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Cervical vertebral column morphology related to craniofacial morphology and head posture in preorthodontic children with Class II malocclusion and horizontal maxillary overjet

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Introduction: In preorthodontic children with Class II malocclusion and horizontal maxillary overjet, cervical column morphology was examined and related to craniofacial morphology and head posture for the first time. **Methods:** Two hundred thirteen children (aged 7-15 years) with a horizontal maxillary overjet of more than 6 mm were divided into 2 groups of skeletal and dentoalveolar overjets. The skeletal overjet group comprised 99 patients (43 girls, 56 boys). The dentoalveolar overjet group comprised 114 subjects (58 girls, 56 boys). Visual assessments of the cervical column and measurements of craniofacial morphology and head posture were made on profile radiographs. **Results:** Deviations in the cervical vertebral column morphology occurred significantly more often in the skeletal overjet group (28%) compared with the dentoalveolar overjet group (17%) ($P < 0.05$). Fusion anomalies were associated with a large sagittal jaw relationship, retrognathia of the jaws, large inclination of the jaws, and extended head posture ($P < 0.05$ and 0.01, respectively). Furthermore, a partial cleft was significantly associated with a large cranial base angle ($P < 0.01$). **Conclusions:** New associations were found between cervical column morphology, craniofacial morphology, and head posture in preorthodontic children with horizontal maxillary overjet. These findings are considered important for diagnostics and thus for a more accurate treatment plan of these patients. (Am J Orthod Dentofacial Orthop 2011;140:e1-e7)

Deviations of the cervical column morphology occur in healthy subjects with neutral occlusion and normal craniofacial morphology as well as in patients with craniofacial syndromes, deviating craniofacial morphology, and severe malocclusion traits. A recent study found that fusions between the upper cervical vertebrae (C2 and C3) occurred in 14.3% of healthy subjects.[1] Fusions of the upper cervical column within that range are thus considered normal.

Previous studies have found an association between malformations of the upper cervical vertebrae and patients with cleft lip and palate.[2-4] Recently, an association was also found between malformation of the upper cervical vertebrae not only in patients with condylar hypoplasia,[1] but also in adult orthodontic surgical patients with skeletal deep bite,[5] skeletal mandibular overjet,[6] skeletal horizontal overjet, and skeletal open bite. These studies showed that cervical column deviations occurred in 72.7% of the condylar-hypoplasia group, 41.5% of the deep-bite group, 61.4% of the mandibular-overjet group, 52.9% of the horizontal-overjet group, and 42.1% of the open-bite group. Deviations occurred significantly more often in all 5 patient groups compared with the control group. This indicates that morphologic deviations of the upper cervical vertebrae are not only associated with malformation of the jaws but also with craniofacial morphology and occlusion.

A previous study of adults found that fusion between C2 and C3 was significantly associated with posture of the head and neck.[1] In this study, the cervical vertebral column was approximately 5° more curved, and the inclination of the upper cervical spine was 8° more backward in adults with fusion.

Accordingly, it is relevant to focus on similar associations between cervical column morphology, craniofacial morphology, and posture of the head and neck in

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The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
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Submitted, April 2010; revised and accepted, October 2010.
0889-5406/$36.00

doi:10.1016/j.ajodo.2010.10.021

preorthodontic children. To our knowledge, no studies have been performed so far on cervical column morphology in relation to craniofacial morphology and head posture in preorthodontic children with Class II malocclusion and horizontal maxillary overjet.

Our aims in this study were to (1) describe the morphology of the cervical column in children with skeletal horizontal maxillary overjet and dentoalveolar horizontal maxillary overjet, (2) compare the morphology of the cervical column in a group of children with skeletal horizontal maxillary overjet (the skeletal overjet group) with a group of children with dentoalveolar horizontal maxillary overjet (the dentoalveolar overjet group), and (3) analyze associations between the morphology of the cervical column, craniofacial dimensions, and head posture in both groups together.

MATERIAL AND METHODS

Two hundred thirteen profile radiographs were systematically selected according to the inclusion criteria mentioned below from patients registered between 1988 and 1997 at the orthodontic clinic of the municipal dental service of Farum, Denmark, and divided into 2 groups according to type of overjet: skeletal and dentoalveolar.

