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CT Anatomy of the Craniovertebral Junction in Infants and Children

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Computed tomographic (GE 9800) images of 129 patients (from newborn to 18 years old) with no evidence of cervical spine pathology were reviewed retrospectively from available material to evaluate normal anatomic appearances in childhood. The synchondroses may appear solid at soft-tissue window settings, while, with appropriate bone-window settings, a lucent line will be seen. Residual lucency and then (generally) sclerosis were seen at synchondroses past the age of classic anatomic fusion. A transversely oriented groove on the undersurfaces of the occipital condyles was imaged in children ages 5–12 years. This groove is described radiologically in that age range for the first time in this report. The development of the ossification centers of C1 was illustrated with CT. The two vertically oriented, rod-shaped ossification centers of the lower dens develop a bilobed appearance in axial section when they begin to fuse. An apparent deficiency of the cortex seen posteriorly in this area (in children as old as 7 years) represents the last remnant of the cleft between the dens centers. The cord was always outlined distinctly by CSF at soft-tissue settings at the foramen magnum and C1 levels without intrathecal or IV contrast enhancement. This anatomic feature is particularly useful since it enables the evaluation of the spinal canal in this region in some cases (especially craniovertebral junction anomalies) without the need for intrathecal contrast materials.

Several descriptions of the development and anatomic appearance of the occipitoatlantoaxial region have been recorded [1–7]. The way in which the atlas and axis develop is complicated but fascinating. The formation of these two vertebrae is quite different from that of other vertebrae. To facilitate an understanding of the various anatomic appearances encountered on CT studies of this region, we have summarized the pertinent features of the development of the ossification centers of C1 and C2.

Development

The atlas usually develops from three different centers of ossification. Two lateral centers first appear around the seventh month of fetal life. The lateral mass and posterior arch on either side (present at birth) develop from these lateral centers (Fig. 1). The anterior arch of the atlas begins as a cartilaginous bar in which the third ossification center develops. This center is seen on plain neck films in only 20% of infants at birth, but can be seen in practically all 1-year-olds. Occasionally the anterior arch is bipartite (2%); it is rarely tripartite.

Classically the posterior arches have been noted to fuse dorsally during the third year of life [7]. Fusion of the anterior and the two lateral centers may occur at the neurocentral synchondrosis at the age of 4 or 5 years, but usually no later than age 7 years. Unlike the other vertebrae, C1 never develops a true body. Rather, the atlas body anlage develops into the dens.

The body and lateral masses of the axis develop from one central and two lateral ossification centers (Fig. 2). The dens ossifies from three centers. In fetal life the

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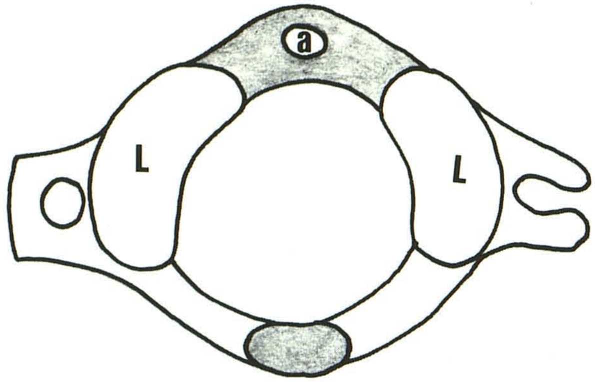


Fig. 1.—Ossification of the atlas. Lateral ossification centers (L) eventually develop into lateral mass and posterior arch of C1 on either side. Anterior arch begins as a cartilaginous bar (*upper shaded area*), and a single ossification center (a) usually develops within it. Posterior synchondrosis (*lower shaded area*) usually disappears on plain films during third year of life with fusion of posterior arches. It may be apparent on CT as late as 4 years 2 months. Fusion at the two anterolateral (neurocentral) synchondroses usually occurs later.

