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Ethnic differences in craniofacial and upper spine morphology between European and Asian children with skeletal Class III malocclusion

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Introduction: The aims of this study were to analyze differences in craniofacial and upper cervical spine morphology, including posterior cranial fossa and growth prediction signs between European and Asian skeletal Class III children, and to analyze associations between morphologic deviations in the upper cervical spine and craniofacial characteristics. **Methods:** A total of 60 skeletal Class III children, 19 Danes and 41 Koreans, were included. Upper spine morphology, Atlas dimensions, and craniofacial morphology, including posterior cranial fossa and growth prediction signs, were assessed on lateral cephalograms. Differences and associations were analyzed by multiple linear and logistic regression analyses adjusted for age and gender. **Results:** In the craniofacial morphology, the inclination of the maxilla (NSL/NL, $P < 0.05$) and the shape of the posterior cranial fossa (s-d, d-p, p-iop; $P < 0.01$ and $P < 0.0001$, respectively) were significantly different between the 2 groups. There was no significant difference in upper cervical spine morphology and Atlas dimensions between the groups. Fusion was significantly associated with the sagittal jaw relationship ($P < 0.05$), and the total upper spine deviations were significantly associated with some growth prediction signs ($P < 0.05$, $P < 0.01$). Atlas dimensions were significantly associated with the prognathia of the mandible ($P < 0.05$), posterior cranial fossa ($P < 0.01$, $P < 0.0001$), and some growth prediction signs ($P < 0.05$, $P < 0.01$). **Conclusions:** Upper spine morphology and Atlas dimensions may provide valuable information for predicting jaw growth and craniofacial morphology in Class III malocclusion. (Am J Orthod Dentofacial Orthop 2019;156:502-11)

Class III malocclusion contains significant genetic components, and its etiology and craniofacial characteristics are different among ethnic groups.[1,2] In Asians, smaller anterior cranial base and midfacial dimensions influence jaw discrepancies, whereas acute cranial base angle, condylar hyperplasia, and anterior positioning of the condyle cause malocclusion in Europeans.[1] Because of different etiologies and genetic factors of the malocclusion, it is important to diagnose the phenotype of the malocclusion and to predict jaw growth in orthodontic treatment planning for growing patients with Class III malocclusion.

Recently, upper spine morphology was found to be associated with craniofacial morphology, and it was suggested as a predictive factor for jaw growth.[3-7] Morphologic deviations in the upper spine and decreased Atlas dimensions were associated with retrognathia of the jaws, a large cranial base angle, and a large inclination of the jaws,[3-7] and these craniofacial characteristics are known to be different among ethnic groups.[1,2,8,9] Because there are significant differences in craniofacial morphology between ethnic groups[8,9] and upper spine morphology is associated with the craniofacial morphology,[3-7] upper spine morphology may be different between the ethnic groups. Recently, the ethnic differences in the upper spine morphology were described in European and Asian children with Class II malocclusion,[3] but it has not previously been reported in children with skeletal Class III malocclusion.

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Class III malocclusion is seen in the deciduous or early mixed dentition, and an early interceptive treatment is recommended.[1,2] Predicting jaw growth and rotation is crucial for treatment success and long-term stability in Class III treatment.[10-13] Björk observed the rotation of the jaws in classic longitudinal implant studies and found 7 structural signs related to jaw growth and rotation prediction seen on lateral cephalograms.[12,13] In the present study, the growth prediction signs by Björk[12] were included, in addition to the cephalometric analysis, and analyzed in association with upper spine morphology. Furthermore, as the posterior cranial fossa belongs to the cerebellar and cervical spine field, and thereby has a similar developmental origin to the upper cervical spine,[14,15] the posterior cranial fossa was also included in the analysis of this study.

The aims of the present study were (1) to analyze differences in upper cervical spine and craniofacial morphology, including posterior cranial fossa and growth prediction signs between Danish and South Korean preorthodontic children with skeletal Class III malocclusion, and (2) to analyze associations between upper cervical spine morphologic deviations or Atlas dimensions and craniofacial characteristics, including posterior cranial fossa and growth prediction signs.

