New C2 synchondrosal fracture classification system[1]

Honors Undergraduate Research Thesis

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Abstract:

Background. Excessive cervical flexion-extension and mild to severe impact injuries can lead to C2 synchondrosal fractures in young children.

Objective. To characterize and classify C2 synchondrosal fracture patterns.

Materials and Methods. We retrospectively reviewed imaging and medical records of children who were treated for cervical spine fractures at our institution between 1995 and 2014. We reviewed all fractures involving the five central C2 synchondroses with regard to patient demographics, mechanism of injury, fracture pattern, associated fractures, other injuries, treatment plans and outcome.

Results. Fourteen children had fractures involving the central C2 synchondroses. There were nine boys and five girls, all younger than six years old. We found four distinct fracture patterns. Eleven complete fractures were further divided into four subtypes (a, b, c and d) based on degree of anterior displacement of the odontoid segment and presence of distraction. Nine of these 11 children had fractures through both odontoneural synchondroses and the odontocentral synchondrosis; one had fractures involving both neurocentral synchondroses and the odontoneural synchondrosis; one patient had fractures through bilateral odontoneural and neurocentral synchondroses. Three children had incomplete fractures defined as a fracture through a single odontoneural synchondrosis with or without partial extension into either the odontocentral or the adjacent neurocentral synchondrosis. All complete fractures were displaced or angulated. Four had associated spinal cord injury, including two contusions (subtype c fractures) and two fatal transections (subtype d fractures). Most of the 11 surviving patients were treated with primary halo stabilization. Subtype c fractures required surgical fixation.

Conclusions. We describe four patterns of central C2 synchondrosal fractures, including two patterns not previously reported. We propose a classification system to distinguish these fractures and aid in treatment planning.

Key Words: C2 · Synchondrosis · Odontoid Fractures · Axis · Cervical Spine · Computed Tomography · Magnetic resonance imaging · child

Introduction:

The pediatric spine, like a mature adult spine, is broken into regions: cervical, thoracic, lumbar, sacrum and coccyx. The cervical spine, the upper most region, is comprised of 7 vertebral bodies, C1-C7. The posterior base of the skull, the occiput, rests on the superior facet of the first cervical vertebral body, C1 (the atlas). The facets serve as the flat superior and inferior portions of vertebral bodies. These form joints with neighboring vertebral bodies [2]. Just below C1 is C2 (the axis), the most commonly injured vertebra in young children. It is uniquely susceptible to injury for a variety of reasons including C2 anatomical structure, loosening of ligaments (the connective tissue that connects bone to bone), decreased muscle tone in the upper cervical musculature, upward shifted biomechanical fulcrum on which the skull hinges forward and backwards, and large cranial to body ratio [2]. Unique to the pediatric spine are open synchondroses. Synchondroses serve as a cartilaginous immovable joint between bone structures that eventually fuses to form a larger bone mass. Open or incompletely fused C2 synchondroses serve as points of structural weakness making them susceptible to fracture even with minor trauma [3-5].

Ossification centers serve as the central point for bone growth. Ossification centers that eventually fuse form synchondroses at the interface of the two cartilaginous structures [2]. A developing C2 vertebra consists of 5 ossification centers: the two neural arches which form a ring around the spinal cord traveling through the spinal column, body, odontoid process (the vertical protruding portion of the C2 also known as the dens) and the chondrum terminale or os odontoideum (the tip of the dens) [6]. These five centers are separated by six C2 synchondroses (Fig. 1). Five of the C2 synchondroses are central: the right and left odontoneural synchondrosis, the right and left neurocentral synchondrosis, the odontocentral synchondrosis [7] (Fig. 1). These synchondroses fuse by age nine in 80% of children: range 7-9.5 years [6]. The apicodental synchondrosis [7, 8] (Fig. 1), the synchondrosis at the tip of the C2 dens, fuses completely by age 10.5 years in 80% of children (range 5.5-13.5) [6]. At this point, the C2 vertebral body is a singular bone structure lacking synchondrosal lines, which would then be characterized as an adult spine. The apicodental synchondrosis has distinct injury patterns when compared to those seen with the central synchondroses. Fractures at this synchondrosis were not included in this study.