The skeletal overjet group comprised 99 patients, 43 girls (ages, 8-14 years; mean, 10.2 years) and 56 boys (ages, 7-15 years; mean, 10.0 years). The inclusion criteria for the skeletal horizontal maxillary overjet group were (1) no prior orthodontic treatment, (2) a skeletal horizontal maxillary overjet of more than 6 mm (the sagittal jaw relationship larger than 1 SD according to the standard described by Björk,[7] assessed on the lateral radiograph of each subject), (3) no craniofacial anomalies or systemic muscle or joint disorders, and (4) accessibility of a profile radiograph before orthodontic treatment with the first 5 cervical vertebrae visible. The sagittal jaw relationship ranged between 4.5° and 14.0° (mean, 6.3°), the horizontal overjet was 6.0 to 12.7 mm (mean, 8.3 mm), the vertical jaw relationship was 14.4° to 39.2° (mean, 27.9°), and the vertical overbite was between −3.4 and 7.6 mm (mean, 2.5 mm) (Table I).

The dentolveolar overjet group comprised 114 subjects, 58 girls (ages, 7-15 years; mean, 10.7 years) and 56 boys (ages, 7-15 years; mean, 10.7 years). The inclusion criteria for the dentoalveolar overjet group were (1) no prior orthodontic treatment, (2) a dentoalveolar horizontal maxillary overjet of more than 6 mm (the sagittal jaw relationship smaller than 1 SD according to the standard described by Björk,[7] assessed on the lateral radiograph of each subject), (3) no craniofacial anomalies or systemic muscle or joint disorders, and (4) accessibility of a profile radiograph before orthodontic treatment with the 5 first cervical vertebrae visible. The sagittal jaw relationship ranged between 1.6° and 4.4° (mean, 2.5°), the horizontal overjet was 6.0 to 12.7 mm (mean, 7.9 mm), the vertical jaw relationship was 9.2° to 37.6° (mean, 24.1°), and the vertical overbite was between −3.0 and 6.6 mm (mean, 3.3 mm) (Table I).

Table I. Craniofacial dimensions and head posture in the skeletal overjet and dentoalveolar overjet groups

	Skeletal (n = 99)		*Dentoalveolar (n = 114)*			
Variable	*Mean*	*SD*	*Mean*	*SD*	*Group* P	*Sex* P
Cranial base angle (°)						
N-S-Ba	133.2	4.9	132.7	5.6	NS	NS
Sagittal dimensions (°)						
ss-n-pg	6.3	1.6	2.5	1.5	‡	NS
s-n-ss	81.7	4.1	79.7	4.0	‡	NS
S-N-Pg	75.4	4.1	77.2	4.1	†	NS
Vertical dimensions (°)						
NL-ML	27.9	4.8	24.1	5.5	‡	NS
NSL-NL	7.2	3.7	6.8	3.2	NS	
NSL-ML	35.0	6.0	30.9	5.9	‡	NS
Incisor relations (mm)						
Overjet	8.3	1.5	7.9	1.4	*	*2
Overbite	2.5	2.3	3.1	1.9	*	†2
Head posture (°)						
NSL/VER	101.2	5.6	100.5	5.4	NS	NS
NL/VER	94.0	4.6	93.7	4.3	NS	NS
NSL/OPT	96.2	8.3	96.7	8.5	NS	NS
NL/OPT	89.0	7.7	89.9	7.8	NS	NS
NSL/CVT	100.8	8.1	101.3	8.5	NS	†1
NL/CVT	93.6	7.2	94.5	7.6	NS	‡1
OPT/HOR	95.0	7.7	93.9	7.5	NS	*2
CVT/HOR	90.4	6.9	89.2	7.1	NS	‡2
OPT/CVT	4.6	2.9	4.6	3.0	NS	†1

‡P <0.001, unpaired t test; †P <0.01, unpaired t test; *P <0.05, unpaired t test; *NS*, not significant, unpaired t test; *2P <0.05, girls smaller than boys, unpaired t test; †2P <0.01, girls smaller than boys, unpaired t test; ‡2P <0.001, girls smaller than boys, unpaired t test; †1P <0.01, girls larger than boys, unpaired t test; ‡1P <0.001, girls larger than boys, unpaired t test. Reference points and lines are shown in Figure 4 and are defined according to Solow and Tallgren[41].

The differences in mean values for the craniofacial dimensions between the 2 groups and sexes are presented in Table I.

The morphology of the cervical column was evaluated by visual inspection of the first 5 cervical vertebrae as they are normally seen on a standardized lateral skull radiograph. Characteristics of the cervical column were classified according to the method of Sandham[2] and divided into 2 categories.

