Traumatic rupture of the neurocentral synchondrosis of the axis in a child

Case report

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The authors report the first case of unilateral traumatic rupture of the C-2 neurocentral synchondrosis. A 26-month-old child was in a vehicular collision that caused his head to be rotated sharply to the left with the neck flexed. He had severe neck pain but was neurologically normal. Computerized tomography scanning showed rupture of the left C-2 neurocentral synchondrosis, a right C-2 pars interarticularis fracture, and anterior angulation of C-2 on C-3. The neck injury was unrecognized until postinjury Day 9 when an MRI study showed a tear of the posterior longitudinal ligament at C2–3 and separation of the C-2 body from the inferior anular epiphysis. A second CT showed widening of the synchondrosis fracture, increased angulation of C-2 on C-3, and distraction of the right C-2 pars fracture. The mechanism of the neurocentral synchondrosis fracture is thought to be hyperflexion-axial loading combined with leftward rotation, which provided the lateral force that overcame the cartilaginous synchondrosis and extruded the lateral mass. The patient underwent open reduction and posterior fusion of C1–3, and was maintained in a halo jacket for 4 months, when CT scans demonstrated solid C1–C3 fusion and ossification of the injured synchondrosis. Unilateral traumatic rupture of the C-2 neurocentral synchondrosis is one component of several injuries involving C-2 sustained before synchondrosis closure. The resulting C2–3 relationship is highly unstable. Reduction and C1–C3 fusion are necessary in patients with significant displacement of the adjacent bony units.

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KEY WORDS • cervical spine injury • neurocentral synchondrosis rupture • centrum epiphysis separation • axis vertebra

Cervical spine injuries in children are uncommon, accounting for approximately 3.7% of all cervical spine injuries and 1.5% of all pediatric trauma.13,22 Because of a proportionately large head relative to the body and other characteristics of the immature spine, the clinicopathological pattern of cervical spine injuries in children is different from that in adults.5,21 Children have a predilection for upper cervical spine injuries: more than two-thirds of cervical spine injuries in children involve the C1–4 levels.11,19 Also, in children from birth to 7 years, traumatic rupture of the cartilaginous synchondroses and separation of the anular epiphyses are relatively common.22,25 Among all vertebrae, C-2 has the most numerous and complex synchondroses, and, because it is in the center of the motion arc of the upper spine, has by far the highest incidence of synchondrosis rupture.19 When rupture does happen, it usually occurs across the dento-central (lower dental) synchondrosis between the basal dental segment of the odontoid and the body of C-2.6,9,16,17

We report a rare example of unilateral traumatic rupture of the neurocentral synchondrosis of C-2 in a young child.

Case Report

History and Examination. This 26-month-old boy was strapped in the rear car seat of a midsized vehicle when it was hit at high speed from behind by an 18-wheeler container truck. The collision caused the roof of the car to cave in on the child’s head, rendering him unconscious in the car seat with his head turned sharply to the left and his neck flexed. He regained consciousness after a few minutes, and was extracted from the car and brought to an emergency department of a community hospital, where a CT scan of the cervical spine was done but read as normal. The child was found to be neurologically normal and was discharged without neck protection. Because he continued to complain of severe neck pain, he was brought to our attention on postinjury Day 9, when upon review-
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As evident from the original CT, we diagnosed rupture of the left C-2 neurocentral synchondrosis and obvious separation of the left lateral mass buttress from both the C-2 body and the basal segment of the odontoid process. The left lateral mass of C-2 had also shifted backward and downward, and there was a right C-2 pars interarticularis fracture. In addition, the body of C-2 was anteriorly angulated on C-3 on the sagittal plane by 14° (Fig. 1).

The patient was admitted to our hospital and put in a cervical collar; an emergency MRI study of the cervical spine was obtained, with the following findings: the posterior longitudinal ligament at the C2–3 disc level was torn, the inferior anular epiphysis of C-2 was separated from the body, and the anterior angulation of C-2 on C-3 had increased to 18°. There were no signs of spinal cord injury or compression (Fig. 2). The patient was scheduled to be placed in a halo jacket, but a second CT before the halo on postinjury Day 11 showed that the separation of the left C-2 neurocentral synchondrosis had widened, and the angulation of C-2 on C-3 had increased to 30°. The right C-2 pars fracture had also become distracted (Fig. 3).