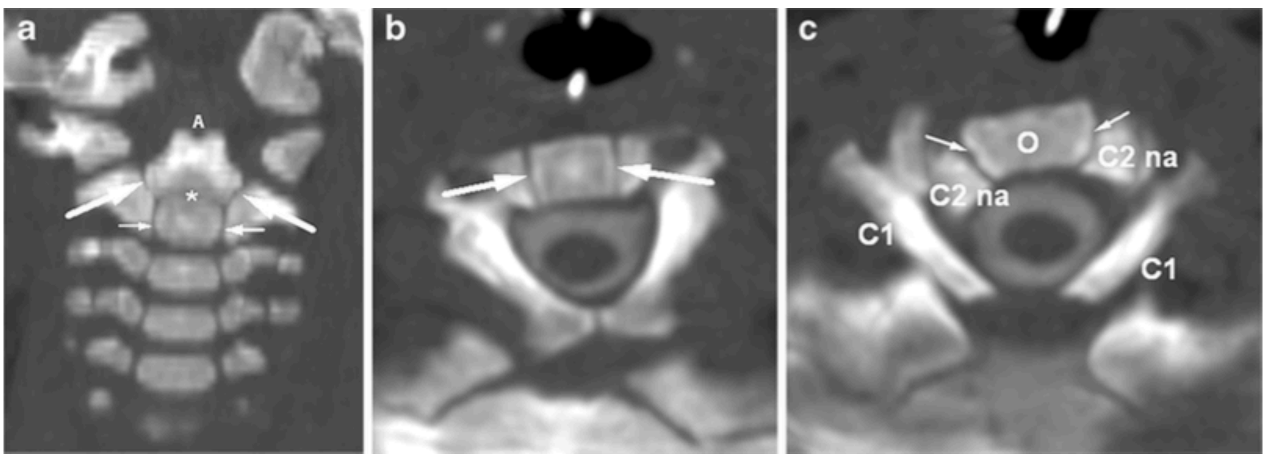

Fig. 1 Normal synchondroses. (**a**) Coronal (image taken from anterior to posterior or "front" position) Computed Tomography (CT) in a 12-month-old boy and (**b, c**) axial (image taken from proximal to distal or "aerial" position) CT images from a CT myelogram (includes contrast dye injected into patient) in 6-month-old boy show normal immature C2 anatomy with unfused synchondroses. The five central C2 synchondroses—bilateral neurocentral (small arrows), bilateral odontoneural (large arrows) and the single transverse odontocentral synchondrosis (*)—are all open. The apicodental synchondrosis (A) is also open and os odontoideum has not yet ossified, or fused. C2 neural arches (C2 na) and C1 lamina (C1) are labeled for reference.

Odontoid fractures were first classified by Anderson and D'Alonzo (types I-III) in a 1974 roentgen (X-ray) series that included adults and five children [9]. The term "synchondrosal slip fracture" has been used to describe the most common fracture in patients characterized as having a pediatric spine, however, this term has been applied without distinction of which synchondrosis is involved [10, 11]. More recently, Hosalkar et al. sought to classify the "open basilar synchondrosis" based upon the degree of anterior displacement, or how far anteriorly the odontoid portion of the C2 is separated from the centrum of C2 [4]. We believe this classification system has utility in diagnosis and treatment planning for C2 synchondrosal fractures; however, it only referred to fractures involving one of the central synchondroses, which was rarely the case in our study.

We observed a spectrum of central C2 synchondrosal fractures at our institution over the last 19 years, including two fracture patterns not previously reported. We propose a new classification system that allows for the distinction of C2 synchondrosal fracture types based on central synchondrosis anatomy.

Materials & Methods:

Our Institutional Review Board approved our retrospective review of the imaging and hospital records of children with cervical spine fractures at a large tertiary children's hospital. We searched our institutional database using the following key words for patients < 21 years: odontoid fracture, C2 fracture, C2 synchondrosal fracture, C2 synchondrosal slip fracture, C2 synchondrotic slip fracture, cervical spine CT, axis fracture, cervical spine fracture, and c-spine fracture. All fractures that did not include the C2 synchondroses were excluded. All fractures involving the apicodental synchondrosis were also excluded.

We evaluated all imaging studies of children with fractures involving the remaining five central C2 synchondroses. Analyzing them with regard to synchondrosal fractures, displacement and angulation of the dens with respect to the C2 body, rotation and distraction (separation) of the vertebral column from the skull or adjacent vertebrae, compression of spinal canal or spinal cord space, other adjacent fractures, integrity of the vertebral joints (facets), and integrity of the disk spaces (the fibrous tissue that vertically separates one vertebral body from the next). Available cervical spine magnetic resonance image (MRI) studies, a common imaging technique used to assess soft tissue damage, were used to assess fracture patterns, ligamentous and tectorial membrane (posterior spinal ligamentous structure) integrity, spinal cord injury, collection of fluid in soft tissue spaces (edema), collection of blood in soft tissue spaces (hemorrhage), alignment between the skull and C1, and the health of the arteries passing through the vertebral area. Hospital medical records were reviewed for additional patient data including age, gender, mechanism of injury, other related diagnoses or injuries, treatment plan and outcome.

Results:

There were 56 cervical spine fractures in children < 21 years of age imaged at our institution from 1995 to 2014. Fourteen (25%) children (nine boys, five girls) had fractures that involved one or more of the central C2 synchondroses. These 14 were younger than six years old (range: 9 months to 5 years 7 months, mean: 3.3 years). Eight patients were involved in motor vehicle crashes (seven were passengers and one was a pedestrian), two sustained trampoline injuries, one had a sledding injury, one was a suspected strangulation and two acquired injuries from falls. All fourteen children (100%) had initial cervical spine radiographs (X-ray) per our institution's trauma protocol. Additional image studies were conducted based on radiographic findings and clinical signs and symptoms. Twelve (86%) children had cervical spine CT, whereas six (43%) children had cervical spine MRI.

We found four distinct fracture patterns, which we labeled types I-IV (Table 1). All of the complete fractures (types I, II and III) (Fig. 2) were either displaced or angulated and were further subtyped based on degree of displacement following Hosalkar et al. (a: 0-10%, b: 10-100%, c: > 100% and d: distraction) [5]. Type IV fractures were incomplete and non-displaced.