1. Posterior arch deficiency, defined as partial cleft and dehiscence.[2] Partial cleft is defined as failure to fuse of the posterior part of the neural arch (Fig 1), and dehiscence is defined as failure to develop of a part of a vertebral unit.

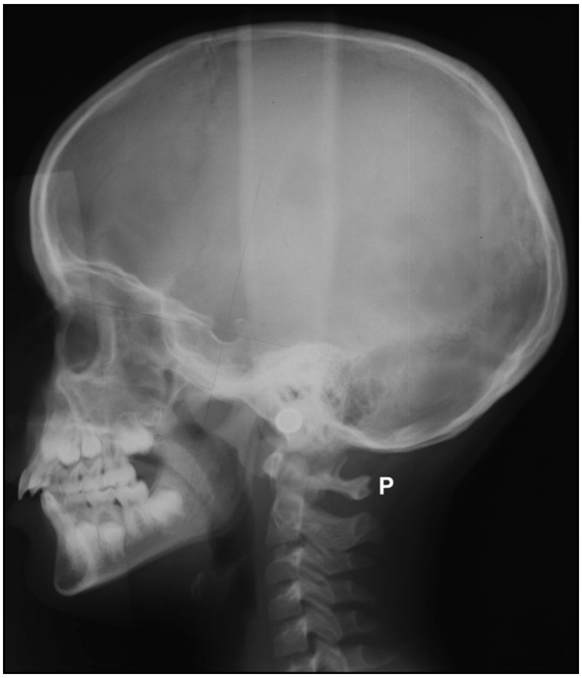

Fig 1. A profile radiograph illustrating a partial cleft of the posterior part of the neural arch of the atlas (*P*).

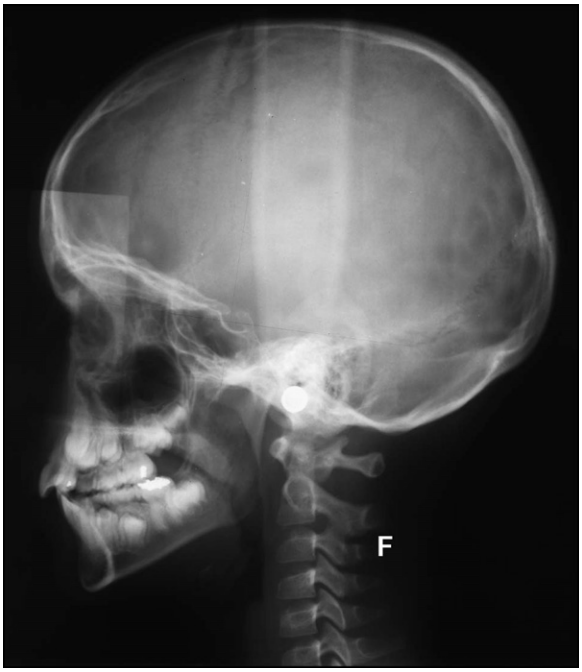

Fig 2. A profile radiograph illustrating fusion of the C2 and C3 vertebrae (*F*).

2. Fusion anomalies, defined as fusion, block fusion, and occipitalization.[2] Fusion is defined as fusion of 1 unit with another at the vertebral bodies, articulation facets, neural arch, or transverse processes (Fig 2). Occipitalization is defined as assimilation, either partially or completely, of the atlas (C1) with the occipital bone (Fig 3). The definition of block fusion was modified according to the method of Sonnesen and Kjær[8] and defined as fusion of more than 2 units at the vertebral bodies, articulation facets, neural arch, or transverse processes.

Only anomalies verified on the later profile radiographs were registered as anomalies of the cervical vertebral column.

The profile radiographs were taken with the teeth in occlusion and in the standardized head posture, the mirror position, as described by Siersbæk-Nielsen and Solow.[9] The 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%.[10] The reference points were marked and digitized directly on the profile radiographs by using a Tiops 2000 digitizer (version 2.7.0, Total Interactive Orthodontics Planning System, TIOPS, Denmark) and analyzed digitally by using Tiops 2005 (version 2.12.4) (Fig 4). Eighteen variables representing the cranial base angle, the vertical and the sagittal craniofacial dimensions, and the head posture were calculated. A list of the variables is given in Table I.

