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Radiology of postnatal skeletal development

XIII. C1–C2 interrelationships

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Abstract. Composites of C1 and C2 were analyzed in various roentgenographic projections to elucidate osseous interrelationships and the effect of overlap of different portions of these two vertebrae in standard radiographic projections during differing stages of postnatal chondro-osseous transformation. In anteroposterior projections the dentocentral synchrondrosis of C2 normally was located below the inferior rim of the C1 anterior ossification center. The upper extent of the dens ossification center was behind this anterior C1 center. The overlap made visualization of the ossiculum terminale difficult. The spinous process of C1 could be confused with the ossiculum. In transverse projections, the normal laxity characteristic of young children allowed considerable variation in rotational interrelationships. Various degrees of such instability are illustrated. In lateral views variation of the anterior contour of the dens was significant. Such variation must be considered developmental due to the location and direction of growth of the chondrum terminale and interactive modeling between C1 and C2 to allow extension at this particular joint.

Key words: Atlas – Axis – Rotatory subluxation – Displacement – Predens space

The developing atlas (C1) and axis (C2) may present significant diagnostic problems prior to skeletal maturation [8, 9]. While the interrelationships of these two vertebrae are relatively easily interpreted in standard lateral projections, there is still some question regarding the normality of configurations such as the predens space [1]. The assessment of anteroposterior and oblique projections often is difficult because of superimposed craniofacial components and air shadows within the oropharynx and nasopharynx. In previous publications the specific radiographic anatomy of the atlas and axis each were presented [10, 11]. This allowed a better appreciation of the detailed radiologic anatomy of each vertebra, without superimposition of multiple osseous elements. In this study the two vertebrae have been analyzed as a conjoint unit, but without superimposed craniofacial elements. Normal radiography and developmental variation (i.e., the predens space) have been assessed. Common disorders such as subluxation and hypermobility have been duplicated with these specimens for specific radiographic analysis.

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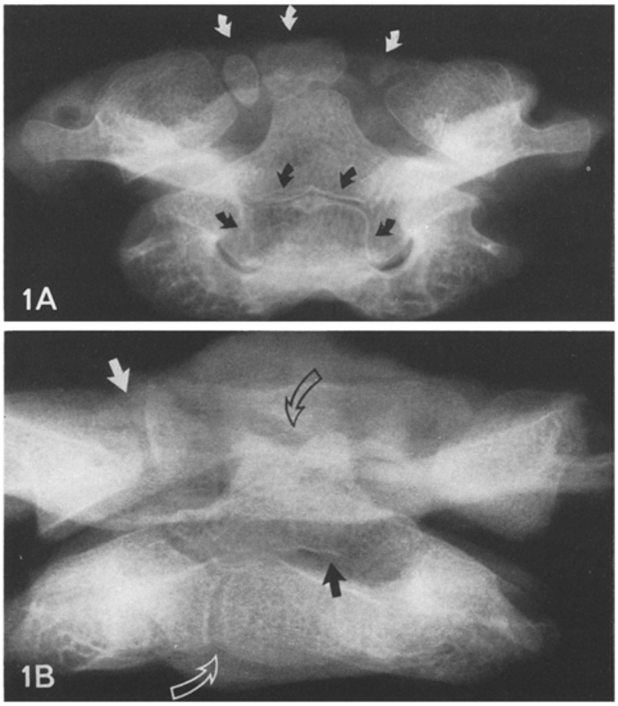
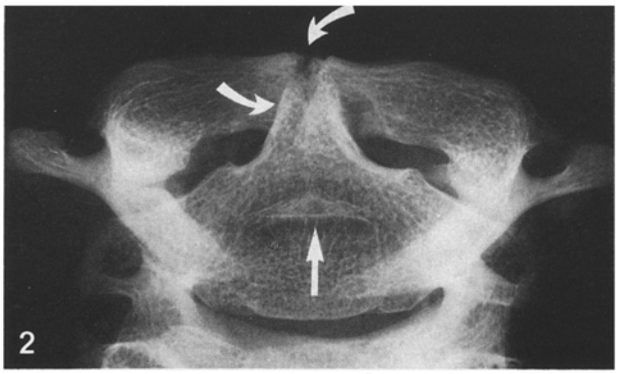
Methods and materials