MATERIALS AND METHODS

All preorthodontic children with skeletal Class III malocclusion registered in the Orthodontic section at the Institute of Odontology, Copenhagen University, Denmark, and the Orthodontic Department of Seoul National University Dental Hospital, South Korea in a period from 2008-2015 were systematically collected. The inclusion criteria were (1) no previous orthodontic treatment, (2) lateral cephalogram taken at pretreatment with the 5 first upper cervical vertebrae visible, (3) sagittal jaw relationship: subspinale-nasion-supramentale (ss-n-sm) is smaller than 0.5° (1 standard deviation [SD] above the mean),[9,16] (4) horizontal mandibular overjet is smaller than 0 mm (1 SD above the mean),[9,17] and (5) before the pubertal growth peak assessed by cervical vertebral maturation method (cervical stage [CS]1-CS3).[18] Patients with craniofacial syndromes or other general diseases were excluded.

The total group included 60 patients (34 boys and 25 girls) aged 8-14 years (mean 9.72, SD 1.25). A total of 19 subjects (14 boys and 5 girls) were included from Copenhagen (mean 10.04 years) and 41 children (20 boys and 21 girls) from Seoul (mean 9.57 years) (Table I).

The study was approved by the Danish Data Protection Agency (no. 2015-57-0121) and the ethical committee of Seoul National University Dental Hospital, South Korea (Institutional Review Board 207/08-16).

When power analysis was performed using cephalometric variables representing craniofacial morphology, at least 15 Danish and 31 Korean subjects were required to have sufficient power (80%) to identify statistically significant differences at the 5% level of significance.

The assessments of craniofacial and upper spine morphology, and the growth prediction signs by Björk,[12] were performed on lateral cephalograms. The lateral cephalograms were taken in the centric occlusion and in the standard mirror position, as described by Siersbaek-Nielsen and Solow.[19] For the Danish children, the lateral cephalograms were taken with a Philips Medio 30 CP X-ray tube (Philips, Eindhoven, Netherlands) with a film-to-focus distance of 180 cm and a film-to-median plane distance of 10 cm. The constant linear enlargement was 5.6%. For the Korean patients, the lateral cephalograms were taken with Asahi CX-90 SP (Toshiba, Tokyo, Japan) with a film-to-focus distance of 150 cm and a film-to-median plane distance of 15 cm. The constant linear enlargement was 10%. Correction for the constant linear enlargement was made for both groups digitally by TIOPS 2005 (version 2. 12.4; Total Interactive Orthodontics Planning System, TIOPS, Copenhagen, Denmark), including the resolution "X" and "Y." The reference points were marked on the lateral cephalograms with TIOPS 2000 digitizer (version 2.7.0, Total Interactive Orthodontics Planning System, TIOPS) and analyzed digitally by TIOPS 2005 (version 2.12.4).

Craniofaical morphology

The reference points were defined according to Solow and Tallgren[20] and Caspersen et al.[21] Reference points and lines for the craniofacial analysis are illustrated in Figure 1, and the variables representing the cranial base angle, the vertical and sagittal dimensions, and the posterior cranial fossa are shown in Table I.

Upper cervical spine morphology and Atlas dimensions

Morphologic deviations of the upper cervical spine were visually assessed and classified into 2 categories: fusion and posterior arch deficiency, as described by Sandham.[22] Fusions were divided into 3 categories: fusion of 2 cervical bodies, block fusion when more than 2 vertebral bodies were fused, and occipitalization of the first cervical vertebrae and the occipital bone (Fig 2).[22] Posterior arch deficiency included partial cleft and dehiscence. Partial cleft was defined as failure to fuse of the posterior part of the neural

Table I. Craniofacial characteristics and Atlas dimensions in skeletal Class III Danish and Korean children