Fracture type	Fracture location	Intact synchondroses	Subtype	# pts $n=14$	Fig.#
I	Right & left odontoneural + odontocentral	Right & left neurocentral	a	2	3
			b	4	4
			c	1	5
			d	2	6
II	Right & left neurocentral + odontocentral	Right & left odontoneural	a		
			b		
			c	1	7
			d		
III	Right & left odontoneural+right & left neurocentral	Odontocentral	a		
			b	1	8
			c		
			d		
IV	Fracture through 1 odontoneural synchondrosis +/− a portion of its adjacent odontocentral or neurocentral synchondroses	4 of 5 including contralateral odontoneural and neurocentral, partial or complete odontocentral and partial or complete neurocentral		3	9

Table 1 Types of C2 synchondrosal fractures. Type I-III are complete fractures, and their subtypes are defined by degree of displacement according to Hosalkar et al. [4] (a: 0-10%, b: 10-100%, c: >100%, and d: distraction). Type IV fractures are incomplete and non-displaced.

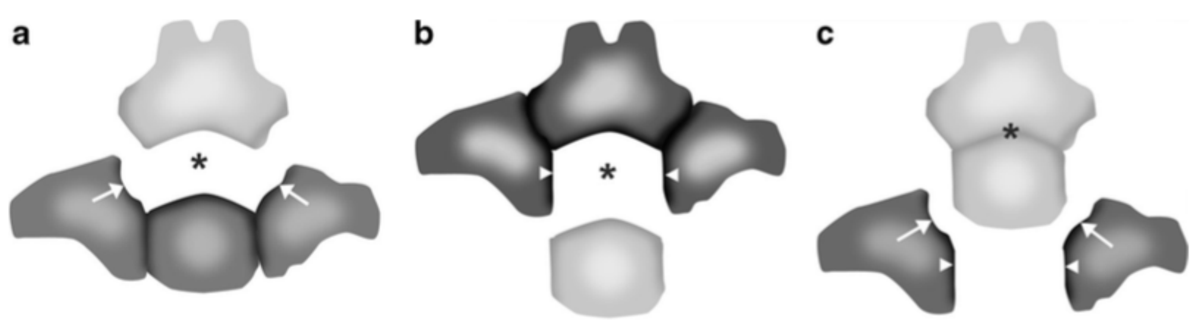

Fig. 2 Coronal diagrams of C2 synchondrosal complete fracture patterns. (**a)** Type I fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*). (**b)** Type II fractures involving the right and left neurocentral (arrowheads) and the odontocentral synchondroses (*). (**c)** Type III fractures through the bilateral odontoneural (arrows) and bilateral neurocentral synchondroses (arrowheads) with intact odontocentral synchondrosis (*).

Most (9/14, 64%) patients had type I fractures extending through both odontoneural synchondroses as well as the odonotcentral synchondrosis (Figs. 2-6). In two of these fractures, the odontoid segment was displaced anteriorly 0-10% (subtype a) (Fig. 3). Four were displaced anteriorly 10-100% (subtype b) (Fig. 4). One type I fracture had >100% anterior displacement (subtype c) (Fig. 5). Two type I fractures were distracted (subtype d) (Fig. 6).

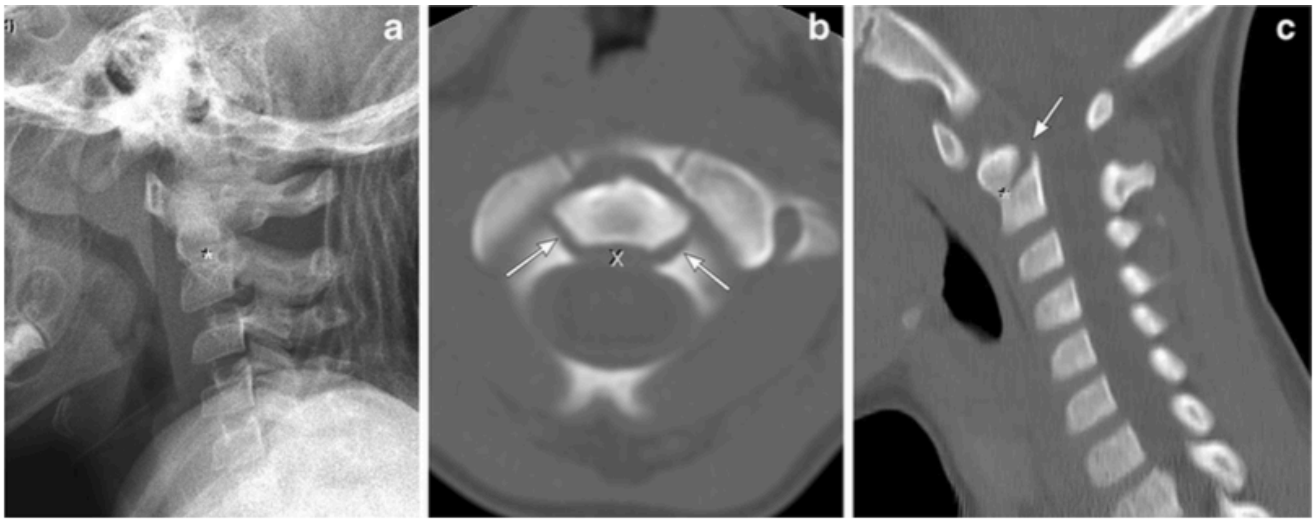

Fig. 3 Type I subtype a fracture in patient 6, a 4-year-old boy with neck pain after trampoline injury. (**a**) Lateral radiograph (X-ray), (**b**) and axial CT and (**c**) sagittal (lateral view) CT images show fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*) with <10% anterior displacement (x) and 13 deg. anterior angulation. This patient also had a T4 compression (collapse of the 4^{th} thoracic vertebrae) fracture (not shown). He was treated with halo stabilization.