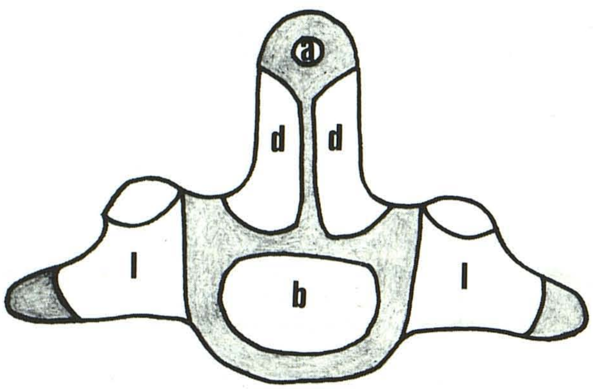


Fig. 2.—Ossification of the axis. Dens develops from bilateral ossification centers (d) that unite at midline by birth. A separate apical dens center (a) begins to ossify at about 2 years of age. Inferiorly, a central ossification center (b) develops into the body of the axis. Two lateral centers (l) develop into lateral masses and arches of C2.

dens appears as a cartilaginous stump projecting upward from the second cervical centrum. Around the sixth fetal month, two laterally situated ossification centers appear within the base of this process. By the time of birth, these dens centers have united medially except for a cleft superiorly. The apex of the dens is filled in with cartilage at birth, but a separate ossification center arises within it at around 2 years of age (Fig. 2). This usually fuses with the dens centers below by 10–12 years of age. Ossific fusion between the dens and body of C2 eventually occurs, but the synchrondosis may persist as an unossified line even in some adults.

A particularly fine and detailed account of the CT appearances of this area in adults has been recorded [8]. In this report we focus on the CT appearances of the developing craniovertebral junction anatomy in children and include some new and more detailed observations.

Materials and Methods

CT images (GE 9800) of 129 patients from birth to 18 years of age with no evidence of cervical spine pathology were reviewed retrospectively from available material. The majority of the scans were obtained looking for other head or neck disease in which the craniovertebral junction, or at least part of it, was seen incidentally. The scanning plane was usually parallel to the orbitomeatal line, or nearly so. The slice width was 1.5–10 mm. Exposure factors ranged from 70 mA, 2 sec, to 140 mA, 4 sec. Some patients received IV iodinated contrast agents and a few were studied after intrathecal administration of metrizamide. Some patients had only soft-tissue windows, some only bone windows, and some both. Follow-up CT studies performed at a later date were available in some of the cases. Axial and parasagittal scans were also obtained through a dry skull specimen of a child whose age was estimated by dentition to be 9 years.

Results

The observations made on reviewing the CT studies in 129 children are recorded within the following anatomic subdivisions.

Occiput

The foramen magnum usually appears oval but occasionally has a shieldlike configuration on axial images. Posterolaterally, the innominate synchondrosis separates the supraoccipital portion of the occipital squama from the exoccipital portion of the occipital bone. Anterolaterally, the basiexoccipital synchondrosis separates the basioccipital bone from the exoccipital portion of the occipital bone (fusion occurs posteriorly before it occurs anteriorly). These synchondroses may appear solid at soft-tissue window settings, while with appropriate bone-window settings a lucent line will be seen (Fig. 3). The basiexoccipital synchondrosis may be more sclerotic at its posterior margin and wider medially. Although anatomic fusion usually occurs by the age of 6 years [1], a medial lucency was seen with CT until age 4 years 9 months (Fig. 4A), and a persistent sclerotic line was seen at the basiexoccipital synchondrosis into the late teens (Fig. 4B). The basiexoccipital synchondrosis was 4 mm anterior to the hypoglossal canal at age 6 months and had increased to 5–6 mm by age 4.

Since the occipital condyle initially has a flat configuration, it is not imaged on axial scanning in younger patients (that is, it does not have the well-defined bump seen in adults). The occipital condyle appears sclerotic posteromedially at the age of 2 years. At 5 years of age its reniform shape becomes apparent, but its lateral border is indistinct. A furrow (distinct and separate from the hypoglossal canal on sagittal cuts and anatomic specimens) (Figs. 5 and 6) was seen with bone-window settings in the occipital condyle directly below the hypoglossal canal and 6 mm posterior to the basiexoccipital synchondrosis from ages 5½ to 12 years in four of 13 children.

Atlas

The posterior arch and lateral mass of the atlas usually develop from a single lateral ossification center on either side. The anterior arch usually develops from another ossification center. Thus, there is a neurocentral synchondrosis anterolaterally on each side (Fig. 7A) and a single midline posterior synchondrosis.

