

# Craniocervical junction as a focus for craniofacial growth studies

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The craniocervical junction is a highly specialized unit simultaneously supporting head during movements in all planes and protecting the spinal cord. Anatomically, it includes an atlantoaxial complex, part of which embryonically arises from the occipital region of the skull. This review deals with the gross anatomy, kinematics, and growth reactions associated with functional alteration in this complex. Particular attention is paid to the atlas, the connecting element between the head and the vertebral column proper. From several studies it is concluded that the horizontal growth of the atlas is regulated by synchondroseal growth, whereas the vertical growth is determined by appositional growth. Some vertebral anomalies and concomitant anomalies of the cranial base are reported, to point out the ontogenetic integration between the skull base and the craniocervical junction. The high frequencies of atlantal posterior arch deficiency in cleft palate patients have led to speculations about common etiologic factors in these conditions. □ *Atlas; cranial base; head posture*

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## Anatomy and physiology of the craniocervical junction

The human craniocervical junction is composed of an occipitoatlantoaxial unit, which has developed to provide the head with its support and movements. The unique features of this complex enable simultaneous head movements in all planes. In amphibians and birds, for instance, either a flexion-extension or a rotation movement is possible (1).

The first cervical vertebra, the atlas, is a bony ring without vertebral body, spinous process, or intervertebral disk (Fig. 1). The anterior arch of the second vertebra, the axis, is an elongated process, dens axis, the rounded uppermost part of which passes through the atlas and articulates with its ventral part (Fig. 2). The atlas is connected to the cranium by ligaments and muscles running between the margins of the foramen magnum and superior surface of the atlantal arches (membrana atlantooccipitalis anterior et posterior; musculus rectus capitis anterior et lateralis). The axis is connected to the cranial base by three ligaments: the paired alar ligaments and the unpaired apical ligament.

Phylogenetically and ontogenetically, the atlas is a remnant of the occipital region of the skull, and the craniovertebral boundary can thus be considered to be located at the atlantoaxial border (2). Whereas the ossification of the vertebral bodies starts in the thoracolumbar region, the maturation of the vertebral arches follows a craniocaudal developmental gradient (3).

The atlantooccipital articulation permits mainly flexion and extension movements of the head. The maximal range of movement in the sagittal plane is about 4°

and 21°, respectively. In addition to a maximum of about 11° flexion and extension at the atlantoaxial junction, this articulation is the main site for head rotation. The full extent of axial rotatory movement is about 90°, less than half of which occurs at the atlantoaxial articulation centered on the midportion of the dens. The rest of the rotation is provided by progressive motion of the other cervical vertebrae. During atlantoaxial rotation there is a small cranioatlantal counterrotation (4, 5).

## Head posture and atlantal anatomy

On the basis of the above-described morphologic characteristics it is plausible to expect that there is a relationship between the function and morphology of the craniovertebral joint.

Growth changes in the upper cervical skeleton in relation to disturbed function of the craniovertebral joint was studied by Kylämarkula (6). Detaching the neck muscles in 56 rats at 14 days of age induced changed head posture, and after 360 days the dorsal arch of the atlas was wider craniocaudally in the operated rats than in untreated controls.

This experiment was followed by an analysis of associations between head posture and atlantal anatomy in humans (7). On the basis of natural head posture in roentgenocephalograms of 72 young adults a significant negative correlation between the craniocervical angulation and the height of the atlantal dorsal arch was found, in that the more elevated the head, the lower the dorsal arch. As there was only a slight association between head posture and atlantal length, it was sug-