One child had a type II fracture involving both neurocentral synchondroses and the odontocentral synchondrosis (Fig. 7). In this child, the odontoneural fracture segment was anteriorly displaced 100% (subtype c), the C2-C3 joint was locked, and the spinal canal was narrowed.

One child had a type III fracture involving the bilateral odontoneural and neurocentral synchondroses with 10-100% anterior displacement (subtype b) (Fig. 8). Three patients had incomplete type IV fractures that involve one odontoneural synchondrosis with or without extension into its adjacent odontocentral or neurocentral synchondroses (Fig. 9).

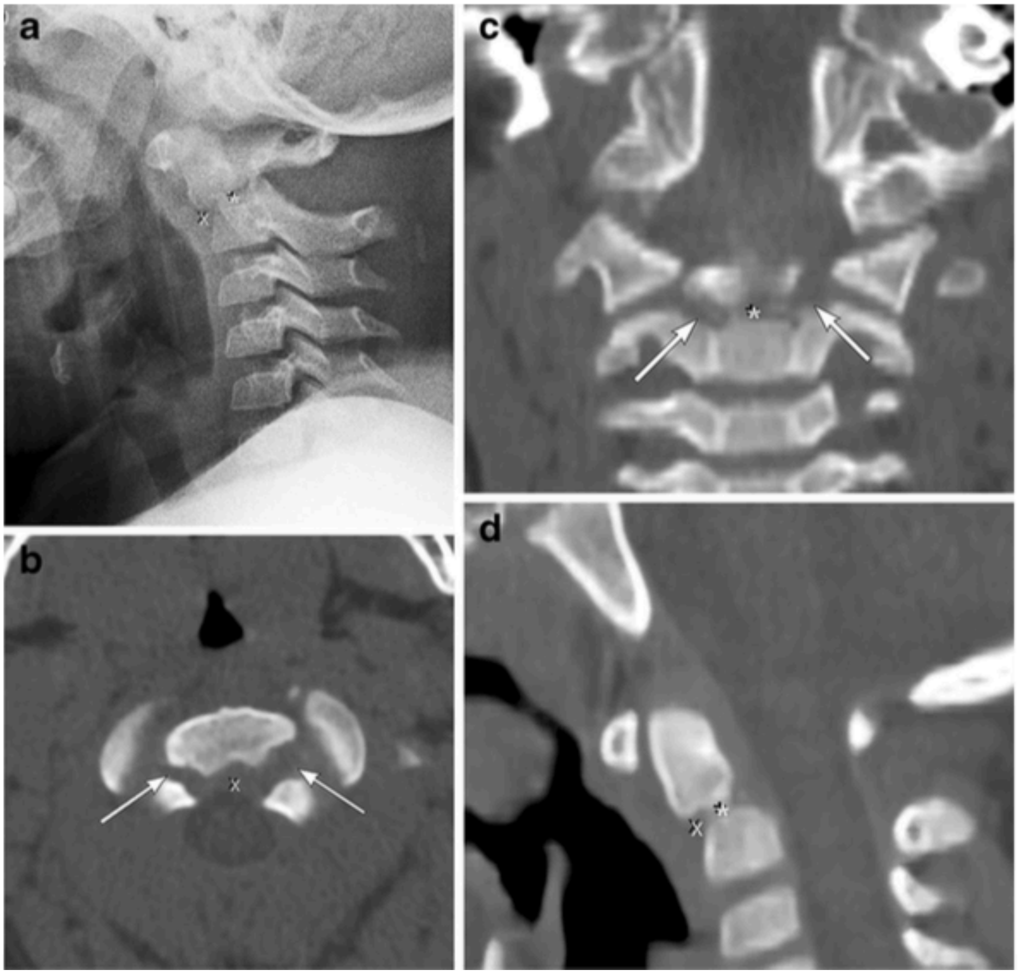

Fig. 4 Type I subtype b fracture in patient 10, a 4-year-old boy with neck pain after motor vehicle crash. (**a**) Lateral radiograph, (**b**) axial CT, (**c**) coronal CT and (**d**) sagittal CT images show fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*) with 3 mm anterior displacement (x), rotation and focal kyphosis (abnormal spine curvature). MRI showed localized edema (fluid collection) at C1-C2 as well as posterior soft tissue edema associated with T4 and T5 compression fractures (not shown). This boy also had a liver laceration (tear/cut) and lung contusion (bruising). The C2 fracture was successfully treated with halo stabilization.

Four (29%) patients had spinal cord injury (two contusions and two fatal transections) (Table 2). Both children with subtype c fractures (type Ic and type IIc) had associated spinal cord contusions. Both children with subtype d fractures (type Id) had marked distraction of their fractures and were presumed to have had fatal spinal cord transections (complete tear). The third fatality (3/14, 21% total fatalities) was a child in whom abusive strangulation was suspected. This child had a type IV subtype b fracture and died of asphyxia.

