# Cervical column morphology related to head posture, cranial base angle, and condylar malformation

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SUMMARY The present study describes the cervical column as related to head posture, cranial base, and mandibular condylar hypoplasia. Two groups were included in the study. The 'normal' sample comprised 21 subjects, 15 females aged 23–40 years (mean 29.2 years), and six males aged 25–44 years (mean 32.8 years) with neutral occlusion and normal craniofacial morphology. The condylar hypoplasia group comprised the lateral profile radiographs of 11 patients, eight females, and three males, aged 12–38 years (mean 21.6 years). For each individual, a profile radiograph was taken to perform a visual assessment of the morphology of the cervical column. For the normal group only, the profile radiographs were taken in the standardized head posture to measure the head posture and the cranial base angle.

Cervical column: Morphological deviations of the cervical column occurred significantly more often in the subjects with condylar hypoplasia compared with the normal group (P<0.05 and P<0.01, respectively). The pattern of morphological deviations was significantly more severe in the subjects with condylar hypoplasia compared with the normal group (P<0.01).

Cervical column related to head posture and cranial base: The cervicohorizontal and cranial base angles were statistically larger in females than in males (P < 0.05 and P < 0.01, respectively). No statistically significant age differences were found. Only in females was the cervical lordosis angle (OPT/CVT, P < 0.01), the inclination of the upper cervical spine (OPT/HOR, P < 0.05), and the cranial base angle (n–s–ba, P < 0.05) significantly positively correlated with fusion of the cervical column. These associations were not due to the effect of age.

### Introduction

Dimensions of the first cervical vertebra (C1), atlas, as well as the posture of the head and neck are associated with factors such as craniofacial morphology, including the cranial base (Solow and Tallgren, 1976; Opdebeek et al., 1978; Marcotte, 1981; von Treuenfels, 1981; Solow et al., 1984; Hellsing et al., 1987; Huggare, 1987, 1991; Sandikcioglu et al., 1994; Huggare and Houghton, 1996), upper airway space (Solow et al., 1984, 1996; Wenzel et al., 1985), to some extent, occlusion (Rocabado et al., 1982; Huggare, 1991; Huggare and Harkness, 1993; Solow and Sonnesen, 1998), and temporomandibular disorders (Kritsineli and Shim, 1992; Hackney et al., 1993; Watson and Trott, 1993; Lee et al., 1995; Sonnesen, 1997; Sonnesen et al., 2001; Visscher et al., 2002). Furthermore, head posture is associated with the development and function of the dentofacial structures (Solow and Siersbæk-Nielsen, 1986, 1992; Sonnesen, 1997; Sonnesen et al., 2001; Solow and Sandham, 2002). Previous research has also focused on associations between the dimensions of C1, atlas, and craniocervical posture (Huggare, 1991; Sandikcioglu et al., 1994). However, no previous studies have described associations between head posture and morphology of C1-C5 or between the cranial base and the morphology of C1C5 in adults with neutral occlusion and normal craniofacial morphology.

Morphological deviations of the upper cervical vertebrae have been investigated in relation to craniofacial aberrations and syndromes. Malformations of the upper cervical vertebrae have been described in patients with cleft lip and/ or palate (Sandham, 1986; Horswell, 1991; Ugar and Semb, 2001). The association between the cervical vertebrae and the maxilla is caused by a developmental fault of the mesenchyme (Sandham, 1986; Ugar and Semb, 2001), as the areas are dependent on the same or similar paraaxial mesoderm (Kjær *et al.*, 1994; Kjær, 1995, 1998; Sadler, 2005). While the associations are well described for the maxilla, no studies have investigated deviations of the cervical vertebrae in patients with mandibular condylar hypoplasia.

The aims of the present study were, therefore, (1) to describe the morphology of the cervical column in adult subjects with neutral occlusion and normal craniofacial morphology and in patients with mandibular condylar hypoplasia, and (2) to examine association between the various morphological characteristics of the cervical column, the cranial base angle, and the posture of the head and neck.