The anterior arch was seen to be bipartite in two children and tripartite in one child. In one 12-year-old it appeared to be absent. In one 7-year-old child, the right posterior arch of C1 was absent. At the age of 2 years, the synchondroses were about 1½–2 mm wide. By age 2½ years, the posterior

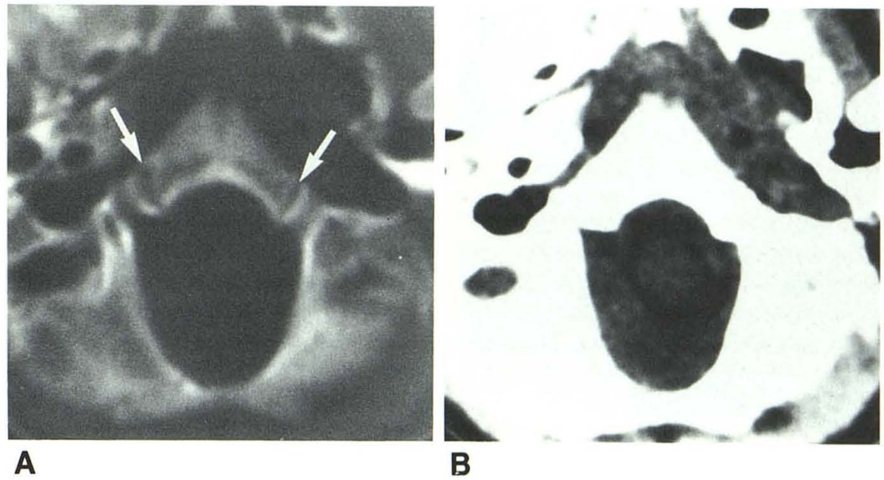


Fig. 3.—1½-year-old boy. Basiexoccipital synchondroses (*arrows*) seen on bone-window setting (*A*) are obscured on soft-tissue setting (*B*) of identical slice.

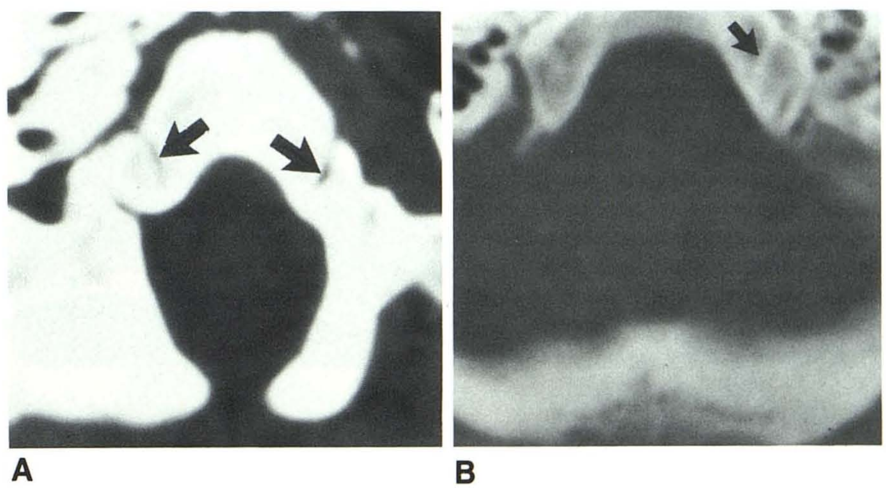


Fig. 4.—Basiexoccipital synchondrosis (*arrows*) is lucent in 4-year 9-month-old boy (*A*) and sclerotic in 16-year-old (*B*).

synchondrosis was usually 1 mm wide; at this age it was either equal to or narrower than the neurocentral synchondrosis.

The posterior synchondrosis was apparent on CT as late as age 4 years 2 months and the neurocentral synchondrosis as late as 7 years 1 month (Fig. 7). The size of the C1 arch increases relative to that of the foramen magnum with age. Before age 2 years, the posterior arch of C1 was frequently seen within the foramen magnum. This was as much as 10 mm in one patient, as measured from the inside border of the posterior arch of C1 to the inside border of the posterior foramen magnum (the distance from the inside border of the posterior arch of C1 to the cord was 6 mm).

The superior articular facet of C1 was not well seen before age 2 years on either 3- or 5-mm-thick axial slices. At the age of 2 years, the reniform shape of the C1 superior articular facet became apparent. The posterolateral margins appeared sclerotic while the medial margins were poorly defined on bone-window settings (partial-volume effect). By age 14 years the margins were well corticated.

The inferior articular facet of C1 was not well seen on axial scans before the age of 2 years. At age 2 years its configuration is oval laterally and flattened medially. The posterolateral margins are seen more sharply than the medial margins. At age 13 years uniformly corticated borders may be seen.