Reliability of the visual assessment of the morphologic characteristics of the cervical vertebral units was determined by interobserver examination, which showed very good agreement (0.82) as assessed by the kappa coefficient.[11]

Reliability of the variables describing the cranial base, the vertical and sagittal craniofacial dimensions, and the head posture was assessed by remeasuring 20 lateral radiographs selected at random from the previously evaluated radiographs. The radiographs were digitized again, and paired *t* tests found no significant differences between the 2 sets of recordings. The method errors calculated by Dahlberg's formula ranged from 0.09° to 0.69°,[12] and the Houston reliability coefficients were from 0.99 to 1.00.[13] The reliability was within the same range as for traditional film-based radiographs.[14]

Statistical analysis

For the craniofacial dimensions, the effect of age was assessed by linear regression analysis and the morphologic characteristics of the cervical column by logistic regression analysis. Differences in the means of the craniofacial dimensions between sexes and groups were assessed by unpaired *t* tests. Differences in morphologic

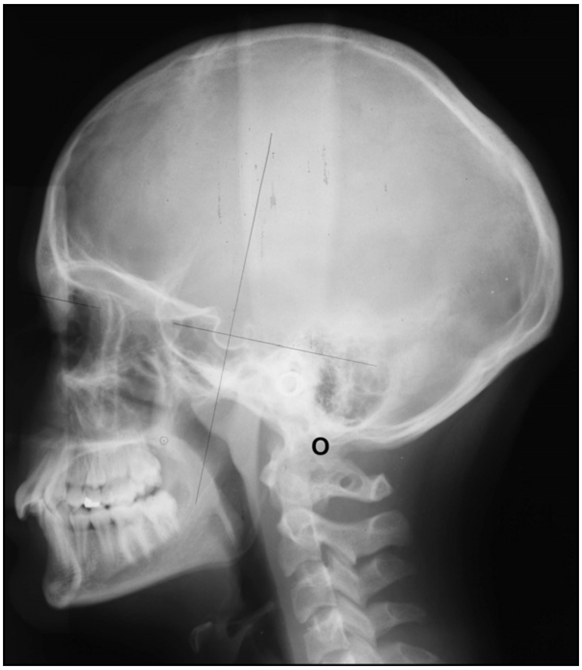

Fig 3. A profile radiograph illustrating occipitalization between the C1 vertebra and the occipital bone (*O*).

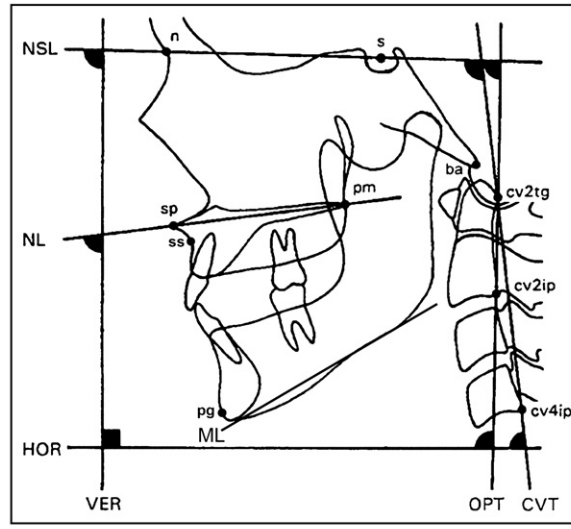

Fig 4. Reference points and lines according to Solow and Tallgren.[41]

characteristics of the cervical column between sexes and groups were assessed by the Fisher exact test. Associations between morphology of the cervical column and each craniofacial dimension were expressed in terms of the Nagelkerke logistic regression correlation coefficients (R^2) ($R = \sqrt{R^2}$)[15] and tested for the possible effect of age and sex by multiple logistic regression analyses. The results from the tests were considered to be significant at *P* values below 0.05. The statistical analyses were performed by using SPSS software (version 13.00, SPSS, Chicago, Ill).

RESULTS

In the skeletal overjet group, 16% had fusion between the C2 and C3 cervical vertebrae. Three percent had occipitalization between the C1 vertebra (atlas) and the occipital bone, and 1% had block fusion, 9% had partial cleft of the posterior part of the neural arch of atlas, and no dehiscence was registered (Figs 1-3, Table II). No statistical sex or age differences were found in the morphologic characteristics of the cervical column.

In the dentoalveolar overjet group, 14% had fusion between the C2 and C3 cervical vertebrae, 0.9% had occipitalization between the C1 vertebra (atlas) and the occipital bone, and no block fusion was registered. Four percent had partial cleft of the posterior part of the neural arch of atlas, and no dehiscence was registered (Table II). No statistical sex or age differences were found in the morphologic deviations of the cervical column.