Characteristics and dimensions	*Danish (n = 19)*		*Korean (n = 41)*		*P*
	(14 boys, 5 girls)		*(20 boys, 21 girls)*		*NS*
CVM methods	N	%	N	%	NS
CS1	11	57.9	13	31.7	
CS2	5	26.3	20	48.8	
CS3	3	15.8	8	19.5	
	Mean	*SD*	*Mean*	*SD*	
Age (y)	10.04	1.42	9.57	1.16	NS
Posterior cranial fossa (mm)					
s-d	63.82	1.82	66.61	2.97	****
s-iop	90.90	4.18	90.32	3.35	NS
d-p	30.94	2.02	32.67	2.57	**
p-iop	35.13	3.85	32.36	3.93	**
iop-s-d (degree)	29.04	2.27	29.46	2.75	NS
Cranial base angle (degree)					
n-s-ba	131.52	5.15	132.36	4.06	NS
Sagittal dimensions (degree)					
s-n-ss	79.10	3.68	77.81	4.01	NS
s-n-pg	80.75	4.21	78.83	3.56	NS
s-n-sm	80.56	4.18	78.92	3.66	NS
ss-n-pg	-1.65	1.38	-1.02	1.86	NS
ss-n-sm	-1.46	1.20	-1.11	1.35	NS
Vertical dimensions (degree)					
NSL/NL	7.60	3.29	9.68	2.85	*
NSL/ML	32.30	5.52	34.29	4.07	NS
NL/ML	24.69	4.16	24.36	5.19	NS
Mandibular form (degree)					
ML/Rlar	123.28	6.95	122.04	5.83	NS
ML/MBLar	18.24	2.90	18.97	2.63	NS
Incisal relations (mm)					
Overjet	-2.74	1.31	2.55	1.38	NS
Overbite	2.70	1.93	2.30	2.08	NS
Dental (degree)					
pr-n-ss	1.46	0.86	1.70	0.81	NS
ILs/NL	111.25	5.83	114.65	7.38	NS
ILi/ML	90.30	6.76	92.91	7.73	NS
CL/ML	74.31	6.40	77.33	6.39	NS
Ols/NL	11.45	3.62	10.86	4.04	NS
Oli/ML	16.35	2.60	16.00	4.23	NS
Atlas dimensions (mm)					
Dorsal arch height	7.95	1.76	8.19	1.97	NS
Posterior neural arch height	3.83	0.61	4.20	0.79	NS
A-P dimension	43.77	2.64	42.67	3.09	NS

Notes: Logistic regression analysis for gender and CVM method. Linear regression analysis for craniofacial variables, adjusted for the effect of age and gender.
CVM, cervical vertebral maturation; *NS*: not significant; *A-P*, anterior-posterior.
**P* <0.05, ***P* <0.01, *****P* <0.0001.

arch, and dehiscence was failure to develop of a part of a vertebral unit (Fig 2).[22] Children with any deviations, either fusions or posterior arch deficiency, were categorized as upper spine morphologic deviations. Children with more than 1 fusion deviation or posterior arch deficiency, or both fusion and posterior arch deficiency were categorized as more than 1 deviation (Table II).[3]

Dimensions of Atlas were measured according to Huggare,[23] and the height of the posterior neural arch at the slimmest part was measured as well (Fig 3; Table I).[3]

Growth prediction signs

The growth prediction signs according to Björk[12] were evaluated as follows: (1) inclination of the condylar head, (2) curvature of the mandibular canal, (3) shape of the lower border of the mandible, (4) inclination of the symphysis, (5) interincisal angle (Ils/Ili), (6) intermolar angle (MOLs-MOLi), and (7) lower anterior face height (sp-gn). The 4 bony structures of signs (1)-(4) were visually assessed by 2 of the authors. The 4 signs that showed clear characteristics of forward or backward growth prediction according to Björk[12] were categorized as forward or backward, and the rest were categorized as neutral growth prediction of the mandible. The 3 continuous variables of (5)-(7) were analyzed digitally with TIOPS 2005 (version 2.12.4) (Fig 4; Table III).