#### Subjects

The collection of subjects with neutral occlusion and normal craniofacial morphology was approved by the Scientific Ethical Committee for Aarhus (Ref. no. 2002 0040). The study comprised two groups.

The 'normal' group were 21 subjects (15 females and six males). The females were aged 23-40 years (mean 29.2 years) and the males 25-44 years (mean 32.8 years). The subjects were either students or staff members at the School of Dentistry, Aarhus University. The selection criteria was a neutral occlusion or minor malocclusion not requiring orthodontic treatment according to the Danish procedure for screening the population for malocclusion entailing health risks (Danish Ministry of Health, 1990; Solow, 1995). Furthermore, the sagittal and vertical jaw relationship should be within 1 standard deviation according to the standard material described by Björk (1947), assessed on lateral radiographs of each individual. None of the subjects had obstructions of the upper airways, craniofacial anomalies, or systemic muscle or joint disorders or had undergone orthodontic treatment.

The group with condylar hypoplasia was obtained from the original files of Professor Arne Björk, Department of Orthodontics, University of Copenhagen. One of these files was marked 'condylar hypoplasia' and contained lateral profile radiographs of 11 patients, eight females, and three males, age 12–38 years (mean age 21.6 years) with mandibular condylar hypoplasia.

#### Methods

#### Morphology of the cervical vertebrae

Visual assessment of the cervical column consisted of C1– C5 units that are normally seen on a standardized lateral skull radiograph. Characteristics of the cervical column were classified according to Sandham (1986) and divided into two categories as 'posterior arch deficiency' and 'fusion anomalies'. Posterior arch deficiency consisted of partial cleft and dehiscence and fusion anomalies of fusion, block fusion, and occipitalization.

#### Head posture and cranial base angle

For the normal group, the profile radiographs were obtained with the teeth in occlusion and in a standardized head posture, the mirror position, as described by Siersbæk-Nielsen and Solow (1982). The radiographs were taken at the Department of Oral Radiology, School of Dentistry, Aarhus University, Denmark, in a Bucky Conds cephalometer (Petersen and Schmidt, Copenhagen, Denmark) with a film-to-focus distance of 180 cm and a film-to-median plane distance of 10 cm. No correction was made for the constant linear enlargement of 5.6 per cent. A plumb-line was hung from the ceiling to mark the true vertical line on the radiographs. The digital radiographic system was photostimulable phosphor plate, Digora (Soredex, Helsinki, Finland), placed in a traditional cassette without an intensifying screen. The reference points were marked and digitized in PorDios for Windows, version 6 (Institute for Orthodontic Computer Science, Middelfart, Denmark; Figure 1), and 10 variables representing the craniovertical, craniocervical, and cervicohorizontal postural relationships; the curvature of the cervical column; and the cranial base angle were calculated. A list of the variables is shown in Table 1.



Figure 1 Reference points and lines measured on the cephalometric films. n–s–ba: angle between nasion, sella, and basion. NSL: nasion-sella line. NL: nasal line through sp and pm. OPT: odontoid process tangent through cv2tp and cv2tp. CVT: cervical vertebra tangent through cv4ip and cv2tg. VER and HOR: true vertical and horizontal lines.

**Table 1** Postural variables and cranial base angle in subjectswith neutral occlusion and normal craniofacial morphology.

