European Journal of Orthodontics 29 (2007) 464–470
doi:10.1093/ejo/cjm043
Advance Access publication 9 August 2007

Cervical vertebral body fusions in patients with skeletal deep bite

Liselotte Sonnesen*,** and Inger Kjær*
Department of Orthodontics, School of Dentistry, Faculty of Health Sciences, *University of Copenhagen and **University of Aarhus, Denmark

SUMMARY Cervical column morphology was examined in 41 adult patients with a skeletal deep bite, 23 females aged 22–42 years (mean 27.9) and 18 males aged 21–44 years (mean 30.8) and compared with the cervical column morphology in an adult control group consisting of 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. None of the patients or control subjects had received orthodontic treatment. For each individual, a visual assessment of the cervical column and measurements of the cranial base angle, vertical craniofacial dimensions, and morphology of the mandible were performed on a profile radiograph.

In the deep bite group, 41.5 per cent had fusion of the cervical vertebrae and 9.8 per cent posterior arch deficiency. The fusion always occurred between C2 and C3. No statistically significant gender differences were found in the occurrence of morphological characteristics of the cervical column (females 43.5 per cent, males 38.9 per cent). Morphological deviations of the cervical column occurred significantly more often in the deep bite group compared with the control group ($P < 0.05$).

Logistic regression analysis showed that the vertical jaw relationship ($P < 0.05$), overbite ($P < 0.001$), and upper incisor inclination ($P < 0.01$) were significantly correlated with fusion of the cervical vertebrae ($R^2 = 0.40$).

Introduction

Morphological deviations of the upper cervical vertebrae have been described in relation to craniofacial aberrations and syndromes (Osborne *et al.*, 1971; Vastardis and Evans, 1996). Malformations of the upper cervical vertebrae have been closely investigated in patients with cleft lip and/or palate (Ross and Lindsay, 1965; Sandham, 1986; Horswell, 1991; Hoenig and Schoener, 1992; Ugar and Semb, 2001; Rajion *et al.*, 2006). Furthermore, it has recently been shown that the abnormal morphology of the upper cervical vertebrae is associated with malformation of the condyle, in terms of mandibular condylar hypoplasia (Sonnesen *et al.*, 2007). Congenital mandibular hypoplasia is associated with syndromes of the head and neck such as Treacher Collins, Hurler, Pierre Robin, or hemifacial microsomia syndromes (Krogstad 1997; Gorlin *et al.*, 2001). The association between abnormal development of the cervical vertebrae and the maxilla and the association between abnormal development of the cervical vertebrae and the mandible might be caused by a developmental fault of the mesenchyme (Sandham, 1986; Ugar and Semb, 2001; Sonnesen *et al.*, 2007) as the areas might be dependent on the same or similar para-axial mesoderms (Kjær *et al.*, 1994; Kjær 1995, 1998; Sadler, 2005).

Recently, an association between the morphology of the cervical column and the posture of the head and neck has been demonstrated (Sonnesen *et al.*, 2007). It has previously been shown that posture of the head and neck is associated with craniofacial morphology (Solow and Tallgren, 1976; Opdebeek *et al.*, 1978; Marcotte, 1981; Von Treuenfels, 1981; Solow *et al.*, 1984; Kylämarkula and Huggare, 1985; Hellsing *et al.*, 1987; Huggare, 1987, 1991; Sandikcioglu *et al*, 1994; Sonnesen *et al.*, 2001). As the morphology of the cervical column is associated with head posture and head posture is associated with craniofacial morphology, including the rotation pattern of the mandible (Solow and Siersbæk-Nielsen, 1986, 1992), it could be hypothesized that there is an association between the morphology of the cervical column and the vertical dimensions of the face.

The aims of the present study were, therefore: (1) to describe the morphology of the cervical column in adult patients with a skeletal deep bite; (2) to compare the morphology of the cervical column in a group of adult patients with skeletal deep bite (deep bite group) with subjects with a neutral occlusion and normal craniofacial morphology (control group); and (3) to analyse the associations between the morphology of the cervical column and cranial base angle, vertical craniofacial dimensions and morphology of the mandible for the total group (deep bite and control).

