synchondrosis is a potentially weak area of C-2, because it does not fuse until a child is 5–7 years old. Therefore, a synchondrosiis fracture is an injury of young children, with an average age of 3–4 years. Odontoid synchondrosis fractures can occur with severe or relatively minor trauma. Patients rarely have a neurological injury and instead present with neck pain or torticollis.

It is often difficult to diagnose upper cervical frac-
Unstable odontoid synchondrosis fractures

Plain radiography may be inadequate to visualize the upper cervical spine. Computed tomography with coronal and sagittal reconstructions may be useful in demonstrating the injury pattern of the odontoid synchondrosis. Magnetic resonance imaging may be helpful in determining the extent of spinal cord, soft tissue, or ligamentous injury at the C1–2 level. Therefore, clinicians must maintain a high index of suspicion for children who refuse to move their neck, seem to be in pain, or have other concurrent/disturbing injuries.

Classification of Odontoid Fractures

The classification of odontoid fractures in adults is well known. However, the literature on odontoid fractures in children is confusing. There is overlap in the older literature, with many cases published more than once or used in multiple analyses. Some series combine pediatric and adult patients. In addition, other authors have considered odontoid synchondrosis fractures as the equivalent of Type II odontoid fractures, as defined by Anderson and D’Alonzo.

Although some similarities may be drawn between pediatric odontoid synchondrosis fracture, adult traumatic spondylolisthesis of the axis (hangman’s fracture with olisthesis), and Type II odontoid fractures, these 3 entities are clearly separate from each other (Table 1). Synchondrosis fractures generally do not represent an actual break in the bone. Rather, they are caused by a shearing force that causes a “slip” in the cartilaginous material instead of an actual break of the bone. Therefore, we agree with others who believe this particular childhood injury is different in mechanism and pathology than an odontoid fracture in the same anatomical location in a patient with a skeletally fused synchondrosis.

Hosalkar et al. reviewed the cases of 17 patients with an odontoid synchondrosis fracture. By combining their data with those of published cases in the literature, these authors proposed a classification system to describe these fractures based on the extent of displacement of the odontoid process from the VB. Type I injuries were defined as fractures through the odontoid synchondrosis and were further subdivided into 3 different groups: subtypes A (0%–10% displacement), B (11%–100% displacement), and C (>100% displacement). Based on this classification system, they recommended halo immobilization for Type IA, closed reduction and halo fixation for Type IB, and surgical stabilization for Type IC. Type II fractures were above the level of the synchondrosis.

Although prior series have not evaluated the angulation of the odontoid, we suggest that the surgeon consider as an additional factor the degree of angulation of the odontoid in the classification system of these injuries. The degree of angulation is a factor in other types of upper cervical fractures as well. The normal functional anatomy at C1–2 allows 20°–30° of excursion in flexion-extension. An angular subluxation of >30°, which is definitively outside the normal physiological range of movement at the atlantoaxial complex, should be considered when deciding management options concurrently with severity of ligamentous injury.

Fig. 2. Case 2. Images of a 21-month-old child with LCH, with involvement of C-2. A: Initial CT scan showing relatively spared alignment of the odontoid process. B: Follow-up CT scan showing that despite treatment with a hard cervical collar, the synchondrosis slip progressed, with an angulation of the odontoid process to 42°. The patient underwent operative reduction and fixation. C–E: Postoperative radiograph (C), 3D reconstructed CT scan (D), and conventional CT scan (E) demonstrating return of the odontoid to anatomical alignment. F: Follow-up CT scan obtained 9 months after surgery showing maintenance of reduction, with bone fusion.
Although synchondrosis fractures are distinct from adult odontoid fractures, the paucity of data regarding pediatric synchondrosis fractures limits our ability to form any conclusions regarding optimal treatment. Therefore, management algorithms are often extrapolated from other pathological conditions. Degree of angulation is an accepted consideration in other types of upper cervical fractures. After systematically reviewing the management of hangman’s fractures, we found that it was recommended that Type IIa fractures be treated with surgical stabilization. Of the many predisposing risk factors for non-union of Type II odontoid fracture in adults, the most consistently identified factor is fracture displacement of 4–5 mm and fracture angulation > 9°. Either early immobilization by external orthosis or surgical intervention is recommended for most Type II odontoid fractures, but neither management option has been proven superior to date. 