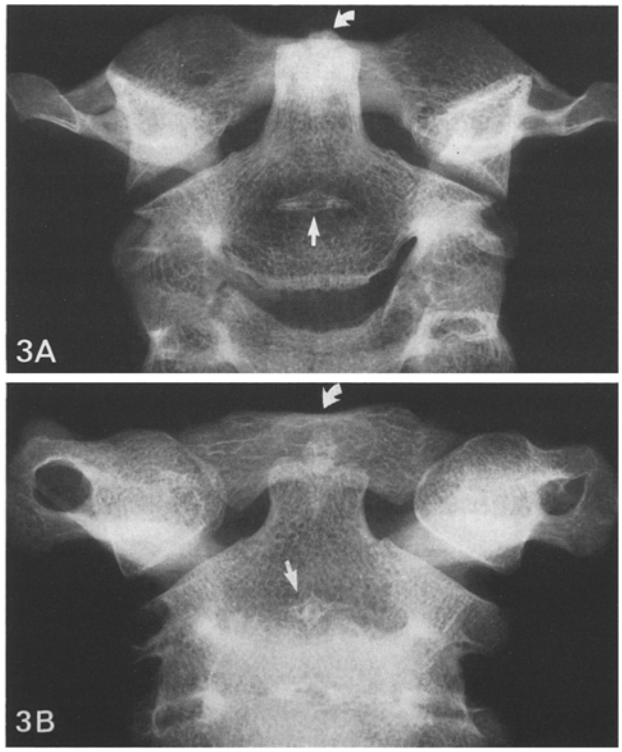
The cervical vertebrae were removed from 36 skeletally immature cadavers ranging in age from full-term neonate to 14 years. The atlas and axis (C1 and C2) usually were separated from the lower cervical vertebrae and dissected free of extraneous soft tissues (muscle, fat), while leaving ligaments intact. Each composite unit was radiographed intact in anteroposterior, oblique, and lateral projections, as well as views duplicating cross-sectional scanning [computed tomography (CT), magnetic resonance (MRI)]. Similar cross-sectional radiography then was done with the two vertebrae either displaced laterally or in maximum rotation relative to each other. In selected vertebrae the dens was removed at the facet level to duplicate a hypoplastic dens. All radiographs were done with the vertebrae placed directly on the film cassette to negate distortion or magnification. In addition the first and second cervical vertebrae from 11 commercially prepared skeletons ranging in age from approximately 3 to 14 years were similarly analyzed.

Results

Anterior projections. Without the superimposition of the cranial and facial bones, the anatomy was better evident. By four to five years of age (Fig. 1) the synchondroses were closing. The proximal ex-