Reliability and method error

The reliability of the cervical vertebral maturation method[18] was evaluated by re-measuring 20 sets after 1 month, and the agreement was excellent ($\kappa = 0.91$).[24] The reliability of the craniofacial and upper spine morphology and growth prediction signs has been reported previously.[3]

Statistical analysis

When normality of distribution was assessed with Shapiro-Wilk test, all the variables were normally distributed. Multiple linear regression analysis was performed to compare craniofacial variables, the posterior cranial fossa, and Atlas dimensions between Koreans and Danes with an adjustment for age and gender. Prevalence of upper cervical spine morphologic deviations and 4 bony structural growth prediction signs were compared by logistic regression analysis, and possible effect of age and gender was adjusted.

In the whole group, associations between the upper cervical spine deviations and craniofacial morphology, including the growth prediction signs, were assessed by logistic regression analysis. Associations between Atlas dimensions and craniofacial morphology were assessed by multiple linear regression analysis. The possible effect of age, gender, and ethnic group was adjusted. The data were analyzed using SPSS software (version 21.00; SPSS, Chicago, IL), and the results were considered significant at P value <0.05.

RESULTS

There was no significant difference in gender, age, and skeletal maturation between the 2 ethnic groups (Table I).

Craniofacial morphology between the groups

Table I presents the means and SDs of the craniofacial variables and Atlas dimensions for the Danish and Korean groups. In the posterior cranial fossa, the Korean group presented significantly larger s-d ($P < 0.001$) and d-p ($P < 0.01$), and smaller p-iop ($P < 0.01$) than the Danish group. The Korean group presented a significantly steeper maxillary plane (NSL/NL; $P < 0.05$) than the Danish group (Table I). There was no significant difference in growth prediction signs between the 2 ethnic groups (Tables I and III).

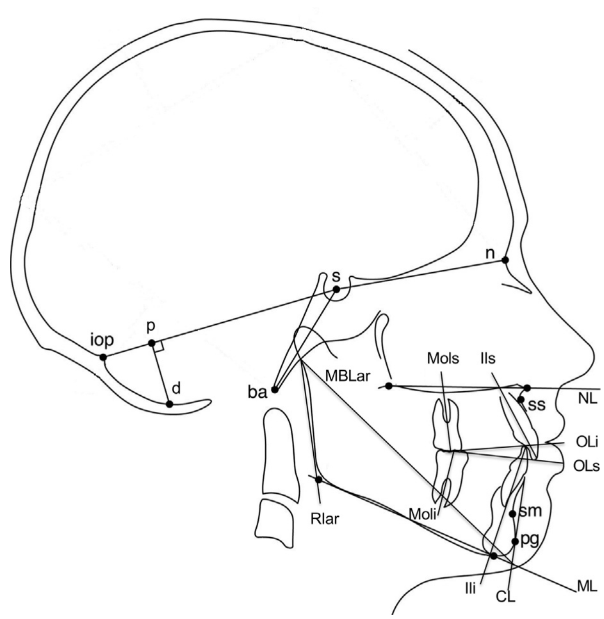

Fig 1. Reference points and lines according to Solow and Tallgren[20] and Caspersen et al.[21]

Upper cervical spine morphology and Atlas dimensions between the groups

The mean values of Atlas dimensions and the prevalence of upper cervical spine morphologic deviations are presented in Tables I and II. In the Danish group, 36.8% of the children had upper cervical spine morphologic deviations; 10.8% had fusion and 26.3% had posterior arch deficiency. In the Korean group, 24.4% had deviations of the upper cervical spine; 7.3% had fusion including a patient (2.4%) who had both fusion of C2-C3 and occipitalization, 19.5% had posterior arch deficiency, and 2.4% had both fusion and posterior arch deficiency. No significant differences were found between the groups (Table II).