Treatment of Odontoid Fractures

According to the system defined by Hosalkar et al., one of our patients would be categorized as having a Type IA and the other a Type IB injury. Both patients showed radiographic progression of the deformity, despite being immobilized with external orthoses. Although the translational displacement of the odontoid process did change some, a larger change was noted in the angulation. In our view, severe angulation > 30° suggests ligamentous instability. It should be noted that up to 4% of uninjured children will have some degree of angulation (< 30°) of the odontoid. 

Most authors advocate that initial treatment for odontoid synchondrosis fractures should be closed reduction and external stabilization, with close radiographic follow-up. There is a high rate of fusion with external orthosis; a meta-analysis reported a 93% fusion rate with a treatment duration of 3–6 months. There are insufficient data available to determine if a Minerva jacket or cervical collar is rigid enough to immobilize the atlantoaxial complex. Therefore, halo fixation has generally been used for treatment of odontoid synchondrosis fractures. Perry and Nickel introduced the halo fixator in 1959, and it remains a mainstay in the treatment of cervical spine pathology. Nevertheless, halo therapy can have complications. Garfin et al. reviewed 179 patients who were treated with a halo device and had complications. The following complications were noted: pin loosening in 36% of patients, infection in 20%, pressure sores in 11%, nerve injury in 2%, dural penetration in 1%, dysphagia in 2%, “disfiguring” scars in 9%, and severe discomfort in 18%. Other authors have reported a high rate of pin loosening; in fact, Nickel et al. reported that all patients treated for > 2 months experienced pin loosening. Intracranial abscess is a rare but well-documented complication.

In addition to complications with the device itself, halo fixation has approximately a 10% rate of failure of both immobilization and healing. The fit of the device largely determines the immobility of the cervical spine. It may be difficult to maintain a properly fitting halo on an infant. Failure to properly or adequately immobilize may lead to failure of fusion. Indeed, there are reported cases of nonunion despite immobilization. Diekema and Allen reported a case in which external immobilization reduced the fracture by only 50%; therefore, they proceeded to perform surgical fusion. There is often a delay in diagnosing an odontoid synchondrosis fracture. Delay in immobilization may reduce the odds of successful healing. Although it has been reported that patients in whom a halo device was applied after diagnostic delay attained complete healing, delay in treatment was a significant factor in nonunion in a large series of both adult and pediatric odontoid fractures.

An analysis of patients with odontoid synchondrosis fractures treated with halo fixation is presented in Table 2. There are other methods of conservative therapy, including the Minerva brace, prolonged traction, cervical collars, and forced recumbency. However, currently the halo is the most commonly used orthosis. Table 2 includes only those studies in which there was sufficient clinical treatment and outcome data specific to this injury. There were complications in 43.3% of the analyzed cases.
Unstable odontoid synchondrosis fractures

TABLE 2: Literature review of patients with odontoid synchondrosis fractures treated with a halo orthosis as the initial therapy*

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Pts</th>
<th>Pts Treated Initially w/ Halo Orthosis</th>
<th>Duration of Treatment (wks)</th>
<th>Pts w/ Complications of Halo Orthosis</th>
<th>Progression of Deformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandabach et al., 1993</td>
<td>13</td>
<td>10</td>
<td>10–24</td>
<td>5: 4 infections, 1 pin loosening</td>
<td>2</td>
</tr>
<tr>
<td>Hosalkar et al., 2009†</td>
<td>17</td>
<td>9</td>
<td>NR</td>
<td>6: 3 pin loosening, 2 halo dislodgement, 1 infection</td>
<td>1</td>
</tr>
<tr>
<td>Sherk et al., 1978</td>
<td>11</td>
<td>5</td>
<td>8–12</td>
<td>NR</td>
<td>0</td>
</tr>
<tr>
<td>Odent et al., 1999</td>
<td>15</td>
<td>6</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Blauth et al., 1996</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tavares &amp; Frankovitch, 2007</td>
<td>2</td>
<td>2</td>
<td>10–12</td>
<td>1 (2 complications): infection, failed metal support</td>
<td>0</td>
</tr>
<tr>
<td>Ewald, 1971</td>
<td>1</td>
<td>1</td>
<td>20</td>
<td>1 infection</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>61</td>
<td>35</td>
<td>13 of 30 (43.3%)</td>
<td>4 of 35 (11.4%)</td>
<td></td>
</tr>
</tbody>
</table>