The tubercle for the transverse ligament begins to be seen at age 2 years as only a density change, but a contour change becomes more evident later (Fig. 7B). The anterior tubercle projecting forward from the arch of C1 (Figs. 7B and 8) becomes noticeable at age 2 years (Fig. 9A).

The foramina transversaria of C1 are usually imaged after the age of 1 year. They appear oval and apparently may be incomplete laterally. They are usually bilaterally symmetric. The apparent size is dependent on the window width and level.

C2

The lower part of the dens has two vertically oriented, rod-shaped ossification centers. With bone windows, these were appreciated as separate ossifications in three of eight patients from 1 year to 2 years 4 months old (Fig. 9A). A bilobed appearance with partial fusion was seen in four of seven patients from 3 months to 2 years 3 months old (Fig. 9B). The posterior dens cleft (Fig. 9C) was generally more promi-

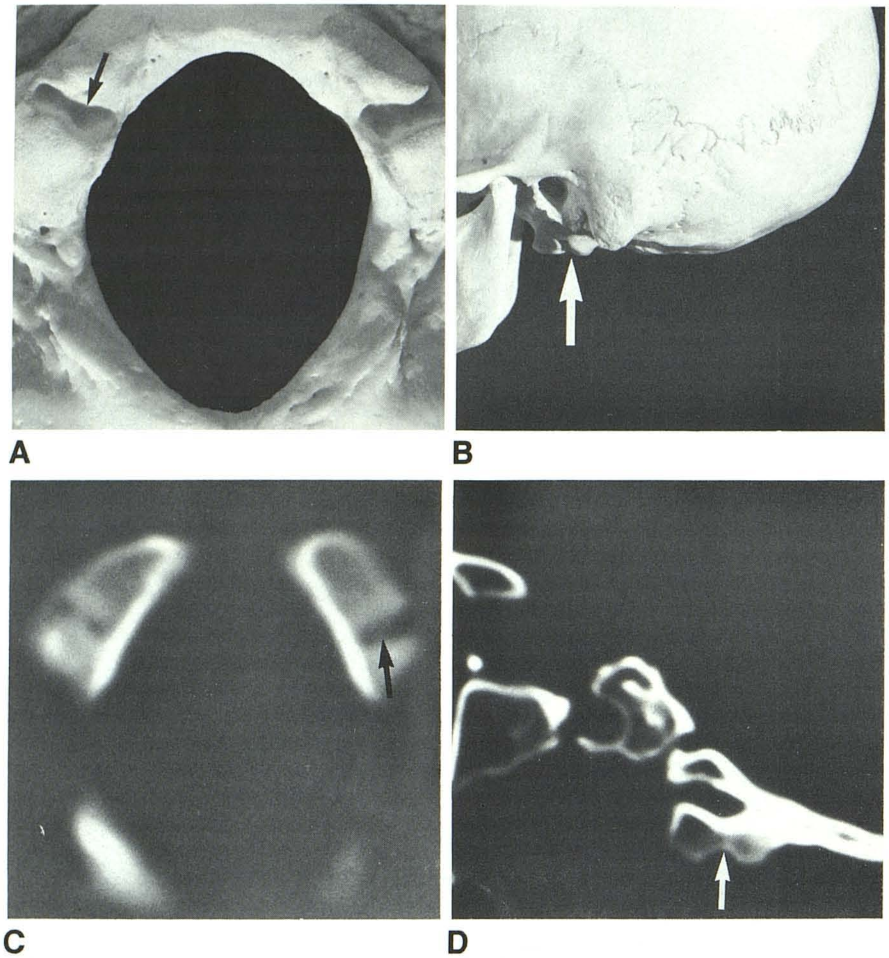


Fig. 5.—Occipital condylar groove (*arrows*).

A and *B*, Base (*A*) and lateral (*B*) photographs of dry skull specimen of child about 9 years old (age estimated by dentition).

C and *D*, Axial (*C*) and parasagittal (*D*) CT slices of skull specimen through occipital condyle distinctly showing groove just below hypoglossal canal.