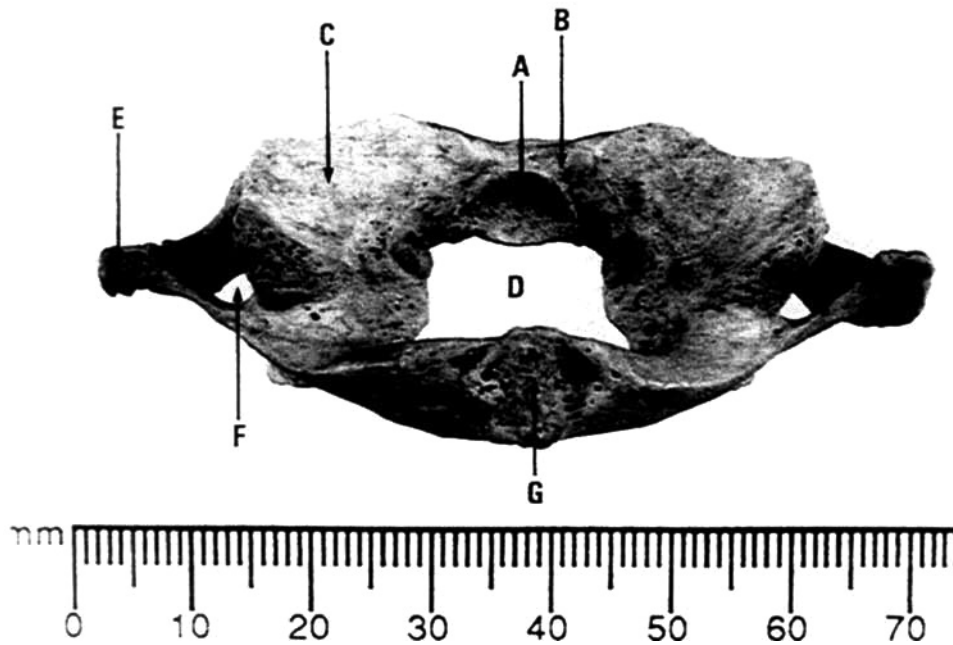


Fig. 1. Atlas in superooblique projection. A = anterior (dentoatlantal) facet; B = anterior (ventral) arch; C = superior (atlantooccipital) facet; D = vertebral foramen; E = transverse process; F = transverse foramen; G = posterior (dorsal) arch.

gested that the horizontal and the vertical growth of the atlas have different control mechanisms. The length growth takes place mainly by activity in the synchondroses interposing the bony elements of the atlas (8), whereas the vertical growth is due to bone apposition regulated by the muscles accountable for the head balance. The correlation pattern between atlantal dimensions and stature supports this conclusion too, since individual body height and appendicular long bone lengths have stronger association with atlantal length and width than with atlantal height (9; Huggare, unpublished observations).

Studies on skeletal materials have shown asymmetry of atlantal superstructures. In skeletal material from New Zealand and Thailand a right-sided dominance of the articular mass height has been observed (10). This could reflect a functional adaptation to a predominantly leftwards tilt of the head (11). Interestingly, osteoarthritic deformation of the atlantooccipital facet occurs predominantly on the left side (12).

### Associations between cervical and craniofacial morphology

Bench (13) mentioned that subjects with a dolicocephalic face often have a straight and long cervical column, whereas that of the brachycephalic patients is curved. Hirschfelder & Hirschfelder (14) were among

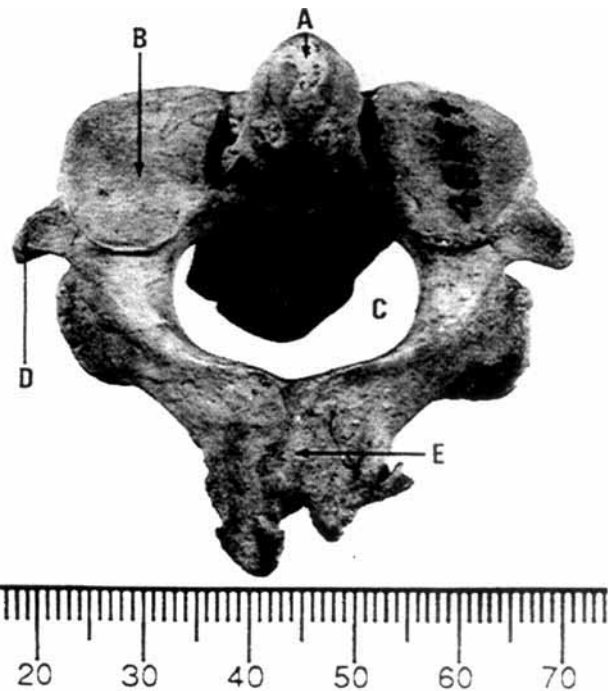


Fig. 2. Axis in superooblique projection. A = dens; B = superior (atlantoaxial) facet; C = vertebral foramen; D = transverse process; E = posterior (spinous) process.