* NR = not reported; Pts = patients.
† The patients’ clinical course was not reported in this study, but the degree of healing was, so the denominators differ in the 5th and 6th columns for “total” entries.

Patients treated initially with a halo device. There was a failure or nonunion rate of 11.4%.

There are studies that report an increased complication rate in surgically treated patients. Odent et al.36 reported 15 cases of odontoid fractures in children < 6 years old. Eleven of these patients were treated with external immobilization, 1 had an unrecognized injury that healed spontaneously, and the other 3 were treated with surgery as the primary option. There were no complications in the conservatively treated group. All 3 of the surgically treated patients suffered a complication, including deep wound infection in 1 and failure of fusion in 2. The surgical instrumentation consisted of posterior wiring.

Surgery is an option for patients with odontoid synchondrosis fractures.7,15,26,41 Surgery has been reported as a primary treatment;41 however, it has generally been used only after conservative therapy fails. Some studies show a high complication rate after surgical fixation.36 However, many of these previously reported cases were limited by the technology of the time. In these studies, fusion was performed with nonrigid fixation or onlay grafts. The availability of improved spinal hardware now allows for rigid screw fixation, which has a higher rate of fusion.10,40

Currently, there are multiple surgical options, including odontoid screw fixation, transarticular screws, translaminar screws, and lateral mass instrumentation.1,4,7,11,18,23,27 We prefer lateral mass screws in C-1, with either pars or translaminar screws in C-2 in younger children. We believe that this construct presents a lower risk of injury to the vertebral artery than transarticular screws do.

There is a concern that mechanically fusing the immature spine will limit growth potential. However, there is limited growth potential in the upper cervical spine, especially after a child is 10 years old.9,47 Further study is needed to evaluate the long-term effects of fusion on younger children. Anderson et al.3 and Brockmeyer9 have reported extensive experience in cervical fusion in children. They have argued that bone may remodel around a construct and that young children may successfully receive instrumentation at C1–C2 without a subsequent growth deformity.

Surgical fixation offers a number of advantages over conservative therapy. For one, the injury is immediately stabilized. For another, rigid fixation obviates the need for halo fixation, thus avoiding the associated complications and discomfort.4,10 Patients can rapidly return to their full activity. In addition, there is a small but definite failure rate of conservative therapy. In our analysis of the literature, 11% of patients treated primarily with a halo failed to achieve fusion.

We suggest that these patients with odontoid synchondrosis fractures associated with significant angulation and injury to surrounding ligamentous complexes should be considered for early surgical intervention. From a review of our own cases and additional ones in the literature, an odontoid angulation of > 30°, significant displacement of 11%–100%, and/or clinical evidence of upper cervical spinal cord injury are highly indicative of ligamentous disruption and significant instability, with potential for neurological compromise. However, because of the rarity of this pathological condition, further investigation using multicenter cohorts is required to determine an optimal management strategy.

Conclusions

For patients with odontoid synchondrosis fractures, conservative therapy may suffice as primary treatment. However, for some patients—those who have severely angulated synchondrosis fractures (> 30°) and displacement suggestive of significant ligamentous injury—surgical fixation should be considered as the primary treatment.

Disclosure

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 to the study and manuscript preparation include the following. Conception and design: Jea. Acquisition of data: Jea. Analysis and interpretation of data: Jea. Drafting the article: Jea. Fullkerson, Hwang. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Jea. Statistical analysis: Jea. Administrative/technical/material support: Jea. Study supervision: Jea.
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