Associations between upper spine vs craniofacial morphology

In the total group, significant associations were found between upper spine morphology and craniofacial morphology, including growth prediction signs

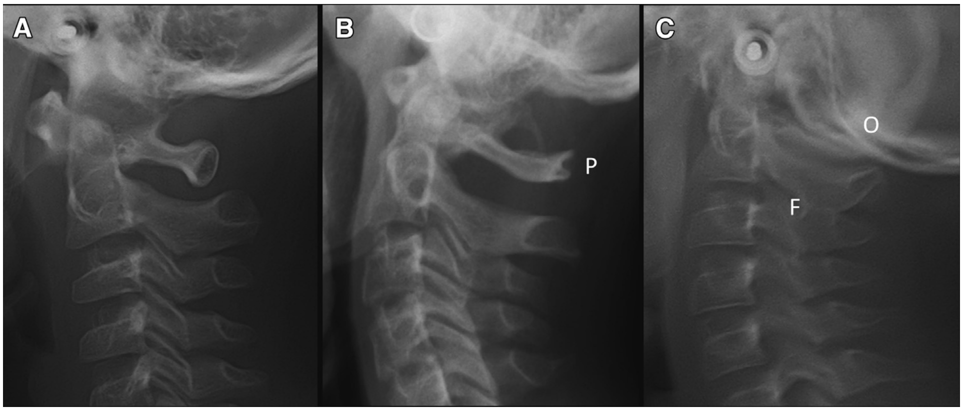

Fig 2. Morphologic characteristics of the upper cervical vertebrae[22]: **A,** normal upper spine; **B** and **C,** morphologic deviations of the upper spine: fusion of the second and third cervical spine at the articulation facet (F), partial cleft of the posterior part of the neural arch of atlas (P), and occipitalization of the first cervical vertebrae and the occipital bone (O).

(Tables IV and V). Fusion was significantly associated with a decreased sagittal jaw relationship (ss-n-sm, ss-n-pg; $P < 0.05$). Posterior arch deficiency was significantly associated with curvature of the mandibular canal. Children with posterior arch deficiency presented 0.42 times less odds of having a forward-directed growth prediction sign in the mandibular canal compared with children without posterior arch deficiency ($P < 0.05$). Upper spine deviations, either fusions or posterior arch deficiency, were significantly associated with curvature of the mandibular canal ($P < 0.01$, odds ratio [OR] = 0.33), lower border of the mandible ($P < 0.05$, OR = 0.517) and inclination of the symphysis ($P < 0.05$, OR = 0.573).

The Atlas dimensions were associated with craniofacial morphology, including the posterior cranial fossa and growth prediction signs (Table V). The anterior-posterior dimension of Atlas was positively associated with the sagittal and vertical dimensions of the posterior cranial fossa (s-d, $P < 0.0001$; s-iop, $P < 0.01$), and the posterior neural arch height was also positively associated with the dimension of the posterior cranial fossa (s-d, $P < 0.001$). Dorsal arch height was positively associated with the prognathia of the mandible (s-n-pg, $P < 0.05$), lower anterior facial height ($P < 0.05$), inclination of the condylar head ($P < 0.05$), lower border of the mandible ($P < 0.05$), and the symphysis ($P < 0.05$).

Table II. Pattern and prevalence of upper cervical spine morphological deviations in skeletal Class III Danish and Korean children

	Danish (n = 19)		*Korean (n = 41)*		
	(14 boys, 5 girls)		*(20 boys, 21 girls)*		
Variables	*n*	*%*	*n*	*%*	*P*
Upper spine deviation	7	36.8	10	24.4	NS
Fusion	2	10.5	3	7.3	NS
Fusion of C2-C3	2	10.5	3	7.3	NS
Block fusion	0	0.0	0	0.0	NS
Occipitalization	0	0.0	1	2.4	NS
Posterior arch deficiency	5	26.3	8	19.5	NS
Partial cleft	5	26.3	8	19.5	NS
Dehiscence	0	0.0	0	0.0	NS
More than 1 deviation	0	0.0	1	2.4	NS

Note: Logistic regression analysis, adjusted for the effect of age and gender.
NS: not significant.