Comparison of the skeletal and dentoalveolar overjet groups showed that deviations in the cervical vertebral column occurred significantly more often in the skeletal overjet group (28%) compared with the dentoalveolar overjet group (17%) ($P < 0.05$, Table II).

In both groups together, the logistic analysis showed that a large sagittal jaw relationship (ss-n-pg, $P < 0.05$) was significantly associated with fusion between C2 and C3 (Table III). Retrognathia of the jaws (s-n-ss, s-n-pg), large inclination of the jaws (NSL/NL, NSL/ML), and extension of the head in relation to the cervical vertebral column (NSL/VER, NSL/OPT, NSL/CVT) were significantly associated with occipitalization between the atlas and the occipital bone ($P < 0.05$ and 0.01, respectively) (Table III). Furthermore, partial cleft of the posterior part of the neural arch of the atlas was significantly associated with a large cranial base angle (NSBa, $P < 0.01$) (Table III). No association was due to the effects of age or sex.

The significant regression coefficients (R) were low to moderate, with numeric values from 0.20 to 0.46 (Table III).

DISCUSSION

In this study, we found that deviations in the cervical vertebral column morphology occurred in 28% in the skeletal overjet group and 17% in the dentoalveolar overjet group. This is within the range of previously reported prevalences of cervical vertebral column morphologic deviations in preorthodontic children who were used as control groups for comparison of cervical vertebral

Table II. Prevalence of morphologic characteristics of the cervical column in patients with skeletal horizontal maxillary overjet (skeletal overjet group) and dentoalveolar horizontal maxillary overjet (dentoalveolar overjet group)

	Skeletal overjet group		*Dentoalveolar overjet group*		
Variable	*n*	%	*n*	%	P
Total column deviations	28	28	19	17	*
Fusion anomalies					
Fusion of C2 and C3	16	16	16	14	NS
Occipitalization	3	3	1	0.9	NS
Block fusion	1	1	0	0	NS
Posterior arch deficiency					
Partial cleft	9	9	5	4	NS
Dehiscence	0	0	0	0	NS

*P <0.05, Fisher exact test; *NS*, not significant, Fisher exact test.

Table III. Significant correlations (R) between the morphology of the cervical column and craniofacial morphology and head posture in the total group (n = 213)

	Fusion between C2 and C3	*Occipitalization*	*Partial cleft*
Cranial base angle			
NSBa	NS	NS	0.34†
Sagittal dimensions			
s-n-ss	NS	−0.36*	NS
s-n-pg	NS	−0.40†	NS
ss-n-pg	0.20*	NS	NS
Vertical dimensions			
NSL/NL	NS	0.42†	NS
NSL/ML	NS	0.46†	NS
Head posture			
NSL/VER	NS	0.39*	NS
NSL/OPT	NS	0.46†	NS
NSL/CVT	NS	0.43†	NS

*P <0.05 (logistic regression); †P <0.01 (logistic regression); *NS*, not significant (logistic regression). Reference points and lines are shown in Figure 4 and are defined according to Solow and Tallgren[41].

column morphologic deviations in cleft lip and palate patients.[2-4,16-18] In these studies, deviations of the cervical vertebral column occurred in 0.8% to 31% in preorthodontic children.

The deviations in the cervical vertebral column morphology occurred significantly more often in the skeletal overjet group compared with the dentoalveolar overjet group. This was expected because previous studies of adult orthodontic surgical patients with severe skeletal malocclusions showed high prevalences of deviations in the morphology of the cervical vertebral column.[5,6,8,19] These studies showed that cervical column deviations occur in 41.5% of patients with severe skeletal deep bite, 61.4% of patients with severe skeletal mandibular overjet, 52.9% of patients with severe skeletal horizontal overjet, and 42.1% of patients with severe skeletal open bite. Deviations occur significantly more often in all 4 patient groups with severe skeletal malocclusions compared with adults with neutral occlusion and normal craniofacial morphology whose cervical column deviations occur in 14%.[1] The prevalence of cervical column deviations in the dentoalveolar overjet group was similar to those in the adult control group. Also, the pattern of cervical column deviations in the dentoalveolar overjet group was similar to the pattern seen in the adult control group; fusion occurred between C2 and C3 in 14%, and partial cleft occurred in the atlas in 4%. The prevalence of cervical column deviations in the skeletal overjet group was higher than that in the adult control group and smaller than that in the adult orthodontic surgical patients with severe skeletal malocclusions. The pattern of the cervical column morphology was different from the dentoalveolar overjet group and the adult control group. In the skeletal overjet group, occipitalization also occurred in 3% and block fusion in 1%.