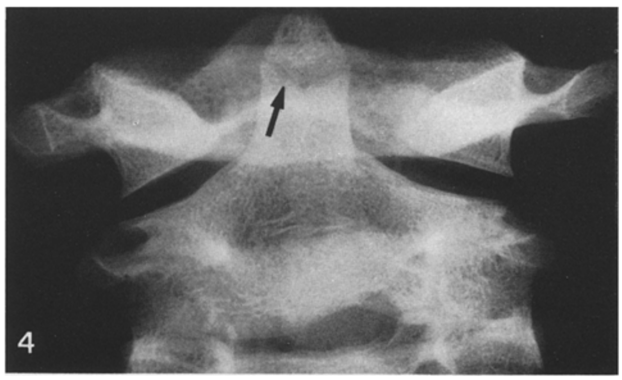


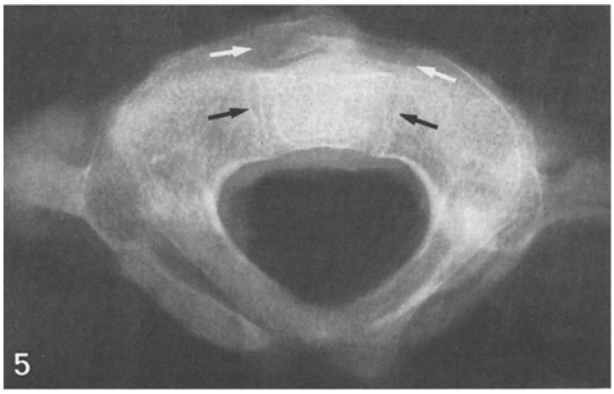
Fig. 1. **A** Anteroposterior view of C1 and C2 from a four-year-old. Note the multifocal ossification in the anterior portion of C1 (*white arrows*). The continuous dentocentral and neurocentral synchondroses (*black arrows*) are closing. **B** Anteroposterior view of C1 and C2 from a three-year-old. Note the paired neurocentral synchondroses of C1 (*solid white arrow*), juxtaposition of the inferior margin of C1 and the tip of the dens (*open black arrow*), and the neurocentral (*open white arrow*) and dentocentral (*solid black arrow*) synchondroses of C2

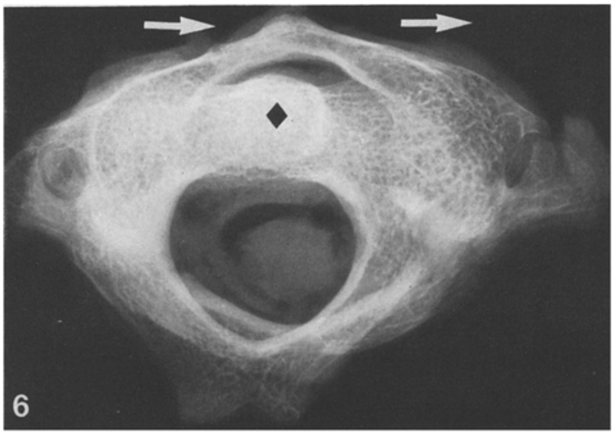
Fig. 2. Anteroposterior view of C1 and C2 from an eight-year-old. The neurocentral synchondroses are completely closed and remodeled, while the dentocentral synchondrosis is still evident (*straight arrow*). The proximal dens has a V-shaped appearance behind a bifid anterior C1 ossification center (*curved arrows*)

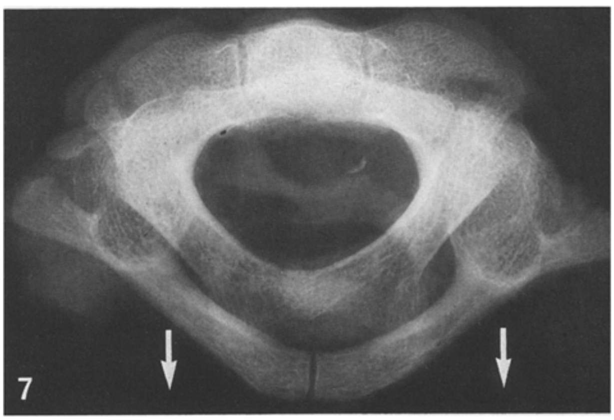
Fig. 3. Anteroposterior views of C1 and C2 from two different 11-year-old children. Note the appearance of the ossiculum terminale behind the anterior ossification center of C1 (*curved arrow*). Also note the variable appearance of the closed dentocentral synchondrosis (*straight arrow*). In **B** the second and third vertebra are congenitally fused with the interspace having a radiographic appearance similar to the dentocentral closure above it