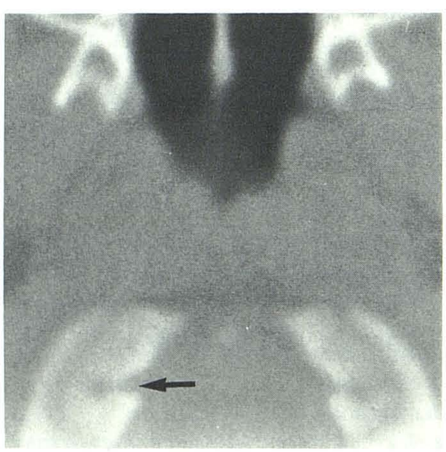


Fig. 6.—Axial slice of 7-year-old child through inferior portion of occipital condyles shows transverse occipital condylar groove bilaterally (*arrow*). Curvilinear lucency separates inferior portions of occipital condyles from superolateral articulating portions of C1 bilaterally.

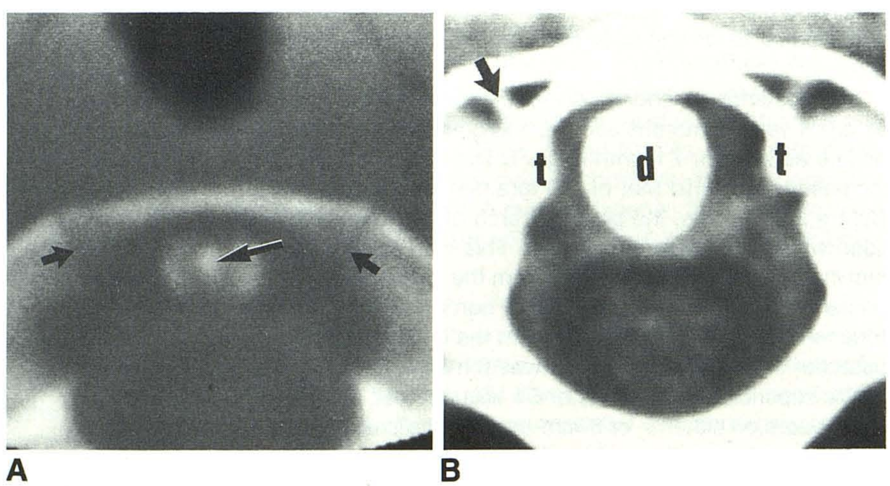


Fig. 7.—Neurocentral synchondrosis of C1 (*small arrows*), lucent at age 7 (*A*) and sclerotic at age 12 (*B*) in two different children.

A, Note sclerotic, developing summit epiphysis of dens (*large arrow*).

B, Note tubercles (t) for transverse ligament projecting medially from C1 arch just lateral to dens (d). Transverse ligament passes from one tubercle to the other running behind the dens. Anterior tubercle for anterior arch of C1 is well developed at age 12.