It is still unknown why these deviations occur in the cervical column and why they occur with different prevalences. Furthermore, the different patterns in groups of patients with varied skeletal craniofacial morphology and malocclusion traits are inexplicable. In the early prenatal period, the vertebral bodies are formed around the notochord by direct induction, and the vertebral arches are derived from the para-axial mesoderm by indirect induction from the notochord. Thereby, the notochord might be responsible for the location and morphology of the vertebral bodies and arches.[20-23] Fusion anomalies as seen in our study could be signs of deviations in the early development or signaling of the notochord before it is surrounded by bone tissue and disappears. These findings suggest a new phenotypic differentiation of children with horizontal maxillary overjet, and the clinical relevance is a more accurate diagnosis and thus an aid for correct treatment of these patients.

In this study, fusion between C2 and C3 was associated with a large sagittal jaw relationship, and occipitalization was associated with retrognathia of the jaws and a large inclination of the jaws. Also, a large cranial base angle was associated with deviations of the cervical vertebral column morphology as partial cleft of the posterior arch of the atlas. This agrees with previous studies, which found that fusion anomalies such as fusion between C2 and C3 and occipitalization are associated with retrognathia of the jaws and a large inclination of the jaws in adults with skeletal open bite, skeletal maxillary overjet, and skeletal mandibular overjet.[6,8,19] These studies also showed that a larger cranial base angle is associated with posterior arch deficiency in terms of partial cleft of the atlas.

An explanation for the associations between the deviations in the cervical vertebral column morphology and the craniofacial morphology including the cranial base could be found in the early embryogenesis. Since the notochord determines not only the development of the cervical vertebrae, especially the vertebral bodies, but also the basilar part of the occipital bone, which is the posterior part of the cranial base angle, it is plausible that the cranial base angle is associated with deviations in the cervical vertebrae.[20-26] Because the cranial base is connected to the cervical vertebral column by the notochord in the early embryogenesis and the jaws are attached to the cranial base, the cranial base could be the developing link between the cervical vertebral column and the jaws.[27] Björk[10] found that the cranial base angle influences the craniofacial morphology and that a large cranial base angle in adulthood is associated with retrognathia of the jaws and increased inclination of the jaws. Furthermore, immunohistochemical studies on wild-type mouse embryos have shown a genetic interrelationship between the body axis and the basilar part of the occipital bone[28] and between the body axis, which surrounds the notochord, and the craniofacial region.[29-36] The jaws, including the condylar cartilage, develop from tissue derived from the neural crest. In the first branchial arch, the neural crest cells migrate from the neural crest toward the mandible, followed by the cells to the maxilla and then the cells to the nasofrontal region.[37] The associations between the deviation of cervical vertebral column morphology and craniofacial morphology including the cranial base shown in this study might be found in the signaling during early embryogenesis between the notochord, para-axial mesoderm, neural tube, and neural crest. How the migration of the neural crest cells is influenced by signals from the notochord before it is surrounded by bone tissue and disappears is still unclear.

Associations between fusion anomalies and posture of the head and neck have previously been described in adults with neutral occlusion and normal craniofacial morphology.[1] Furthermore, associations between dimensions of the cervical vertebrae, atlas, and head posture have been reported.[38-40] In this study, an association between fusion anomalies in terms of occipitalization and an extension of the head in relation to the cervical vertebral column was found. These findings have not been reported previously in children with horizontal maxillary overjet.

CONCLUSIONS

Deviations in cervical vertebral column morphology occurred significantly more often in the skeletal overjet group (28%) than in the dentoalveolar overjet group (17%). Deviations of cervical vertebral column morphology were significantly associated with a large sagittal jaw relationship, retrognathia of the jaws, a large inclination of the jaws, and a large cranial base angle. Furthermore, deviations in the cervical vertebral column morphology were significantly associated with extension of the head in relation to the cervical vertebral column. The associations between cervical column morphology, craniofacial morphology, and head posture have not previously been described in preorthodontic children with horizontal maxillary overjet. These new findings are considered to be important for the diagnosis and more accurate treatment of children with horizontal maxillary overjet.

We thank the orthodontic clinic of the municipal dental service of Farum, Denmark, for donating the material for this study; Jens Bjørn-Jørgensen for setting up the Tiops digitizing program on analog radiographs; and Maria Kvetny for linguistic support and manuscript preparation.

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