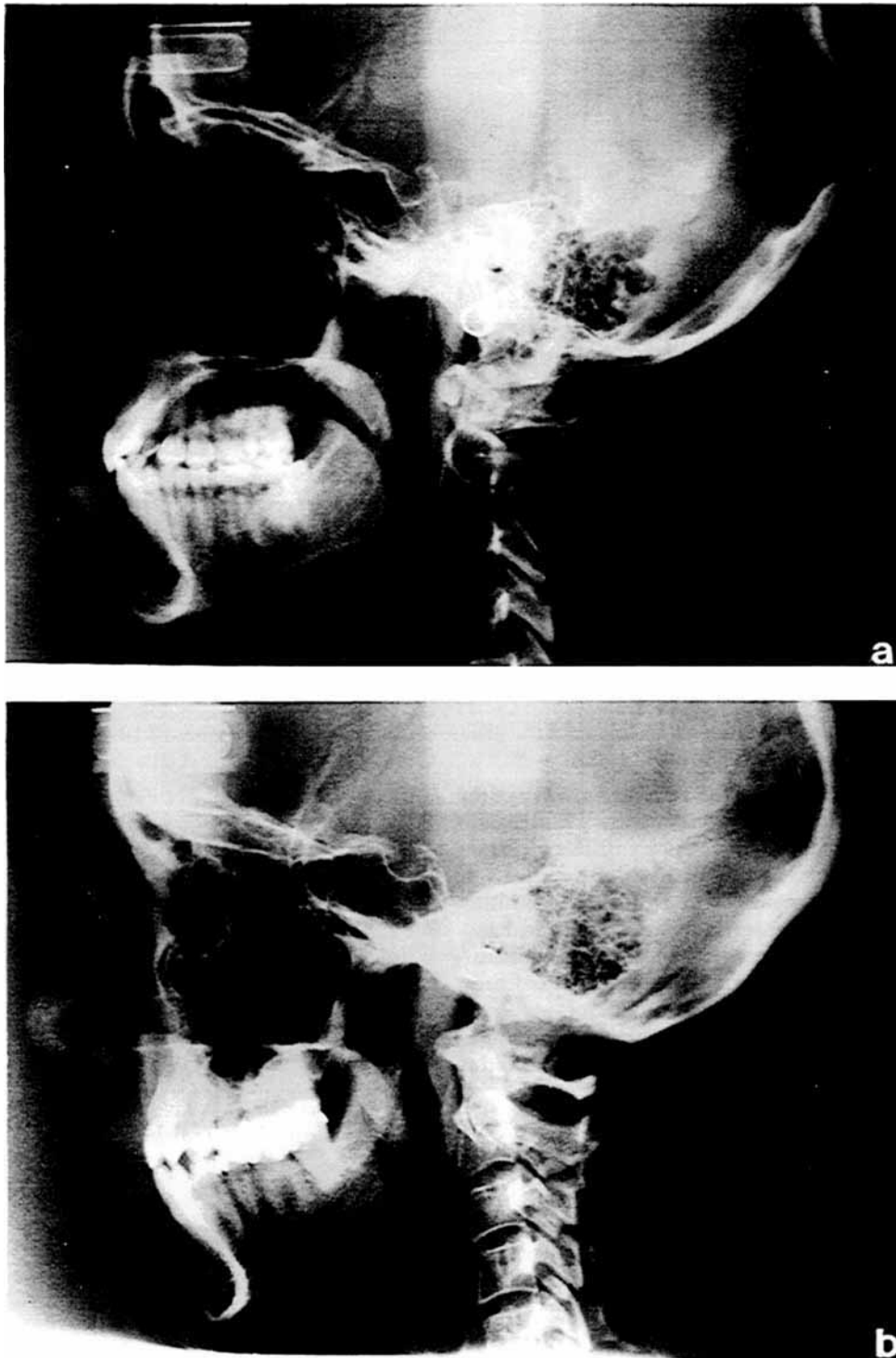


Fig. 3. Roentgenocephalograms of two women, representing the high-arch group (3a) and the low-arch group (3b). (From Huggare, *Eur J Orthodont* 1991;13:435-40, by permission of Oxford University Press).

the pioneers in studying associations between features of the atlantoaxial junction and facial morphology. They

found that hypoplasia of the atlas dorsal arch was common in progenic patients. Cephalometric radio-