Subjects

The deep bite group consisted of 41 patients, 23 females aged 22–42 years (mean 27.9) and 18 males aged 21–44 years (mean 30.8). The inclusion criteria for the deep bite group were: (1) adult patients between 20 and 45 years of age; (2) no history of orthodontic treatment during childhood; (3) skeletal deep bite [the vertical jaw relationship smaller than 1 standard deviation (SD) according to the standard material described by Björk (1947), assessed on lateral radiographs of each individual]; (4) at least 24 permanent teeth present; (5) no craniofacial anomalies or systemic muscle or joint disorders; and (6) accessibility of a profile radiograph before orthodontic treatment with the five first cervical vertebral units visible. Twenty-two patients of the total number of patients who applied for orthodontic treatment in the period from March 2002 to December 2003 at the Department of Orthodontics, School of Dentistry, Aarhus University, Denmark, fulfilled the six inclusion criteria. Furthermore, 19 profile radiographs were systematically selected according to the above mentioned inclusion criteria from 378 patients registered in the orthodontic surgical patient archive since 1975 at the Department of Orthodontics, University of Copenhagen.

The control group consisted of 21 subjects, 15 females aged 23–40 years (mean 29.2) and six males aged 25–44 years (mean 32.8). The subjects were either students or staff members at the Dental School, Aarhus University. The selection criteria were: (1) 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); (2) no previous history of orthodontic treatment; (3) sagittal and vertical jaw relationship within 1 SD according to the standard material described by Björk (1947), assessed on lateral radiographs of each individual; (4) at least 24 permanent teeth present; (5) no craniofacial anomalies or systemic muscle or joint disorders; and (6) accessibility of a profile radiograph with the five first cervical vertebrae units visible. The control group has been described in detail previously (Sonnesen *et al.*, 2007).

Methods

Visual assessment of the cervical column morphology on lateral profile radiographs and measurements of the cranial base angle, vertical craniofacial dimensions, and morphology of the mandible on profile radiographs were performed by one of the authors (LS).

Morphology of the cervical vertebrae

The visual assessment of the cervical column consisted of the first five cervical vertebral 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: 'posterior arch deficiency' and 'fusion anomalies'. Posterior arch deficiency consisted of partial cleft and dehiscence. Fusion anomalies consisted of fusion, block fusion, and occipitalization. While assessing the cervical column morphology, the craniofacial structures were covered with a non-transparent paper, ensuring that the author remained blind to the group type (deep bite or control). Only anomalies that were verified on the later profile radiographs were registered as anomalies of the cervical column.

Cranial base and vertical craniofacial dimensions

For the control group and the 22 patients in the deep bite group, the profile radiographs were taken with the teeth in occlusion and in a standardized head position, the mirror position, as described by Siersbæk-Nielsen and Solow (1982). The radiographs were taken at the Department of Oral Radiology, Dental School, Aarhus University, Denmark, in a Hofman Selectomat 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 used a 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). Nine variables representing the cranial base angle, vertical craniofacial dimensions, the morphology

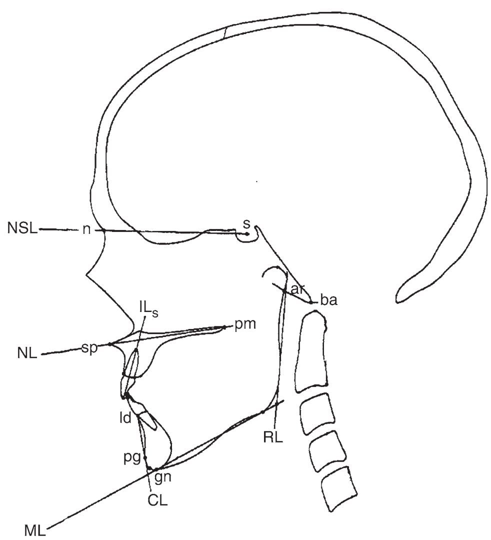

Figure 1 Reference points and lines used according to Solow and Tallgren (1976): CL: chin line, the tangent to the chin through id; ILs: upper incisor line, the axis of the upper central incisor; ML: mandibular line, the tangent to the lower border of the mandible through gn; NL, nasal line, the line through sp and pm; NSL, nasion-sella line, the line through n and s; RL: ramus line, the tangent to the posterior border of the mandible; id: infradentale, the most antero-superior point on the lower alveolar margin; gn: gnathion, the most inferior point on the mandibular symphysis; sp: spinal point, the apex of the anterior nasal spine; pm: pterygomaxillare, the intersection between the nasal floor and the posterior contour of the maxilla; n: nasion, the most anterior point of the frontonasal suture; s: sella, the centre of the sella turcica, the upper limit of the sella turcica is defined as the line joining the tuberculum and the dorsum sellae; ba: basion, the most postero-inferior point on the clivus.

of the mandible, and the inclination of the upper incisors to distinguish between an Angle Class II division 1 or 2 malocclusion were calculated.