Fig. 5 Type I subtype c fracture in patient 7, a 3-year-old girl after a motor vehicle crash. (**a**) Lateral radiograph and (**b**) axial CT images show fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*) with 8.2 mm (>100%) anterior displacement (x), 8 deg. rotation, significant angulation (16 deg on XR [not shown], 21 deg on CT) and atlanto-occipital dissociation (C1-skull separation). (**c**) On coronal CT, the odontoid process appears to be absent giving it the "missing tooth" sign. (**d**) Sagittal T2-W MR image after attempted reduction and halo stabilization shows improved fracture alignment with anterior, posterior and apical ligamentous injury, pre-vertebral edema (p) and cord impingement. MRI also shows clival hematoma (arrowhead). Initial halo stabilization failed and this patient ultimately underwent a procedure to fuse the fracture with posterior occipital-C4 hardware.

Six (43%) children had MRI studies and all had abnormalities in surrounding musculature. Four children had brain CT. Clival hematomas were present in the two children with subtype c injuries who survived motor vehicle crashes with distinct atlanto-occipital dissociation (AOD) in one and subtle AOD in the other. Two of the fatally injured children had been in motor vehicle crashes and had massive subarachnoid hemorrhages visible in brain CT. Four (67%) of these six patients had directly visualized ligamentous injury on MRI or CT of the cervical spine: tectoral membrane injury (patient 1), C1-C2 ligamentous injury (patient 10), anterior and posterior ligamentous injury at the posterior atlanto-axial and apical ligaments (patient 7), and apical and lateral atlanto-dental ligament injury (patient 12). Four (67%) children had localized soft tissue edema associated with ligamentous injury: C1 and C2 (patients 2 and 13), the anterior and posterior C1-3 interval (patient 7), and at the C1-2 facets and C2 neural arch (patient 12).

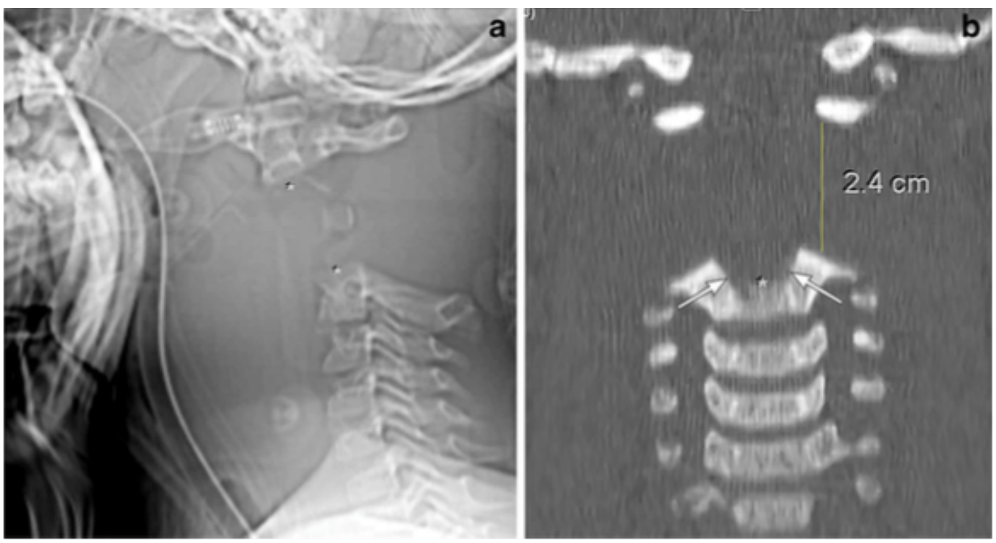

Fig. 6 Type I subtype d fracture in Patient 3, a 4-year-old boy with fatal injury after motor vehicle crash. (**a**) Lateral scout (X-ray) and (**b**) coronal CT images show fractures of the right and left odontoneural (arrows) and the odontocentral synchondroses (*) with 7.2 mm anterior displacement, 14 deg anterior angulation and marked, 2.4 cm, distraction of the odontoid segment. Brain CT (not shown) revealed massive subarachnoid hemorrhage.

Six of the 14 (43%) had other fractures, including those of the skull and/or facial bones (3), thoracic spine (2), scapula (1), clavicle (1), and long bones (2). One patient had lung injuries and one had liver and lung injuries. Eleven (79%) children survived their injuries. Six of these children had type I subtype a or b fractures and were treated with primary halo stabilization. The two children with subtype c fractures and spinal cord injury were treated with primary surgical fixation. Patient 1 (type IIc) was treated via C1-3 cerclage wire surgical stabilization and patient 7 (type Ic) was stabilized with occipital-C4 posterior fusion. All three children with incomplete Type IV fractures were treated conservatively, two with cervical collar only.

Fig. 7 Type II subtype c fracture in patient 1, a 4-year-old female after a motor vehicle crash. (**a**) Lateral radiograph, (**b**) axial CT, (**c**) sagittal (lateral view) CT and (**d**) coronal CT reformation images show fractures involving the right and left neurocentral (arrowheads) and the odontocentral synchondroses (*) with 100% anterior displacement (x) and marked pre-vertebral edema (p). C2 ring and odontoid are displaced anteriorly relative to the C2 body (C2 body). (**d**) Coronal CT image shows a rocket sign consisting of the C2 body being punched out from the rest of C2 leaving the neural arches and dens as one unit in the shape of a rocket on a launching pad. MRI (not shown) revealed spinal cord and tectal membrane injury, mild atlanto-occipital dissociation and a clival hematoma. This patient was treated with primary C1-3 cerclage wire fixation.