Fig. 4. Anteroposterior view of C1 and C2 from a 14-year-old showing a well developed ossiculum terminale and physis (*arrow*) behind C1

tent of dens ossification was at the lower margin of C1 anterior ossification. Variations in anterior ossification of C1 created irregular radiodensities. Similarly, the neurocentral synchondroses of C1 and C2 and the dentocentral synchondrosis of C2 created overlapping radiolucencies. Like any other growth plate, closure of these synchondroses was preceded by formation of a sclerotic line as the subchondral bone thickened (Fig. 1A). By eight to nine years the proximal dens ossification ex-







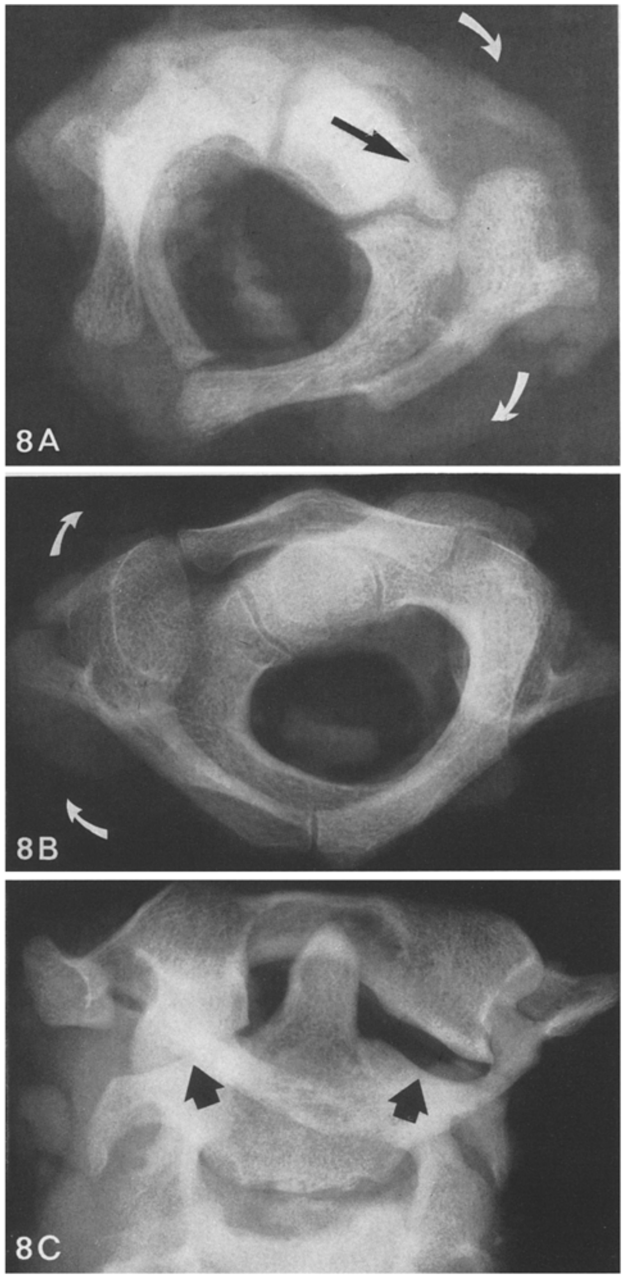


Fig. 5. Normal "CT" cross-sectional interrelationships of C1 and C2. The *arrows* indicate the contiguous neurocentral synchondroses of C1 (*white*) and C2 (*black*)

Fig. 6. Extent of pure lateral translation (*white arrows*) possible in a C1-C2 composite from a ten-year-old (– dens)

Fig. 7. Extent of pure anteroposterior displacement (*arrows*) possible between C1 and C2 in a four-year-old following removal of the proximal two-thirds of the dens to simulate a hypoplastic dens