For the remaining 19 patients included in the deep bite group, 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).

The mean values for the vertical craniofacial dimensions, the mandibular morphology and cranial base angle are shown in Table 1. The vertical jaw relationship (NL/ML), the mandibular inclination (NSL/ML), the jaw angle, and the overbite were statistically smaller in the deep bite group than in the control group ($P < 0.001$), whereas the beta angle was larger in the deep bite group ($P < 0.001$). Maxillary ($P < 0.05$) and mandibulary ($P < 0.01$) inclination and the jaw ($P < 0.05$) and cranial base ($P < 0.05$) angles were statistically significantly larger in females than in males, while the beta angle ($P < 0.001$) was statistically significantly smaller in females. No statistical age differences were found.

Reliability

The reliability of the visual assessment of the morphological characteristics of the cervical vertebrae units was determined by inter-observer examinations between the authors. 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 the cranial base and vertical craniofacial dimensions was assessed by remeasurement of 20 lateral radiographs selected at random from the previously recorded radiographs. The radiographs were digitized again after 2 weeks, 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 cephalometric measurements were normally distributed. For the cranial base angle and the vertical craniofacial dimensions, 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 cranial base and the vertical craniofacial dimensions between genders and between groups were assessed by unpaired t-test. Differences in occurrence of morphological characteristics of the cervical column between genders and between the groups were assessed by Fisher's exact test. Associations between the morphology of the cervical column, cranial base, and vertical craniofacial dimensions were expressed in terms of Spearman rank order correlation coefficients and tested for the possible effect of age and gender by multiple logistic regression analyses. A multiple logistic regression analysis, with stepwise backward elimination, was performed to determine the relationship between the morphology of the cervical column as the dependent variable and the variables that were significantly correlated with the morphology of the cervical column as independent variables.

For the logistic regression analysis, the significance of the results depends not only on the sample size but also on the prevalence of the dependent variable. Therefore, in the present study only morphological deviations of the cervical

Table 1 Craniofacial dimensions in the skeletal deep bite group and in the control group. Group and gender differences.

Variable (degrees)	Deep bite ($n=41$)		Controls ($n=21$)		Group	Sex
	Mean	SD	Mean	SD	P	P
Vertical dimensions					Unpaired t-test	
NL/ML	13.8	4.0	22.3	3.1	***	NS
NSL/NL	7.5	3.2	7.4	3.0	NS	*
NSL/ML	21.3	4.9	29.7	4.8	***	**
Cranial base angle						
n-s-ba	131.6	3.8	130.9	4.6	NS	*
Mandibular form						
Beta angle	25.8	2.3	22.5	2.5	***	***[a]
Jaw angle	112.6	5.1	120.4	5.4	***	*
CL/ML	69.5	7.4	72.4	5.2	NS	NS
Incisor relations						
lls-nl	106.3	14.5	109.7	6.1	NS	NS
Overbite (mm)	7.4	1.8	2.3	0.9	***	NS

***$P < 0.001$.
NS, not significant.
*$P < 0.05$, females larger than males; **$P < 0.01$, females larger than males; ***[a]$P < 0.001$, females smaller than males.

column that occurred in more than 15 subjects were analysed. The multiple correlation coefficient (R^2) in the logistic regression analysis was calculated according to Nagelkerke (1991). 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 skeletal deep bite group, 41.5 per cent had fusion of the cervical column and 9.8 per cent posterior arch deficiency (Table 2, Figure 2). The fusion always occurred between C2 and C3. No statistical gender differences were found in the occurrence of morphological characteristics of the cervical column (females 43.5 per cent, males 38.9 per cent).

In the control group, 14.3 per cent fusion of the cervical column, and 4.8 per cent both fusion and posterior arch deficiency (Table 2). The fusion always occurred between C2 and C3. No statistical gender differences were found in the occurrence of morphological characteristics of the cervical column (females 13.3 per cent, males 16.7 per cent).

Comparison of the deep bite group with the control group showed that the morphological deviations of the cervical column occurred significantly more often in the deep bite group ($P < 0.05$, Table 2).