DISCUSSION

The present study describes the upper cervical spine morphology and craniofacial characteristics in Asian and European children with skeletal Class III malocclusion and demonstrates the associations between upper spine morphology and craniofacial morphology, including growth predictions signs. As Koreans and Danes are relatively homogeneous ethnic groups and represent craniofacial morphologic characteristics of Europeans and North East Asians, the children were included as representatives of the 2 ethnic groups. There were no significant differences in age, gender, and skeletal maturation between the groups. It has been reported that most of the dentofacial parameters did not show a significant sexual dimorphism in Class III malocclusion before the pubertal growth peak[25] and that the peak in the mandibular growth occurs during the year after CS3, between CS3 and CS4.[18] In the present study, all the children were before the pubertal growth peak.

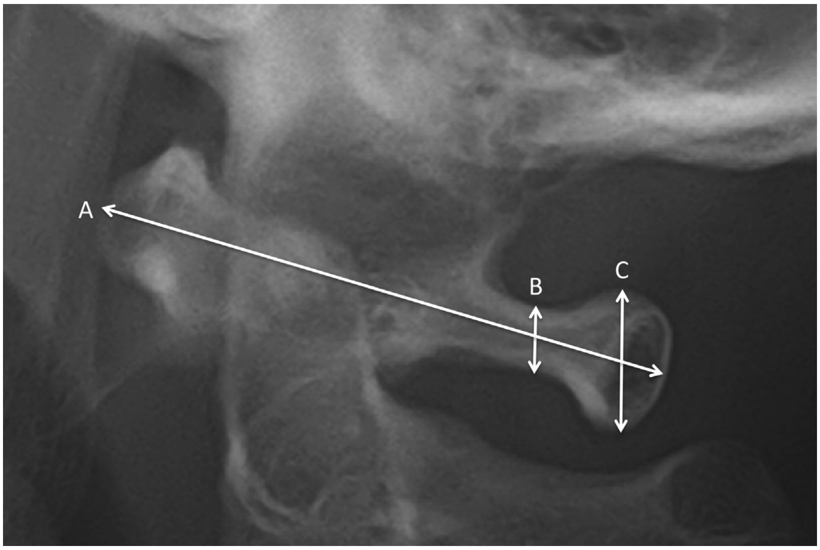

Fig 3. Reference lines for the Atlas dimensions[23]: Anterior-posterior dimension **(A)**, the height of the slimmest part of the posterior neural arch **(B)**, and the height of the dorsal arch **(C)**.