Fig. 4. Roentgenocephalogram of a patient with chondrodysplasia. Note the reduced length of the atlas.

graphs of 78 adults, selected to represent extreme cases with regard to the vertical dimension of the atlantal dorsal arch, displayed that subjects with a flat dorsal arch had enlarged cranial base and gonial angles. In females, a low arch was further associated with features typical of skeletal open bite, such as an increased mandibular plane angle and a reduced lower posterior to anterior face height ratio (Fig. 3) (15). These findings have been verified in prehistoric skeletal materials and living humans from different populations (16). Noteworthy, there were no statistical associations between craniomandibular morphology and the height of the dorsal arch of the axis (Huggare and Houghton, Unpublished observations).

#### The atlas as a predictor of mandibular growth

Houston (17) suggested that the growth in the cervical spine is a primary determinant for the growth of the anterior face which contributes to the mandibular growth rotation. There are indeed reasons for assuming that the morphology of the uppermost part of the cervical spine could have significance for prediction of mandibular growth rotation. First, cervical and craniocervical posture and their growth changes are accompanied by predictable mandibular growth reactions (18, 19), and, on the other hand, the individual head posture in mature subjects is

associated with the anatomy of the atlantal dorsal arch (7). Secondly, there is a significant association between dorsal arch dimensions and posterior mandibular ramal height (Huggare and Houghton, Unpublished observations). Further, the atlas fashion is well established already at the age of 2 years (13), and its dorsal arch has greater dimensional variability than all the other cervical vertebrae (20).

Two retrospective longitudinal studies have been made to test the above assumption (21, 22). In the first one a sample of 18 Finnish children was followed from age 8 to 10 years without orthodontic treatment, and 18 more subjects were selected on the basis of mandibular growth rotation during orthodontic treatment. A significant correlation ( $r = 0.68$ ) was found between the amount of horizontal growth of the mandible and the initial height of the atlas dorsal arch. Patients with backward rotation of their mandibles during orthodontic treatment had a flat dorsal arch compared with those who expressed a forward mandibular rotation (21). In the second study, the mandibular growth direction of 36 Chinese children in Hong Kong had a similar pattern of correlation as in the Finnish children, but the correlation increased significantly to  $r > 0.70$  by combining the dorsal arch height with variables of head posture (22).

#### Craniovertebral malformations

There is a high frequency of craniovertebral anomalies

in patients with craniofacial anomalies, especially in anomalies involving the cranial base (23–25). Some of these are of special interest for illuminating the regulatory mechanisms operating on the occipitoatlantoaxial structures.

Conditions affecting cartilage growth, such as achondroplasia, are characterized by a reduction of the atlantal anteroposterior dimension, whereas the vertical dimension is fairly normal (26) (Fig. 4). On the other hand, diverging head balance is associated with the vertical growth component of the atlas. Patients treated for scoliosis and patients with craniomandibular dysfunction hold their heads slightly elevated, and they also have reduced vertical height of the atlantal dorsal arch, whereas the length of their atlas corresponds to that of healthy controls (27, 28). Adenoidal hypertrophy and cleft lip and palate impede normal nasal breathing and is a trigger for an elevated head posture. Children with adenoidal hypertrophy have in fact a small posterior atlantal arch height but a normal atlantal length (29), and atlantal posterior arch deficiency is at least seven times commoner in cleft palate patients than in healthy controls (30, 31).

The fact that atlantal posterior arch deficiency, due to incomplete midline fusion, is commoner in isolated cleft palate than in other cleft types could indicate a common mechanism involved in vertebral and palatal shelf fusion during embryonic development (32). It has also been postulated that the cellular origin of the nasal capsule and septum originates in the early embryonic sclerotomes of the upper cervical vertebrae (33). A functionally oriented explanation has also been presented. Disturbance of the cervical growth at the time of palatal shelf elevation might impair the change in head posture that has to take place to free the mandible and lower the tongue position (32).

Complete absence of the atlantal posterior arch has been found incidentally on roentgenograms (34, 35). Only one report includes a cephalometric evaluation that shows a markedly flattened cranial base and increased gonial and mandibular plane angle (36). These features represent the extreme of what is to be expected in a female with a diminutive dorsal arch (15).

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