Discussion:

We report a spectrum of C2 synchondrosal fractures, including 2 new fracture patterns. These fractures involve the 5 central synchondroses in various combinations and cannot be effectively classified using other published systems for C2 or odontoid fractures. C2 synchondrosis fractures in children under 7 years of age have previously been described as slip fractures or odontoid synchondrotic slip fractures, with two forms previously described [10, 11]. Hosalkar et al. [5] classified the more common synchondrosal fracture type into 3 subtypes based upon degree of anterior displacement of the odontoid fracture segment and this has had clinical utility [5]. Our classification system uses Gore et al.'s terminology for the synchondroses [7], allowing for an anatomical description of more synchondrosal fracture patterns (types I-IV) and it incorporates Hosalkar et al.'s classification of degree of displacement (as subtypes a, b, c and d), which we found to correlate with treatment and outcomes.

Previous articles describing C2 synchondrosal fractures have presented little cross sectional imaging data despite the proven value of axial CT imaging (image taken superior to inferior) with multi-planar and 3D reformations [12, 13]. Cervical MRI data is virtually nonexistent in the literature on these fractures. Although all patients at our institution are initially imaged with cervical spine radiographs, all the patients in our study went on to have at least one cross-sectional imaging study. Most (12/14, 86%) had cervical CT; two children who died shortly after presentation had brain CT, but did not have a cervical CT or MRI; and six children had cervical spine MRI, five of which were performed at presentation.

Anteriorly displaced fractures produced unique appearances on coronal CT reformatted images. If the type I odontoid fracture fragment is displaced close to 100% anteriorly (type Ib or type Ic) or distracted (Type 1d), it can look as if the dens is absent giving it the "missing tooth" sign (Fig. 5c, 6d). The type III fracture, which involves both odontoneural and neurocentral synchondroses, results in a twin towers sign, with each neural arch representing one of the towers with nothing in between them (Fig. 8e). The type III fracture is rare, accounting for only one of our 14 patients and with only one previously described case [11].