Operation. Because of the apparent gross instability, the patient underwent open reduction and posterior fusion of C-1 to C-3 with soft sublaminar cables (Softwire Cable System; Codman) and interposition cortical iliac bone graft between the C-1 and C-2 arches (modified Brooks fusion). Two pairs of soft sublaminar cables were used; one strapping the laminae of C-2 and C-3 into a single friction block, which was tightened first so that the essentially bisected C-2 ring could be securely anchored to C-3 on both sides. The second pair of cables passing between the posterior arch of C-1 and the combined laminae of C-2 and C-3 was then tightened to keep the interposition bone graft in place. Pulling the C-1 ring back toward C-2 also had the effect of reducing the anteriorly angulated dens-axis unit back into vertical alignment with the C-3 body. The fusion segments were then covered with onlaid autologous cancellous and cortical bone grafts from both iliac crests. A halo jacket was applied using 8 pins, each sustaining a 2-lb torque.

Postoperative Course. The child was mobilized on postoperative Day 1, and discharged from hospital on postoperative Day 6. The halo jacket was maintained for 4 months. Serial postoperative imaging demonstrated solid bony fusion of C1–C3, the C-2 body was much better aligned on C-3, and the extruded left C-2 lateral mass was reapproached to the centrum. There was also obvious ossification across the ruptured neurocentral synchondrosis, but not on the opposite side or at the inferior epiphysyal plate above the anular epiphysis (Fig. 4).

Discussion

Understanding the embryology of the vertebrae is a prerequisite in the study of traumatic rupture of vertebral synchondroses. In the human embryo, each primordial vertebra is derived from the condensation of somitic mesenchymal clusters called the axial and lateral sclerotomes. Shortly thereafter, a cartilaginous vertebra is formed during the 5th–6th gestational weeks by the integration of 5 chondrification centers within the preceding mesenchymal mold: 1 representing the centrum, 2 for the neural arches, and 2 for the costal processes. In the cartilaginous axis, formation of the dens requires the additional incorporation of the basal and subsequently the apical dental segments; the former arises from the resegmented first cervical sclerotome and the latter from the caudal half of the proatlas.

Ossification of the cartilaginous axis begins at the 4th fetal month with the appearance of a midline ossification center within the centrum and 2 flanking centers

Fig. 1. Cervical spine CT scans obtained on the day of injury. A: Sagittal reconstruction shows subtle anterior angulation of C-2 on C-3 (14°), and mild anterior translocation of the posterior C-1 arch into the spinal canal. B: Coronal reconstruction shows rupture of the left C-2 neurocentral synchondrosis (NC), with obvious separation of the left lateral mass buttress (LM) from the C-2 centrum (Cen) and the basal segment of the odontoid process (BS). C: Axial cut through C-2 shows that the left lateral mass of C-2 is also shifted backward on the centrum and slightly downward. The right C-2 pars fracture is undisplaced and not obvious at this stage. DC = dentocentral synchondrosis.

Fig. 2. Cervical spine MRI studies obtained on postinjury Day 9. Left: Sagittal T2-weighted image shows a tear in the posterior longitudinal ligament at the C2–3 disc level (interruption of the dark line joining the posterior bodies); the inferior anular epiphysis is separated from the C-2 body by an obvious gap (G); and the anterior angulation of C-2 on C-3 has increased to 18°. There are no signs of spinal cord injury. Right: Coronal T2-weighted image shows hemorrhage and edema within the ruptured left neurocentral synchondrosis (arrow).
in the neural arches (first ossification phase). At the 6th fetal month, the second ossification phase begins with 2 centers at the basal dental segment.\textsuperscript{5,14,18,20,23} At birth, C-2 therefore consists of 5 ossification centers separated by 4 major synchondroses: 2 are between the centrum and the neural arches (neurocentral synchondrosis—rostrally each of these synchondroses also extends up to the basal dental segment); a single synchondrosis lies between the basal dental segment and the centrum (dentocentral synchondrosis); and another between the posterior ends of the neural arches (posterior midline synchondrosis). During the 3rd–5th postnatal years, a third and last ossification phase begins in the apical dental segment, giving rise to the “upper” dental synchondrosis, also called the apicodental synchondrosis\textsuperscript{8,10,14,15,18,24} (Fig. 5).

The neurocentral synchondroses close between the ages of 2 and 9.5 years, the dentocentral synchondrosis between the ages of 2 and 9 years, the apicodental synchondrosis between the ages of 6 and 14 years, and the posterior midline synchondrosis by the age of 3 years.\textsuperscript{10,18,23,24} Besides the synchondroses, the only other cartilaginous structure at birth is the inferior epiphyseal plate above the anular epiphysis (C-2 does not have a superior epiphysis).