Variable (degrees)	Females $(n = 15)$		Males $(n = 6)$		Р
	Mean	SD	Mean	SD	
Craniocervical					
NSL/OPT	96.82	7.95	100.37	5.77	NS
NSL/CVT	104.03	8.12	106.12	6.23	NS
NL/OPT	88.81	7.27	93.53	3.96	NS
NL/CVT	95.93	7.27	99.60	3.48	NS
Craniovertical					
NSL/VER	99.83	6.02	95.67	3.59	NS
NL/VER	91.69	5.08	89.28	4.57	NS
Cervicohorizontal					
OPT/HOR	92.98	5.23	85.37	4.42	**
CVT/HOR	85.77	4.36	79.82	5.23	*
Cervical curvature					
OPT/CVT	6.81	2.44	5.37	2.32	NS
Cranial base angle					
n–s–ba	132.35	4.53	127.61	2.92	*

\*P < 0.05, \*\*P < 0.01, unpaired *t*-test, NS: not significant.

For the condylar hypoplasia group, the profile radiographs were collected before 1982 and were not taken in a standardized head posture. The measurements for head posture were therefore not included in this part of the study. The profile radiographs were taken in a cephalostat with a film-to-focus distance of 180 cm and a film-to-median plane distance of 10 cm. No correction was made for the constant linear enlargement of 5.6 per cent (Björk, 1975).

#### Reliability

The reliability of the visual assessment of the morphological characteristics of the cervical vertebrae units was determined by inter-observer examinations between two authors (LS and IK). The inter-observer examinations showed 'very good' agreement ( $\kappa = 0.82$ ) as assessed by the kappa coefficient (Cohen, 1960).

The reliability of the variables describing head posture and cranial base angle was assessed by remeasurement of 20 lateral radiographs selected at random from the previously recorded radiographs. The radiographs were again digitized, and the differences between the two sets of recordings were calculated. No significant differences between the two sets of recordings were found. The method errors ranged from 0.09 to 0.69 degrees (Dahlberg, 1940) and the reliability coefficients from 0.99 to 1.00 (Houston, 1983).

#### Statistical methods

The normality of the distributions was assessed by the parameters of skewness and kurtosis and by Shapiro-Wilks W-test. The postural variables and cranial base angle were normally distributed. For the postural variables and cranial base angle, the effect of age was assessed by linear regression analysis, and for the occurrence of morphological characteristics of the cervical column by logistic regression analysis. Differences in the means of the postural variables and the cranial base between genders were assessed by unpaired t-test. Differences in the occurrence of morphological characteristics of the cervical column between genders and between the two groups were assessed by Fisher's exact test. Associations between morphology of the cervical column, head posture, and cranial base were expressed in terms of Spearman rank order correlation coefficients and tested for the possible effect of age by multiple regression analyses. The results from the tests were considered to be significant at P values below 0.05. The statistical analyses were performed using the Statistical Package for Social Sciences, version 13.00 (SPSS Inc., Chicago, Illinois, USA).

#### Results

#### Morphology of the cervical column

In the normal group, 14.3 per cent had fusion of the cervical column and 4.8 per cent both fusion and posterior arch

deficiency (Table 2). Fusion always occurred between C2 and C3 (Figure 2). No statistically significant gender differences were found in the occurrence of morphological characteristics of the cervical column (females 13.3 per cent, males 16.7 per cent).

For the condylar hypoplasia subjects, 72.7 per cent had fusion anomalies and 36.4 per cent posterior arch deficiency (Table 2). Fusion occurred between C2 and C3 (45 per cent) and between C3 and C4 (9 per cent). Occipitalization always occurred in combination with either fusion or posterior arch deficiency (36 per cent, Figure 3).

Morphological deviations of the cervical column occurred significantly more often in patients with mandibular condylar hypoplasia compared with the neutral occlusion and normal craniofacial morphology group (P < 0.05 and P < 0.01, respectively, Table 2). The morphological deviations were significantly more severe in the condylar hypoplasia subjects compared with the normal group (P < 0.01, Table 2).

**Table 2** Prevalence of morphological characteristics of cervicalcolumn in subjects with neutral occlusion and normal craniofacialmorphology and in patients with mandibular condylar hypoplasia.