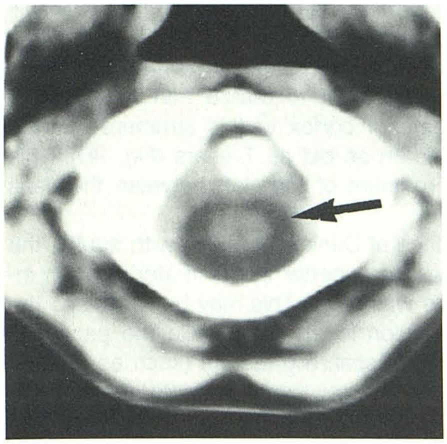
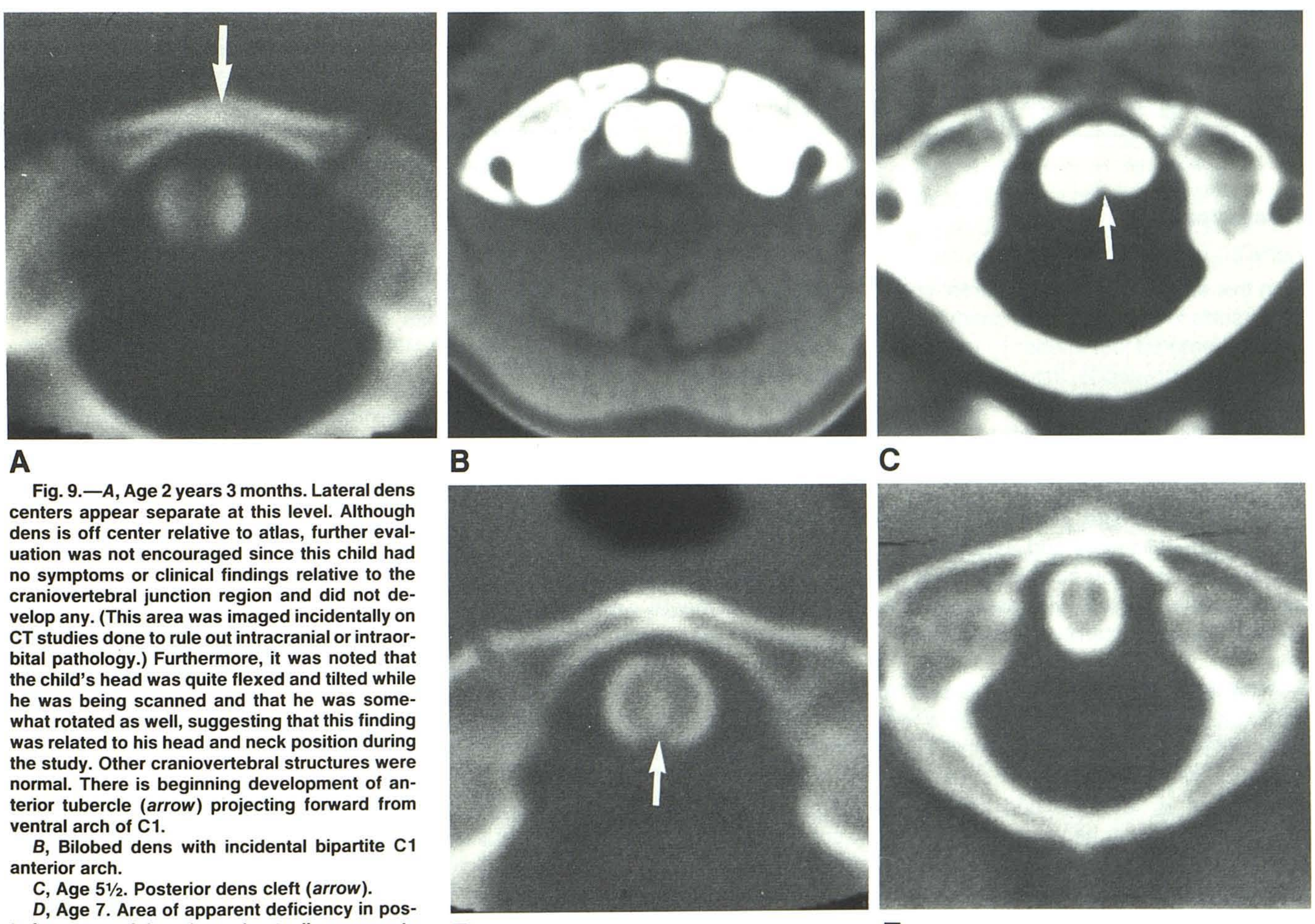


Fig. 8.—Spinal cord and surrounding subarachnoid space. This example shows how high-resolution CT can clearly delineate subarachnoid space (arrow) and spinal cord in children at C1 level without intrathecal contrast material. These structures are imaged routinely at craniovertebral level on high-resolution studies. Note also anterior tubercle projecting forward slightly from anterior arch of C1.

nent than the anterior dens cleft. An apparent deficiency of the cortex posteriorly in this area was seen as late as 7 years of age (Fig. 9D). The overall shape of the dens is oval at the base, becoming egg-shaped (wider anteriorly) near the tip in cross section. A central high density at the tip was seen in 13 of 23 patients 2–9 years old (Fig. 7A). A sclerotic line through the odontoid was seen in four of 10 patients from 12 years to 17 years 11 months old (Fig. 9E). The body of the axis has one ossification center, and there is an ossification center for each side of the arch (Fig. 2). The synchondrosis between the dens and the body is not imaged well in cross section. The synchrondrosis between the body and lateral arches was well seen and was visible bilaterally in one child as old as 15 years.

At the age of 2 years the superior articular facet of C2 becomes apparent. Its lateral margins are indistinct. Its overall shape is oval, and it is flattened medially. Its lateral margins fit within the inferior articular facet of C1. The cortical borders become more distinct with age. Indistinct anterior and posterior cortical margins may be seen from ages 6 through 15 years. A posteromedial indistinct cortical margin was seen through age 17 years.