Fig. 8. Extent of rotatory subluxation (*white arrows*) possible with ligaments still intact between C1 and C2 at two (**A**) and five (**B**) years. The *black arrows* in **A** indicates an accessory ossification center in the neurocentral synchondrosis. (**C**) Anteroposterior view of C2 showing how rotatory subluxation causes a relative shift of the dens toward the more displaced C1/C2 facet (*arrows*) making one facet joint appear overlapped and the other widened

tended further due to longitudinal growth (Fig. 2), nearing the upper rather than lower margin of anterior C1 ossification. The dentocentral synchondrosis was present as a "ghost". The contour of the proximal dens was usually chevron or V-shaped, rather than transverse. By ten to eleven-years secondary ossification was evident in the chondrum terminale behind the anterior ossifica-

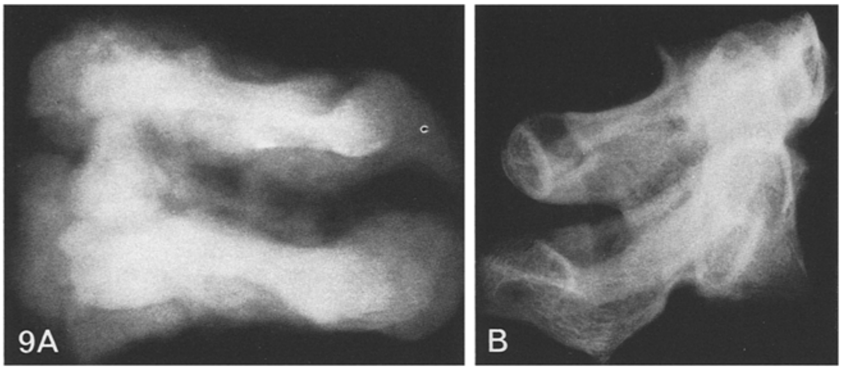


Fig. 9. A Lateral view of C1 and C2 in a three-month-old infant. There is *no* ossification in the anterior portion of C1, giving the false impression that C2 may be subluxating anteriorly. **B** Lateral view of C1 and C2 in an eight-year-old

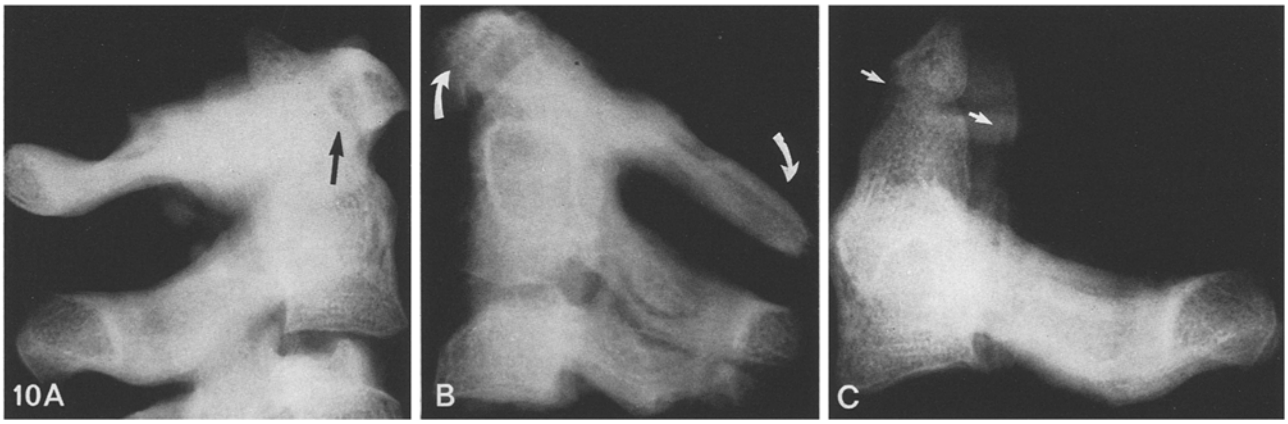


Fig. 10. A A lateral view of C1 and C2 in a ten-year-old. Note the V-shaped predens space (*arrow*). **B** In hyperextension (*arrows*) the anterior ring of C1 curves along this anterior margin of the dens, showing mobility is a factor in the development of this morphologic contour. **C** A lateral view of C2 from an 11-year-old. Note the retrograde "angulation" of the anterior surface of the dens and the ossiculum, as well as the retrograde tilt of the physis (*arrows*)