Variable	Normal occlusion		Condylar hypoplasia		Р
	п	%	n	%	
Normal	18	85.7	3	27.3	**
Fusion anomalies	3	14.3	8	72.7	**
Fusion	3	14.3	6	54.5	*
Occipitalization	0	0.0	4	36.4	**
Posterior arch deficiency	1	4.8	4	36.4	*
Partial cleft	1	4.8	4	36.4	*
More than one deviation	1	4.8	6	54.5	**

\*P < 0.05, \*\*P < 0.01, Fisher's exact test.



**Figure 2** Morphological characteristics of the cervical column in subjects with neutral occlusion and normal craniofacial morphology. (1) Fusion of the second and third cervical vertebrae. (2) Partial cleft of the posterior portion of the neural arch of atlas.

# *Head posture and cranial base angle related to the cervical column*

The mean values for head posture and cranial base angles in the normal sample are shown in Table 1. The cervicohorizontal and cranial base angles were statistically larger in females than in males (P < 0.01 and P < 0.05, respectively). No statistically significant age differences were found.

For the normal females, cervical lordosis (OPT/CVT, P < 0.01) and inclination of the upper cervical spine (OPT/HOR, P < 0.05) were significantly positively correlated with fusion of the cervical column (Table 3). The cervical column was approximately 5 degrees more curved and the inclination of the upper cervical spine 8 degrees more backwards in the subjects with fusion. Furthermore, the cranial base angle was significantly positively correlated with fusion of the cervical column (Table 3). The cranial base angle was approximately 7 degrees more flexed in the subjects with fusion (Table 3). These associations were not due to the effect of age.

For the normal males no associations between fusion of the cervical column, head posture, or cranial base angle were found.



**Figure 3** Tracings of morphological deviations of the upper cervical column in patients with mandibular codylar hypoplasia. (1) Fusion. (2) Posterior arch deficiency.

**Table 3** Head posture and cranial base in females with and without fusion of the cervical column in subjects with neutral occlusion and normal craniofacial morphology.

Variable	Fusion	Mean	SD	Mean difference	Correlation
OPT/HOR	Yes	100.05	6.29	8.16*	0.55*
	No	91.89	4.36		
OPT/CVT	Yes	11.05	0.07	4.86**	0.70**
	No	6.19	1.89		
n—s—ba	Yes	138.45	3.46	7.04*	0.55*
	No	131.41	3.97		
OPT/CVT n–s–ba	Yes No Yes No	11.05 6.19 138.45 131.41	0.07 1.89 3.46 3.97	4.86** 7.04*	0.70** 0.55*

\*P < 0.05, \*\*P < 0.01, no effect of age

Even though the groups were small, they provide useful and valid information. It is not possible to extend the two samples as they are unique. The mandibular condylar hypoplasia group is an historic sample collected over a long period of time and consisted of patients with severe condylar malformations. The profile radiographs of subjects with neutral occlusion and normal craniofacial morphology and no medical indications are now difficult to obtain in Denmark because of the Danish law implemented by the national ethical committee system.

Previous studies have found an association between the morphology of C1, atlas, head posture, and the cranial base (Kylämarkula and Huggare, 1985; Huggare, 1991; Sandikcioglu *et al.*, 1994). In the present study, cervical lordosis, inclination of the upper cervical spine, and the cranial base angle in females were significantly positively correlated with fusion of the cervical column. These findings have not been reported previously.

As the head is resting on the spine, determined in prenatal life by the notochord, it may be advisable to examine more closely the early formation of the axial skeleton. The notochord develops in the human germ disc and determines the development of the cervical vertebrae, especially the vertebral bodies and also the basilar part of the occipital bone in the cranial base (Müller and O'Rahilly, 1980; Kjær et al., 1994; Kjær, 1995, 1998; Kjær and Fischer-Hansen, 1995; Kjær and Niebuhr, 1999; Sadler, 2005; Figure 4). Therefore, a deviation in the development of the notochord may influence the surrounding bone tissue in the spine as well as in the posterior part of the cranial base. The paraaxial mesoderm forming the vertebral arches and remaining parts of the occipital bone are also formed from notochordal inductions. On post-natal profile radiographs, the bone tissue formed around the notochord are the vertebral bodies and the basilar part of the occipital bone. The common origin of the spine and posterior part of the cranial base is the background for the hypothesis of associations between the cervical spine, head posture, and cranial base.