The cartilaginous synchondrosis is thus a biologically active bipolar growth plate sandwiched between 2 ossification centers. Ossification therefore occurs simultaneously at both interfacing surfaces. As in other actively growing loci, the synchondroses are structurally the weakest parts of a vertebra. In our case, the mechanism of injury is probably axial loading with hyperflexion and left rotation. The flexion-axial loading grinds the lateral masses of C-1 against those of C-2, and the sharp left rotation thrusts the left C-2 neural arch away from the centrum, generating massive angular shearing forces that ultimately result in complete dissociation of the neurocentral synchondrosis. The same twisting stress that splits opens the left neurocentral synchondrosis then carries through diagonally to cause the right C-2 pars fracture, in like manner when breakage of one part of a rigid ring “necessitates” a second break in another part of the ring. Finally, hyperflexion also leads to rupture of the posterior longitudinal ligament at C2–3, and separation of the inferior anular epiphysis from the C-2 body. The combination of these injuries renders the upper cervical spine extremely unstable. In the only example of traumatic rupture of the C-2 neurocentral synchondrosis in the literature, the injury is bilateral and the mechanism is pure hyperflexion-axial loading without rotation.\textsuperscript{16} The parasagittal shearing forces shatter both neurocentral synchondroses and result in angulation of the dens-axis unit similar to our case. Unilateral rupture of the C-2 neurocentral synchondrosis therefore involves more complex forces in combination than the pure hyperflexion forces that disrupt the dentocentral synchondrosis, which explains why the latter is so much more common.\textsuperscript{3,6,9,17}

The right-sided C-2 pars interarticularis fracture also evokes resemblance to the angulated traumatic spondylo-
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listhesis of C-2 (Type IIa hangman’s fracture), but in the latter injury, the C-2 pars fracture is bilateral and symmetrical, and the presumed mechanism is a purely parasagittal flexion distraction force rather than the complex and multidirectional twisting forces involved in our case. Also, classic Type IIa hangman’s fracture is a “bony” injury that is relatively stable and can be treated with reduction in extension and compression in a halo jacket, whereas in our case the chasm is in the cartilage (with potentially weaker healing), and with the steep angulation and progressively widening shift of the bony units, the degree of instability was considered to be unsuitable for closed treatment alone.

Besides the obvious factor of the patient’s young age, we elected to use sublaminar cables in lieu of intraaxial screws also because we thought the widely separated C-2 body and left lateral mass might pose difficulty in lining up these two structures while planning the trajectory for the C-2 isthmus screw. We incorporated C-1, C-2, and C-3 into the construct because the left neural arch of C-2 was essentially loose and the right C-2 pars was fractured; the construct strength therefore depended solely on the cables directly binding C-1 to C-3. We reinforced the construct with the halo, fully recognizing its potential complications in young children.

Surgical stabilization had the benefit of early mobilization. The patient in the literature with bilateral rupture of the C-2 neurocentral synchondroses was treated with closed reduction, Minerva cast, and prolonged bed rest for 3 months. Healing and presumed stability were achieved but C-2 was left persistently angulated on C-3.16

Last, at the histological level, the healing of ruptured cartilage in synchondrosis injury is different from that of a bone fracture. Clinical data from cases of dentocentral synchondrosis show that healing across a ruptured synchondrosis can provide adequate clinical stability.6,9 Osseous fusion across a ruptured dentocentral synchondrosis has been described,4 but fibrous union is probably more common.3 In the present case we observed radiological signs of ossification across the ruptured neurocentral synchondrosis at 3 months, but not in the contralateral neurocentral synchondrosis, suggesting that the new ossification is not due to enforced immobilization or manifestation of scheduled physiological closure.10,14,18,23,24 By contrast, ossification was not discernible at the injured inferior epiphyseal plate above the anular epiphysis (Fig. 4). Long-term follow-up is needed to assess the potential emergence of lateral deformity due to mismatched growth from unilateral closure of paired growth centers.12

In summary, unilateral traumatic rupture of the neurocentral synchondrosis of C-2 is usually not an isolated injury but one component of multiple injuries involving other cartilaginous parts of the involved axis, resulting often in C2–3 instability. External immobilization with a halo jacket and close monitoring is an option if displacement is minimal, but open reduction and C1–3 fusion are necessary in patients with significant distraction and/or displacement of the adjacent bony units.

Fig. 5. Diagrams showing the axis with the neurocentral synchondrosis and the dentocentral synchondrosis. AS = the apical segment (cartilaginous) of the dens; BS = the basal segment of the dens; C = C-2 centrum. Copyright Dachling Pang. Published with permission.
Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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