tion center of C1 and should not be misconstrued as the spinous process of C1 (Fig. 3). By adolescence, the ossiculum terminale occupied most of the cartilaginous precursor (Fig. 4). It often extended superiorly, beyond the upper margin of anterior atlas ossification with a V-shaped physis still separating this from the rest of the dens. This tended to be a late-closing physis (16 to 18 years).

In all specimens, no matter what the stage of development, the distance from the lateral margin of the ossification center of the dens to the medial margin of the ossification center of either facet joint was equal, creating an obvious symmetry. Even when C1 was rotated less than 30 degrees these distances were essentially symmetric. However, rotational changes beyond 30 degrees, and certainly those over 45 degrees were associated with not only asymmetric distances, but also completely different appearances to the facets, with one being overlapped and the other being wider than normal. Further, because of dimensional differences in the coronal and sagittal diameters of the C1/C2 articular surfaces, rotational changes also caused individual facet asymmetry, with the medial lateral ossification extent of the C1 portion being variably different from the corresponding regions of C2 (Fig. 8C). When the C1/C2 facets were anatomically normal the medial and lateral margins of ossification were essentially equal.

Transverse projections. In the routine cross-sectional relationship of C1 and C2, the shape of the spinal canal was similar, although not always with the same coronal and sagittal diameters. This sometimes resulted in the neural arches of C1 being more lateral than those of C2 (Fig. 5). The neurocentral synchondroses tended to be in a similar location and direction from the midline, causing them to overlap and create multiple, parallel radiolucencies and radiodensities. The dens (C2) was always posterior to the anterior ossification center of C1 in these projections.

At all stages of development, especially prior to 10 years of age, significant translation in several directions was possible. Lateral displacement of 5–6 mm could be demonstrated without disruption of any ligaments (Fig. 6). Such displacement did not impair the spinal canal. When the dens was transected at the level of the facet joints (below the inferior margin of C1), thus experimentally simulating a hypoplastic dens, the normal ligamentous laxity allowed significant anteroposterior translation (Fig. 7). Contingent upon the extent of anteroposterior translation, compromise of the spinal canal became increasingly evident. Without any ligamentous disruption, considerable rotational displacement could be accomplished (Fig. 8). In such instances the basic anatomic relationship of one facet tended to be intact, while displacement almost to the point of complete dislocation took place in the other facet joint.

Lateral projections. The dens was situated behind the anterior ossification center during all phases of development. However, because of the delay in appearance of the anterior ossification center in C1, lateral films of composites from children under 6 months of age showed contiguous ossification in the dens and the anterior extent of ossification of the posterior centers of C1 (Fig. 9). The dentocentral synchondrosis of C2 normally was located distal to the inferior margin of the anterior ossification center and at or below the inferior margin of the C1-C2 articulation (facet joint).

The contour of the anterior margin of the primary and secondary (ossiculum terminale) ossification centers of the dens was extremely variable. The anterior surface of the primary centers tended to be between 80 and 85 degrees compared to the axis of the subchondral end plate at the inferior margin of C2, with this causing a mild posterior "tilt" to the dens (Figs. 10 and 11); in contrast, the posterior surface of the dens was closer to 90 degrees. However, the ossiculum terminale ossified with a highly variable tilt posteriorly that always was greater than the mild posterior tilt of the primary dens center. This ossification pattern was a reflection of the already present contour in the cartilage (chondrum terminale). The posterior tilt of the ossiculum terminale, a normal developmental variation, was thus responsible for the V-shaped predens space.