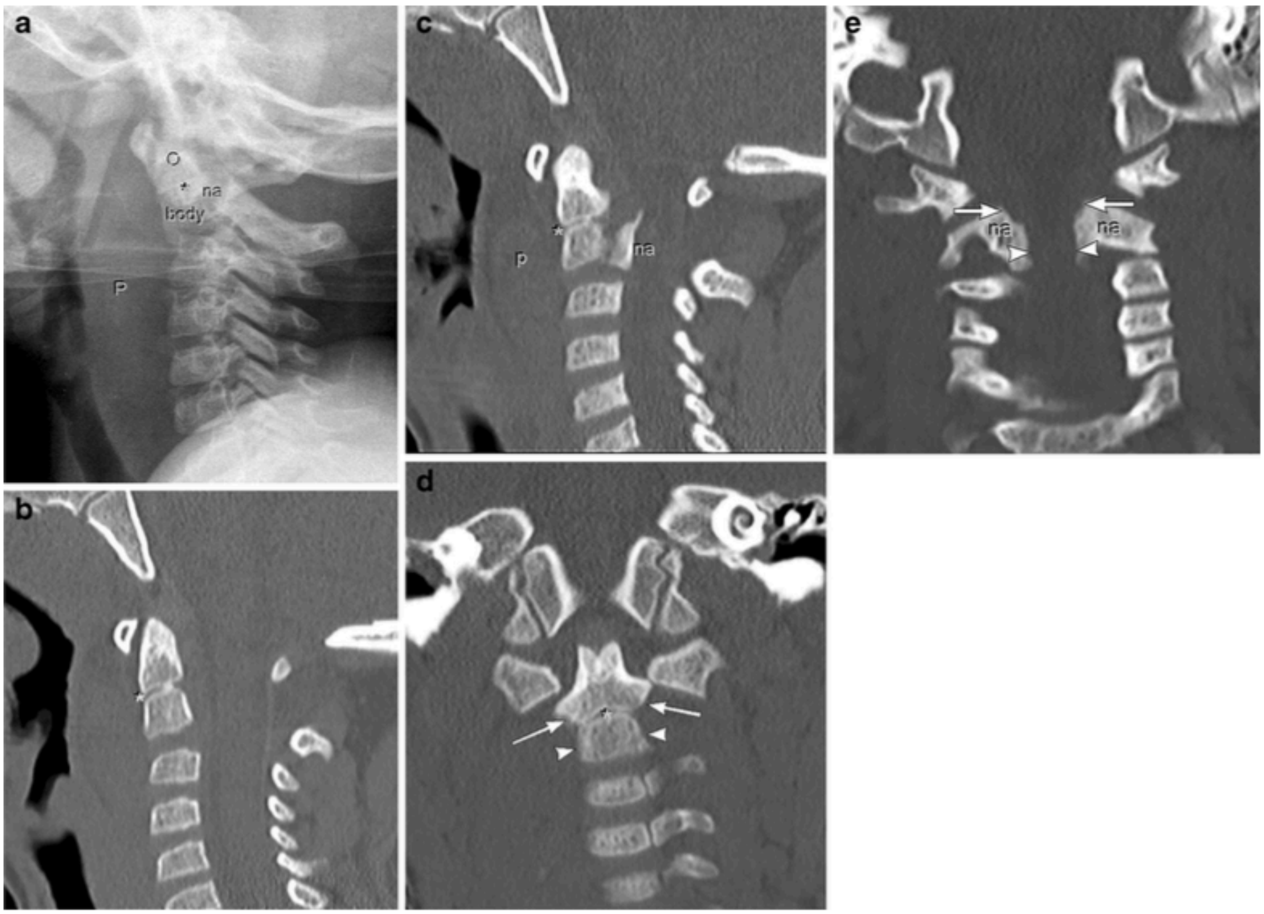

Fig. 8 Type III subtype b fracture in patient 5, a 4-year-old boy who was struck by a motor vehicle while walking. (**a**) Lateral radiograph, (**b**) midline sagittal CT, (**c**) right parasagittal CT, and (**d**, **e**) coronal CT reformations images show fractures through the bilateral odontoneural (arrows) and bilateral neurocentral synchondroses (arrowheads) with anterior displacement and anterior angulation of the odontoid (o). The neural arches (na) are in normal position. This results in a twin towers sign with each neural arch representing one of the towers with nothing between (**e**). The ondontocentral synchodrosis (*) is intact. There is marked pre-vertebral edema (p). This boy also had a non-displaced scapula fracture. The C2 fracture was treated via primary halo stabilization.

The type II fracture extends through both neurocentral synchondroses as well as the odontocentral synchondroses and also has an unusual appearance on coronal CT reformations. In the one example of this fracture in our series (type IIc), the centrum/body remained in position, the neural arches/dens fragment was displaced anteriorly, and the C2/C3 facets were locked. There was significant spinal cord injury. On the coronal CT reformatted images, there was a "rocket" sign consisting of the centrum/body being punched out from the rest of C2 leaving the neural arches and dens as one unit in the shape of a rocket on a launching pad (Fig. 7d). Ours is a unique report of this fracture pattern.

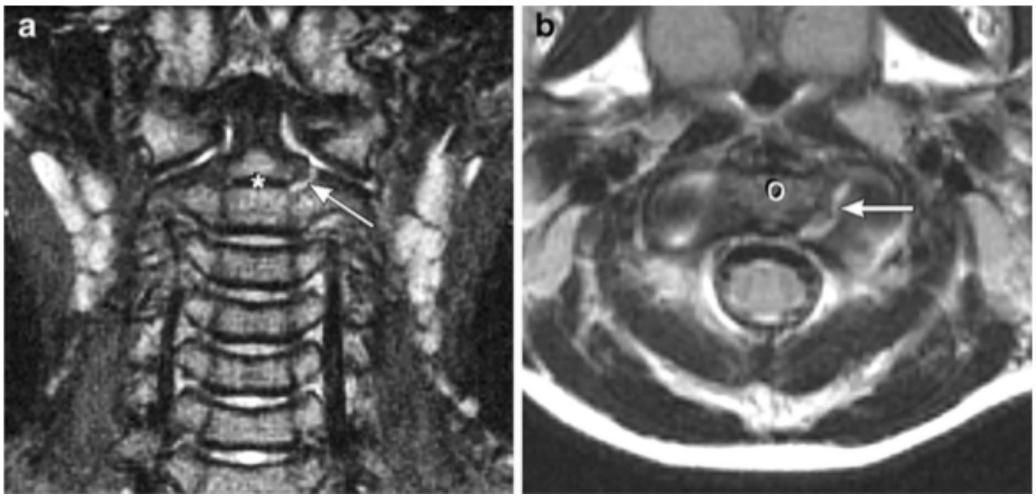

Fig. 9 Type IV fracture patient 12, a 2-year-old girl after motor vehicle crash. (**a**) Coronal and (**b**) axial MRI images obtained with patient in cervical collar show fracture line with bright T2 signal edema extending through only the left odontoneural synchondrosis (arrow) adjacent to the odontoid (o). The odontocentral synchondrosis (*) is intact. There was also associated apical and left atlantodental ligament injury with edema noted along the C1-C2 facets, body of C2 and left C2 neural arch (not shown). The girl was treated with cervical collar stabilization only.

Type IV fractures, the other new C2 fracture pattern we observed, were incomplete synchondrosal fractures occurring in three girls. Associated ligamentous injury is minor and mostly localized over the area of the incomplete fracture. Most in our series occurred after minor falls and all were managed with conservative treatments. In each case, there was a fracture through the entirety of one of the odontoneural synchondroses. One of these fractures stopped at that point and in the other two, one partially extended into the odontocentral synchondrosis and in the other partially into the superior aspect of the adjacent neurocentral synchondrosis before

Table 2. Demographics, injuries, and treatment of 14 children with C2 synchondrosal fractures, organized by fracture type