A B C

D E

Fig. 9.—*A*, Age 2 years 3 months. Lateral dens centers appear separate at this level. Although dens is off center relative to atlas, further evaluation was not encouraged since this child had no symptoms or clinical findings relative to the craniovertebral junction region and did not develop any. (This area was imaged incidentally on CT studies done to rule out intracranial or intraorbital pathology.) Furthermore, it was noted that the child's head was quite flexed and tilted while he was being scanned and that he was somewhat rotated as well, suggesting that this finding was related to his head and neck position during the study. Other craniovertebral structures were normal. There is beginning development of anterior tubercle (*arrow*) projecting forward from ventral arch of C1.

B, Bilobed dens with incidental bipartite C1 anterior arch.

C, Age 5½. Posterior dens cleft (*arrow*).

D, Age 7. Area of apparent deficiency in posterior cortex of dens (*arrow*) actually represents last remnant of cleft between dens centers.

E, Age 17. Smooth cortex posteriorly but persistent sclerotic line at dens fusion site.

Neural Tissue

The cord or cervicomedullary junction was always seen distinctly, outlined by CSF on soft-tissue window settings at the foramen magnum (Fig. 3B) and C1 levels (Fig. 8) without intrathecal or IV contrast enhancement. The cord is round to pyriform at the foramen magnum; it is oval but ventrally flattened below. Above the level of the transverse ligament there is more CSF posterior to the cord and less anteriorly; below this there is more CSF anteriorly with the child's head and neck in a neutral position.

Ligaments

Without metrizamide the dentate ligaments could be imaged vaguely, although with metrizamide they were seen routinely. The transverse ligament could always be identified (Fig. 7B).

Vertebral Arteries

After leaving the foramen transversarium of C1, the vertebral arteries curve around the superior articular facet of C1 posteriorly. They pierce the dura laterally. After entering the subarachnoid space, they course anteromedially in the subarachnoid space. They were imaged bilaterally in the subarachnoid space in 59% ($n = 39$) of studies without contrast material and in 83% ($n = 29$) with IV enhancement. The percentage of bilateral visualization without contrast material was higher for scans obtained at greater milliampere-seconds.

Discussion

In this study, we identified a transverse furrow seen on the undersurface of the occipital condyles in children (Figs. 5 and 6). It is centered just inferior to the hypoglossal canal. To the best of our knowledge, this is the first radiographic description of this feature; however, it was described in the anthropologic literature by Redfield [9], who termed it the condylar fossa. He observed it in 6- to 12-year-old skeletons and also in a few adult skulls.

CT, with its greater sensitivity to density differences, can show residual lucency and then sclerosis at synchondroses that appear fused on plain films. Knowledge of their location can prevent confusion with fractures. Specific features of the studies on synchondroses are discussed in the Results section.

Although the arch of C1 can appear to be in the foramen magnum (while actually being below with partial-volume effect), this is a real anatomic possibility in neonates and infants, especially when the head is in extension. This was shown to be possible in neonates and infants less than 2 years old [10]. This can occur because of the relatively small size of C1 with respect to the foramen magnum at that age.

Isolated absence of ossification of the posterior arch of the atlas is usually an asymptomatic incidental finding. This is caused by incomplete development or absence of the cartilaginous component forming the posterior arch [11, 12]. This variant was well recognized before the era of CT.

The dens undergoes various changes in its CT appearance as it develops. It is important to realize that an apparent deficiency of the posterior cortex of this structure may be seen normally in children as old as 7 years (Fig. 9D). This represents the last remnant of the cleft between the dens centers.

Unlike the experience of Daniels et al. [8] with adults, the dentate ligament was seen better in our material when intrathecal metrizamide was used. This may be related to the metrizamide concentration in the CSF while the patient is being scanned, technical scanning factors (such as milliampere-seconds), and the window level and width at which the scan is viewed.

In each of our patients, subarachnoid CSF distinctly outlined the cervicomedullary junction or spinal cord at the foramen magnum and C1 levels (Figs. 3B and 8). This anatomic feature has been particularly useful in evaluating certain patients with clinical problems at the craniovertebral junction. Since it is often possible with high-resolution CT to sharply outline the subarachnoid space and cord at this level (even without contrast materials), we have been able to fully evaluate noninvasively patients with already evident bony anomalies, other osseous lesions including fractures, instability resulting from various types of pathology, and extraaxial tumors. It is beyond the scope of the present anatomic report to elaborate on this; however, the reader is referred to other material documenting our experience with standard CT and its role in such instances [3]. In any event, many cases of this sort are now being handled with MR imaging.

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