Vertical craniofacial dimensions related to the cervical column morphology

For the total group, correlation analysis showed that the vertical jaw relationship and the vertical overbite were significantly positively correlated with fusion of the cervical column, while upper incisor inclination was significantly negatively correlated with fusion. Furthermore, the vertical jaw relationship, jaw angle, upper incisor inclination, and lower alveolar prognathism were significantly negatively correlated with posterior arch deficiency. These associations were not due to age or gender. The significant Spearman correlation coefficients were low to moderate, numerical values ranging from 0.25 to 0.45 (Table 3). Logistic regression analysis showed that the vertical jaw relationship ($P < 0.05$), overbite ($P < 0.001$) and upper incisor inclination ($P < 0.01$) remained significantly correlated with fusion of the cervical column ($R^2 = 0.40$). Logistic regression analysis of the posterior arch deficiency was not included in the analyses because of the low prevalence.

Table 2 Prevalence of morphological characteristics of cervical column in patients with skeletal deep bite (deep bite group) and in subjects with neutral occlusion and normal craniofacial morphology (control group).

Variable	Deep bite group		Control group		Fisher's exact test
	n	%	*n*	%	*P*
Normal	24	58.5	18	85.7	*
Fusion anomalies	17	41.5	3	14.3	*
Posterior arch deficiency	4	9.8	1	4.8	NS
More than one deviation	4	9.8	1	4.8	NS

*$P < 0.05$.
NS, not significant.

Discussion

Morphology of the cervical column

The prevalence of deviations in the morphology of the cervical vertebrae in patients with a skeletal deep bite was high compared with the control group. The pattern of cervical column morphology in the present study was in accordance with the pattern seen in subjects with neutral occlusion and normal craniofacial morphology, where the fusion always occurred between C2 and C3 and, on a limited number of occasions, in combination with posterior arch deficiency (Sonnesen *et al.*, 2007). Compared with a pathological sample of patients with mandibular condylar hypoplasia (Sonnesen *et al.*, 2007) the prevalence of morphological deviations of the cervical column in the present study was relatively low, and the pattern of morphological deviations of the cervical column deviated from the pattern seen in patients with mandibular condylar hypoplasia (Sonnesen *et al.*, 2007). In these patients, fusion also occurred between C3 and C4 in 9 per cent, and occipitalization was seen. The explanation for these different patterns of morphological deviations of the cervical column is still not known.

Vertical craniofacial dimensions

The differences between the vertical craniofacial morphological dimensions in the two groups were expected because of the selection criteria in the present study.

The sexual dimorphism found in the present investigation was contrary to previous studies, where no statistical gender differences between cephalometric angular measurements were found (Ursi *et al.*, 1993; Thilander *et al.*, 2005).

The pattern of the sexual dimorphism, however, is in accordance with previous growth studies (Björk, 1947, 1975; Solow, 1980). In the present research, the cranial base angle was larger in females, and, corresponding to the large cranial base angle, the maxillary and mandibular inclination and the jaw angle were also larger and the beta angle was smaller. Björk (1975) suggested that a large cranial base angle in adulthood was associated with a 'long face' craniofacial morphology.