Pt. #	Gender/Age	Mechanism of Injury	Fracture Type	Edema and/or ligament injury	Spinal Cord Injury	Intracranial Injury	Other Injuries	C2 treatment/outcome
9	M 23 m	MVC	I subtype a			**None	None	Halo
6	M 4 years	Trampoline	I subtype a				T-spine fx	Halo
4	M 9 m	Child abuse, suspected strangulation	I subtype b					None/death
10	M 4 years	MVC	I subtype b	*Yes			T-spine fx Liver Lung Ulna fx Clavicle fx	Halo
2	M 4 years 10 m	Trampoline	I subtype b			None		Halo
8	M 5 years 7 m	Sledding	I subtype b				None	Halo
7	F 3 years 5 m	MVC	I subtype c	*Yes AOD	Cord compression and contusion	**Small clival hematoma		Failed halo, occipital-C4 posterior fusion
11	M 13 m	MVC	I subtype d	AOD	Presumed cord transection	**Massive SAH IVH (4th ventricle)	Lung	None/death
3	M 4 years 3 m	MVC	I subtype d	Yes	Presumed cord transection	**Small clival hematoma, Massive SAH, IVH (4th ventricle)	Orbit fx Skull fx	None/death
1	F 4 years	MVC	II subtype c	*Yes Mild AOD	*Compression central cord syndrome	*Clival hematoma small SDH	Scull fx Tibia fx	Halo
5	M 4 years 3 m	MVC Pedestrian	III subtype b	Yes			Scapula fx	Halo
12	F 2 years 1 m	Fall	IV	*Yes			None	Collar
13	F 4 years 9 m	MVC	IV	*Yes			None	Collar
14	F 13 m	Fall (bed)	IV				Skull fx Femur fx	Unknown

AOD atlanto-occipital dissociation, *fx* fracture, *IVH* intraventricular hemorrhage, *m* months, *MVC* motor vehicle crash, *SAH* subarachnoid hemorrhage, *SDH* subdural hemorrhage
*Cervical spine MRI findings
**Brain CT Findings

breaking out into the C2 body (Fig. 9a). These fractures represent the mild end of the spectrum of C2 synchondrosis fractures.

The spectrum of injury for types I, II, and III fractures ranged from less severe to deadly, which correlates to the degree of displacement by subtype. First, subtypes a and b fractures were mildly displaced and edema mostly localized anteriorly and posteriorly at the C1-C2 level, with no evidence of spinal cord injury, and no evidence of atlanto-occipital dissociation. These children had trampoline and sledding injuries as well as motor vehicle related injuries. Next, patients with subtype c fractures all had severe anterior and posterior edema from the skull base thru C2 and in one case edema extended to the C7 level anteriorly. These patients also had clival hematomas consistent with tectorial membrane injury or disruption [14], mild to severe atlanto-occipital dissociation and, most importantly, spinal cord compression and contusion due to displacement of the odontoid fracture segment anteriorly along with the entirety of C1 and the skull. Finally, both children with subtype d fractures had been in motor vehicle crashes and died shortly after arriving in the emergency room of presumed spinal cord transection.

Fracture classification systems are typically devised to guide treatment planning. While management is not standardized for central C2 synchondrosal fractures in children, typically reduction, if necessary, followed by conservative halo stabilization until the fracture has healed has been advocated and reportedly successful [5, 15-16]. Severe displacement, defined as greater than 100% anterior displacement, has been suggested as an indication for surgical stabilization [5]. Our patients were ultimately managed in treatment groups defined by fracture type and subtype. Specifically, incomplete, non-displaced, IV fractures were treated conservatively—not treated or placed in a cervical collar. Types I, II, or III subtype a and b fractures were successfully treated with halo reduction and stabilization. The two surviving patients with type Ic and type IIc fractures who had the greatest degree of displacement, were treated with surgical stabilization, although one failed initial attempt at halo reduction and stabilization. Both children with subtype d fractures died before their cervical spine injury could be addressed.

While we saw four distinct fracture patterns, we did not see any fractures that involved a single neurocentral synchondrosis by itself or with partial extension into the adjacent odontocentral or odontoneural synchondroses. In addition, it is not physically possible for the odontocentral synchondrosis to be fractured by itself leaving the odontoneural or neurocentral synchondroses intact. Multiple other fracture combinations of 2 or more synchondroses are technically feasible but were never encountered. Our proposed classification system can easily be expanded if these are reported in the future.

Limitations of our study include the low number of patients with these rare fractures, even at our large children's hospital. We identified only one child for each of our types II and type III fracture patterns and only 3 patients with the not previously described, incomplete and non-displaced type IV fractures. While all of the complete fractures in our series were displaced or angulated, and we expect such fractures to be recognized prospectively, incomplete fractures may be overlooked and underreported. Likewise fractures involving the other synchondroses may have gone unrecognized and not identified in our report searches. Other limitations include the older CT studies limited by technique, varied CT scanning protocols over the 19 year study period and the fact that not all patients at our institution have CT scans as part of their evaluation of suspected cervical spine trauma.

Conclusion

Posttraumatic cervical spine injury in young children may result in fractures through one or more of the C2 synchondroses. We identified 4 distinct fracture patterns of the central C2 synchondroses including two patterns not previously reported. These rare fractures should be readily identifiable as they are commonly displaced or angulated. Patients with marked displacement or distraction had associated spinal cord injury. Treatment choices varied with fracture type and subtype. We propose a classification system to describe and distinguish the injury patterns and aid in treatment planning of childhood central C2 synchondrosis fractures.

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