When C1 was "hyperextended" it was apparent that the facets regulated an axis of motion that defined the arc of motion of the anterior portion of C1. To accommodate this motion, it was necessary for the anterior portion of the dens to curve in a pattern mirroring the pattern of C1 motion (Fig. 10).

The shape of the chondrum terminale thus comes about from (a) progressive modeling due to C1/C2 motion, especially extension and, (b) the direction of growth of the chondrum terminale physis, which allows a slightly posterior pattern of longitudinal growth. The eventual shape of the ossiculum terminale is thus modeled in the cartilaginous precursor and is not a result of direct osseous modeling.

Fig. 11. Lateral view of C2 from a 14-year-old. Note the curvilinear anterior surface as well as the posteriorly located ossiculum terminale and physis. Such an appearance of the physis indicates growth in a curvilinear, posterior direction

Discussion

The primary problems with clinical anteroposterior projections of the developing upper cervical spine relate to: (a) superimposition of craniofacial skeletal components, (b) air shadows in the nasopharynx and oropharynx, and (c) superimposition of anterior and posterior segments of C1 and C2. Even in an open mouth view C1 and C2 still overlap. The current studies have elucidated some of the developing anatomy and the radiographic appearances of the two vertebra as a composite unit.

In anteroposterior projections the most important factors to evaluate are the symmetric appearance of the C1-C2 facet joints and the central location of the dens. Prior to five years of age, the two neurocentral synchondroses of C1 should be equidistant from the dens. After closure of these structures it is best to measure from the medial margin of each C1 facet. Other important anatomic nuances include the "ghost" of the dentocentral synchondrosis and the superimposition of the spinous process (albeit small) and the ossiculum terminale. Further, the often chevron or V-shaped appearance of the cartilage between the ossiculum and the body of the dens should not be misinterpreted as a fracture of C1.

Because of the normal degrees of ligamentous laxity present in children, various patterns of displacement may occur. In flexion-extension lateral radiographs there may be 4 to 8 mm of separation between the posterior margin of C1 and the anterior margin of the dens. Congenital variation of C1 and C2 are relatively common and sometimes difficult to distinguish from trauma. Several examples are included in previous publications [10, 11], as well as this one. One of the more common lesions is hypoplasia of the dens, which may occur in many of the skeletal dysplasias as well as disorders such as Down syndrome [4, 7]. As evident in Fig. 7, the absence of significant portions of the dens will allow major anteroposterior displacement between the atlas and axis without any ligamentous disruption. This is possible because of the normal laxity present in most children and the hypermobility (hyperlaxity) often present in children with Down syndrome.

Because of difficulties visualizing this region in routine roentgenographic projections, other methods may prove more efficacious. In particular, cross-sectional scanning (CT or MRI) is an excellent way of visualizing the entire ring, and is quite helpful in determining the extent of healing on follow-up evaluation. Ossification variations and synchondroses should not be confused with traumatic disruption of the ring. It is important that the radiologist and treating physician both familiarize themselves with the radiologic variations illustrated in this and other publications [10, 11].

Several authors have analyzed the V-shaped predens space, particularly regarding its implication for the evaluation of trauma [1, 14]. They felt that the lateral radiographic appearance was due to increased flexion mobility at the atlantoaxial level with developmental elongation or laxity of the cranial end of the transverse ligament and/or the posterior ligament complex.

Our studies instead suggest that it arises as a variation in development of the chondrum and ossiculum terminale, with such a posterior tilt of the anterior surface of the upper dens being normal. The mechanism of formation of the anterior contour stems from two factors. First, the physis at the superior end of the dens has a slight to moderate retrograde tilt relative to the longitudinal axis of the dens. Accordingly, longitudinal growth will progressively tilt the chondrum terminale posteriorly. Second, the chondrum terminale is comprised of cartilage for the first five to seven years. Such material is biologically plastic and capable of altering shape over time commensurate with the degrees of extension possible during early childhood.

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