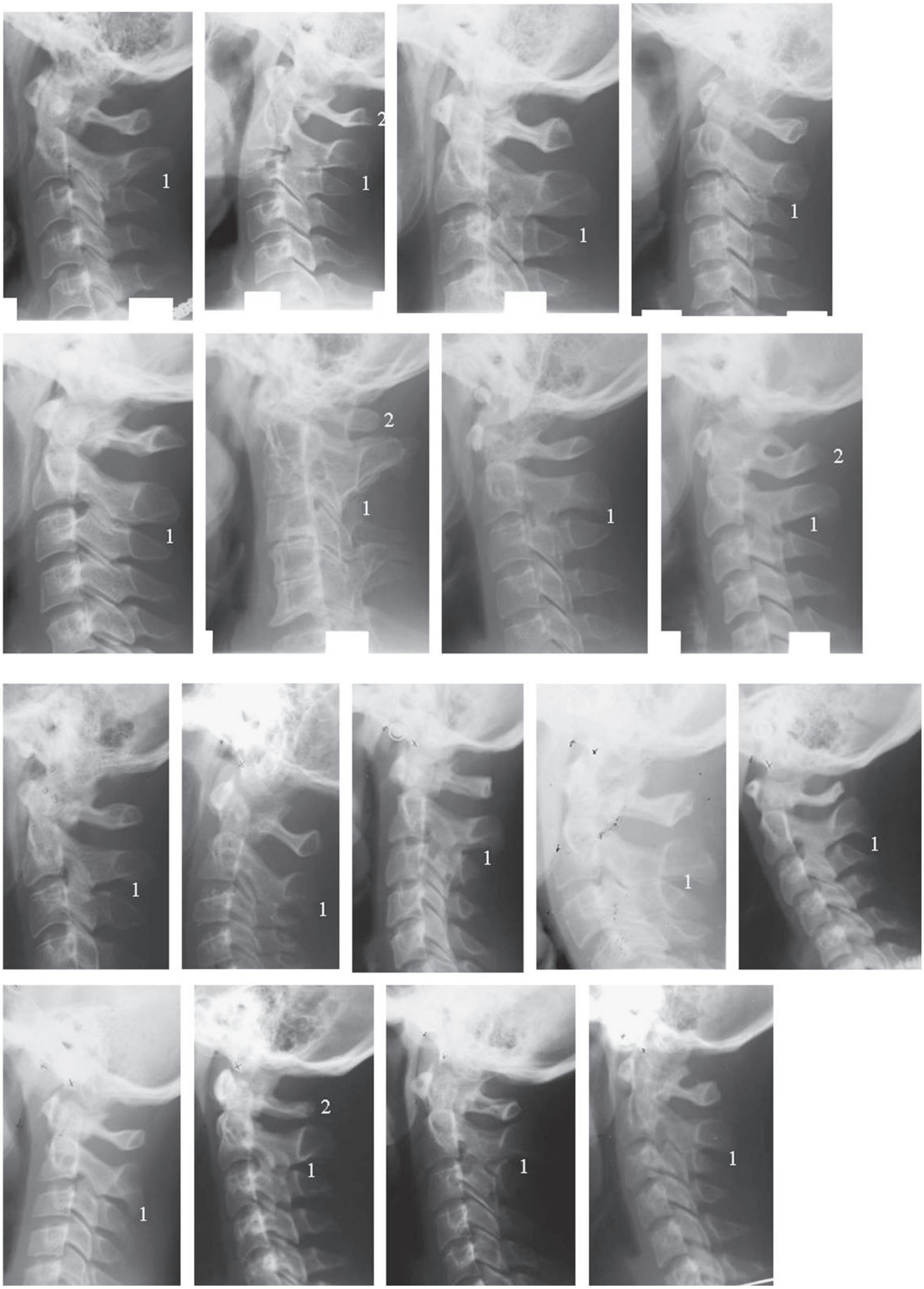

Figure 2 Morphological characteristics of the cervical column in patients with a skeletal deep bite. 1: Fusion of the second and third cervical vertebrae (fusion anomalies). 2: Partial cleft of the posterior portion of the neural arch of atlas (posterior arch deficiency).

Table 3 Significant correlations (Spearman) between morphology of the cervical column and vertical jaw relationship (ML/ML), jaw angle, overbite, upper incisor inclination (lls-nl), and lower alveolar prognathism (CL/ML) in the total group (n = 62).

	Fusion	Posterior arch deficiency	More than one deviation
ML/NL	−0.33**	−0.25*	−0.25*
Jaw angle	NS	−0.28*	−0.28*
Overbite	+0.45**	NS	NS
lls-nl	−0.37**	−0.33**	−0.33**
CL/ML	NS	−0.29*	−0.29*

*P < 0.05; **P < 0.01.
NS, not significant.

Associations

Previously, an association has been shown between malformations of the upper cervical vertebrae and malformations of the maxilla (Sandham, 1986; Horswell, 1991; Ugar and Semb, 2001) and also recently with the condyle (Sonnesen *et al.*, 2007). Furthermore, in the present study an association has been shown between morphological deviations of the upper cervical vertebrae and a deep bite, as well as vertical craniofacial morphology. This indicates that the morphological deviations of the upper cervical vertebrae are associated not only with malformation of the jaws but also with craniofacial morphology and occlusion.

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 homeobox-containing regulatory genes organized in four clusters located on different chromosomes, HoxA, -B, -C, and -D (Acampora *et al.*, 1989; Doboule and Dolle, 1989; Krumlauf, 1994; Ruddle *et al.*, 1999). How the migration of neural crest cells is influenced by signals from the notochord is still unclear.