Signs of deviations in the development of the notochord could be fusion anomalies and/or posterior arch deficiency of the cervical column as seen in the present study. Fusion of C2 and C3 was associated with posture of the head and neck in terms of cervical lordosis and the inclination of the upper cervical spine. Furthermore, fusion was associated with the cranial base angle. These are observations supporting the hypothesis of associations between structures of common notochordal origin.

The jaws, including the condylar cartilage, develop from tissue that derives from the neural crest. In the first branchial arch the neural crest cells migrate from the neural crest towards the mandible, followed by the cells to the maxilla, and lastly by the cells to the nasofrontal region (Kjær, 1998). The neural crest cells express Hox genes that are



**Figure 4** Schematic drawing of the central nervous system and the surrounding axial skeleton, consisting of the spine, the basilar part of the occipital bone, the cranial part of the craniofacial skeleton, and the theca bones. N: The original location of the notochord is marked in black and extends from the coccygeal region to the sella turcica (S). (Reprinted from Kjær, 1995, with permission from Taylor & Francis A.S.)

homeobox-containing regulatory genes organized in four clusters located on different chromosomes, Hox A, -B, -C, and -D (Acampora *et al.*, 1989; Duboule and Dolle, 1989; Krumlauf, 1994; Ruddle *et al.*, 1999). How the migration of the neural crest cells are influenced by signals from the notochord is still unclear. In previous studies an association has been found between malformations of the upper cervical vertebrae and patients with cleft lip and/or palate (Sandham, 1986; Horswell, 1991; Ugar and Semb, 2001), where the migration of the neural crest cells to the maxillary area might deviate from normal. While the associations between the cervical column and the maxilla are well described, no studies have reported an association between deviations of the cervical vertebrae and the mandible.

In the present study the morphological deviations of the cervical column occurred significantly more often in patients with mandibular condylar hypoplasia compared with those with neutral occlusion and normal craniofacial morphology. One explanation for the association between the mandibular condyle and the cervical column may be signalling from the notochord to the neural crest cells determined for condylar development before the notochord is surrounded by bone tissue and disappears (Müller and O'Rahilly, 1980; Kjær *et al.*, 1994; Kjær, 1995, 1998; Kjær and Fischer-Hansen, 1995; Nolting *et al.*, 1998; Sadler, 2005). Signalling during early embryogenesis between the notochord, para-axial mesoderm, the neural tube, and the neural crest, as described above, are believed to be important for the connection between malformation of the craniofacial structures and the cervical vertebrae.

It was also found in the present study that the pattern of morphological deviations was significantly more severe in patients with mandibular condylar hypoplasia compared with subjects with neutral occlusion and normal craniofacial morphology. Experimental laboratory studies are needed to find an explanation for the different patterns in the two samples.

#### Conclusions

Morphological deviations and the patterns of such deviations of the cervical column occurred significantly more often in patients with mandibular condylar hypoplasia compared with subjects with neutral occlusion and normal craniofacial morphology. In subjects with normal condylar development, the cervicohorizontal and cranial base angles were statistically larger in females than in males. For females, cervical lordosis, inclination of the upper cervical spine, and the cranial base angle were significantly positively correlated with fusions of the cervical column. This correlation was not found in males.

The cervical column related to head posture, cranial base angle, and condylar malformation has not been described previously. It is suggested that the key to understanding the associations between apparently random structures such as the cervical column, the cranial base, head posture, and the mandibular condyle is the notochord and the common signalling from the notochord forming these craniofacial structures during early embryogenesis.

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