An explanation for the association found in the present study between the cervical column, deep bite, and vertical craniofacial morphology may be found in the signalling from the notochord to the neural crest cells determined for the craniofacial morphology 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 may explain the association between malformation of the craniofacial structures and the cervical vertebrae.

Conclusions

In the deep bite group, 41.5 per cent had fusion of the cervical column and 9.8 per cent posterior arch deficiency. The fusion always occurred between C2 and C3. Morphological deviations of the cervical column occurred significantly more often in the deep bite group compared with the control group. Furthermore, logistic regression analysis showed that the vertical jaw relationship, overbite, and upper incisor inclination were significantly correlated with fusion of the cervical column (R^2 = 0.40).

The results indicate that the morphological deviations of the upper cervical vertebrae are associated not only with malformation of the jaws but also with craniofacial morphology and occlusion.

Address for correspondence

Liselotte Sonnesen
Department of Orthodontics
School of Dentistry
20 Nørre Allé
DK-2200 Copenhagen N
Denmark
E-mail: lls@odont.ku.dk

Acknowledgements

We extend sincere thanks to the students and staff members at the Dental School, Aarhus University, Denmark, and to Jan Hesselberg Madsen, specialist in orthodontics, co-ordinator of the treatment of orthodontic surgical patients at the Department of Orthodontics, University of Copenhagen.

References

Acampora D 1989 The human HOX gene family. Nucleic Acids Research 17: 10385–10402

Björk A 1947 The face in profile. Svensk Tandläkebladet 40: (Supplement) 5B

Björk A 1975 Kæbernes relation til det øvrige kranium. Nordisk Lärobok i Ortodonti, Sveriges Tandläkarförbunds, Förlagsförening

Cohen J 1960 A coefficient of agreement for nominal scales. Educational and Psychological Measurement 20: 37–46

Dahlberg G 1940 Statistical methods for medical and biological students. Interscience Publications, New York

Danish Ministry of Health 1990 Bekendtgørelse om kommunal tandpleje (Order No. 338) Schultz Grafisk A/S, Copenhagen

Doboule D, Dolle P 1989 The structural and functional organization of the murine HOX gene family resembles that of *Drosophila* homeotic genes. European Molecular Biology Association 8: 1497–1505

Gorlin R J, Cohen M M, Hennekam R M 2001 Syndrome of the head and neck, 4th edn. Oxford University Press, Oxford

Hellsing E, McWilliam J, Reigo T, Spangfort E 1987 The relation between craniofacial morphology, head posture and spinal curvature in 8, 11 and 14-year-old children. European Journal of Orthodontics 9: 254–264

Hoenig J F, Schoener W F 1992 Radiological survey of the cervical spine in cleft lip and palate. Dentomaxillofacial Radiology 21: 36–39

Horswell B B 1991 The incidence and relationship of cervical spine anomalies in patients with cleft lip and/or palate. Journal of Oral and Maxillofacial Surgery 49: 693–697

Houston W J B 1983 The analysis of errors in orthodontic measurements. American Journal of Orthodontics 83: 382–390

Huggare J 1987 A cross-sectional study of head posture and craniofacial growth in children from the north of Finland. Proceedings of the Finnish Dental Society 83: 5–15

Huggare J 1991 Association between morphology of the first cervical vertebra, head posture, and craniofacial structures. European Journal of Orthodontics 13: 435–440

Kjær I 1995 Human prenatal craniofacial development related to brain development under normal and pathologic conditions. Acta Odontologica Scandinavica 53: 135–143

Kjær I 1998 Neuro-osteology. Critical Reviews in Oral Biology Medicine 9: 224–244

Kjær I, Fischer Hansen B 1995 The adenohypophysis and the cranial base in early human development. Journal of Craniofacial Genetics Deviation Biology 15: 157–161

Kjær I, Keeling J W, Græm N 1994 Midline maxillofacial skeleton in human anencephalic fetuses. Cleft Palate-Craniofacial Journal 31: 250–256

Krogstad O 1997 Aplasia of the mandibular condyle. European Journal of Orthodontics 19: 483–489

Krumlauf R 1994 Hox genes in vertebrate development. Cell 78: 191–201

Kylämarkula S, Huggare J 1985 Head posture and the morphology of the first cervical vertebra. European Journal of Orthodontics 7: 151–156

Marcotte M R 1981 Head posture and dentofacial proportions. Angle Orthodontist 51: 208–213

Müller F, O'Rahilly R 1980 The early development of the nervous system in staged insectivore and primate embryos. Journal of Comparative Neurology 193: 741–751

Nagelkerke N J D 1991 A note on a general definition of the coefficient of determination. Biometrika 78: 691–692

Nolting D, Fischer Hansen B, Keeling K, Kjær I 1998 Prenatal development of the normal human vertebral corpora in different segments of the spine. Spine 23: 2265–2271

Opdebeek H, Bell W H, Eisenfeld J, Mishelevich D 1978 Comparative study between the SFS and LFS rotation as a possible morphogenetic mechanism. American Journal of Orthodontics 74: 509–521

Osborne G S, Pruzansky S, Koepp-Baker H 1971 Upper cervical spine anomalies and osseous nasopharyngeal depth. Journal of Speech and Hearing Research 14: 14–22

Rajion ZA 2006 A three-dimensional computed tomographic analysis of the cervical spine in unoperated infants with cleft lip and palate. Cleft Palate-Craniofacial Journal 43: 513–518

Ross R B, Lindsay W K 1965 The cervical vertebrae as a factor in etiology of cleft palate. Cleft Palate Journal 36: 273–281

Ruddle F H 1999 Evolution of chordate hox gene clusters. Annals of the New York Academy of Sciences 870: 238–248

Sadler T W 2005 Embryology of the neural tube development. American Journal of Medical Genetics 135C: 2–8

Sandham A 1986 Cervical vertebral anomalies in cleft lip and palate. Cleft Palate Journal 23: 206–214

Sandikcioglu M, Skov S, Solow B 1994 Atlas morphology in relation to craniofacial morphology and head posture. European Journal of Orthodontics 16: 96–103

Siersbæk-Nielsen S, Solow B 1982 Intra- and interexaminer variability in head posture recorded by dental auxiliaries. American Journal of Orthodontics 82: 50–57

Solow B 1980 The dentoalveolar compensatory mechanism: background and clinical implications. British Journal of Orthodontics 7: 145–161

Solow B 1995 Guest editorial: orthodontic screening and third party financing. European Journal of Orthodontics 17: 79–83

Solow B, Siersbæk-Nielsen S 1986 Growth changes in head posture related to craniofacial development. American Journal of Orthodontics 89: 132–140

Solow B, Siersbæk-Nielsen S 1992 Cervical and craniofacial posture as predictors of craniofacial growth. American Journal of Orthodontics and Dentofacial Orthopedics 101: 449–458

Solow B, Siersbæk-Nielsen S, Greve E 1984 Airway adequacy, head posture, and craniofacial morphology. American Journal of Orthodontics 86: 214–223

Solow B, Tallgren 1976 Head posture and craniofacial morphology. American Journal of Physical Anthropology 44: 417–435

Sonnesen L, Bakke M, Solow B 2001 Temporomandibular disorders in relation to craniofacial dimensions, head posture and bite force in children selected for orthodontic treatment. European Journal of Orthodontics 23: 179–192

Sonnesen L, Pedersen C, Kjær I 2007 Cervical column morphology related to head posture, cranial base angle and condylar malformation. European Journal of Orthodontics 29: 398–403

Thilander B, Persson M, Adolfsson U 2005 Roentgen-cephalometric standards for a Swedish population. A longitudinal study between the ages of 5 and 31 years. European Journal of Orthodontics 27: 370–389

Ugar D A, Semb G 2001 The prevalence of anomalies of the upper cervical vertebrae in subjects with cleft lip, cleft palate, or both. Cleft Palate-Craniofacial Journal 38: 498–503

Ursi W J, Trotman C A, McNamara J A Jr, Behrents R G 1993 Sexual dimorphism in normal craniofacial growth. The Angle Orthodontist 63: 47–56

Vastardis H, Evans C A 1996 Evaluation of cervical spine abnormalities on cephalometric radiographs. American Journal of Orthodontics and Dentofacial Orthopedics 109: 581–588

Von Treuenfels H 1981 Die Relation der Atlasposition bei prognather und progener Kieferanomalie. Fortschritte der Kieferorthopädie 42: 482–491

Weber J S *et al.* 1993 Sexual dimorphism in normal craniofacial growth. The Angle Orthodontist 63: 47–56