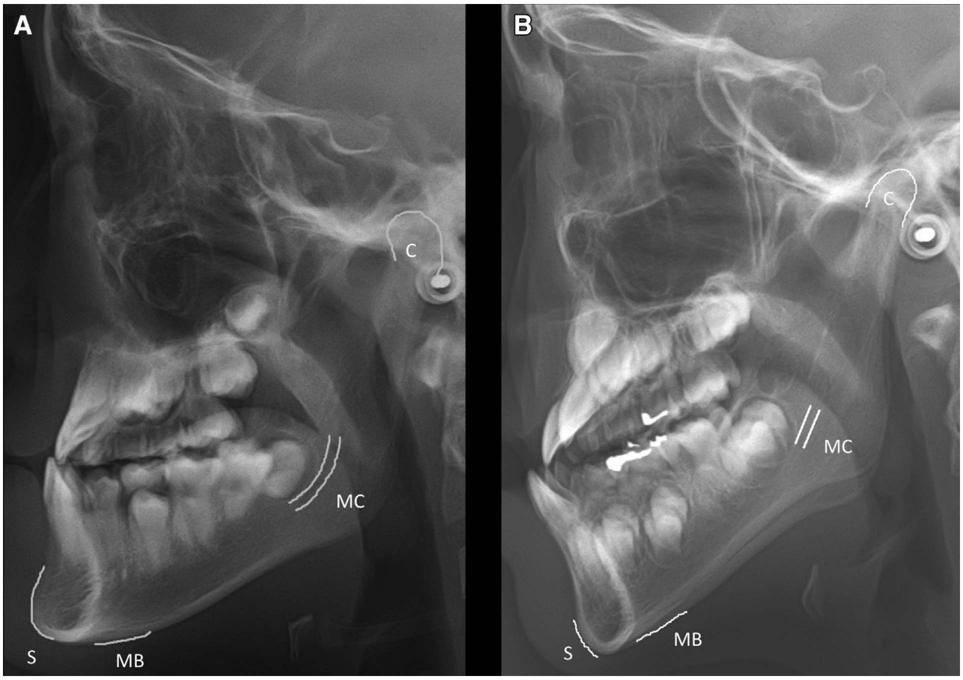

Fig 4. Lateral cephalograms illustrating Björk's growth prediction signs.[12] **A,** An example of all the forward growth prediction signs present and **B,** an example of all the backward growth prediction signs present: Inclination of the condylar head (C), curvature of the mandibular canal (MC), shape of the lower border of the mandible (MB), and inclination of the symphysis (S).

Differences between the ethnic groups

Previously, it has been reported that Asians presented larger vertical facial dimensions and jaw divergence than European Americans.[8,9] However, only the inclination of the maxilla was significantly different between the 2 ethnic groups in the present

Table III. Seven growth prediction signs in skeletal Class III Danish and Korean children—3 continuous and 4 categorical data

Variables	*Danish (n = 19)* (14 boys, 5 girls)		*Korean (n = 41)* (20 boys, 21 girls)		*P*
Continuous variables	Mean	SD	Mean	SD	
LAFH (sp-gn, mm)	58.32	4.08	58.64	3.89	NS
Ils/Ili (degrees)	133.77	7.57	128.01	11.62	NS
Mols/MoLi (degrees)	177.05	4.11	177.82	5.43	NS
Categorical variables	N	%	N	%	
Condylar head					NS
Backward	6	31.6	12	29.3	
Forward	0	0	7	17.0	
Neutral	13	68.4	22	53.7	
Mandibular canal					NS
Backward	12	63.2	21	51.2	
Forward	0	0.0	4	9.8	
Neutral	7	36.8	16	39.0	
Border of mandible					NS
Backward	10	52.6	15	36.6	
Forward	0	0.0	3	7.3	
Neutral	9	47.4	23	56.1	
Symphysis					NS
Backward	4	21.1	8	19.5	
Forward	1	5.3	11	26.8	
Neutral	14	73.7	22	53.7	

Notes: Linear regression analysis for the continuous variables, adjusted for the effect of age and gender. Logistic regression analysis for the categorical variables, adjusted for the effect of age and gender.
LAFH, lower anterior facial height; *NS*: not significant.

study. The disagreement between the studies may be due to the age of the subjects; the previous studies have been performed on adults and the present study was performed on children.[8,9] It has been reported that the craniofacial morphology may not be fully characterized before the pubertal growth peak. Moreover, in the present study, the inclination of the mandible could counteract the differences in the inclination of the maxilla, which may have resulted in a similar vertical jaw relationship in both groups.[12,13]

The Korean group presented a significantly deeper (s-d and d-p) and narrower (p-iop) shape of the posterior cranial fossa than the Danish group. It may be due to a more posterior-inferior positioned d-point in the Korean group. The results were in agreement with a recent study of Class II children,[3] and it may reflect the general craniofacial morphologic differences between the 2 ethnic groups.

There was no significant difference in the upper cervical spine morphology and Atlas dimensions between the 2 ethnic groups, which is in agreement with a previous study.[3] It may suggest that there is no ethnic difference in the upper cervical spine, and the prevalence of the upper spine deviations is consistent regardless of race.

Associations between upper spine morphology vs craniofacial characteristics

Previously, it has been found that morphologic deviations of the upper cervical spine and decreased Atlas dimensions were associated with retrognathia, large inclination of the jaws, and a large cranial base angle,[3,7,26] but only the sagittal jaw relationship was significantly associated with fusion of the upper cervical spine in the present study. The variables showing the prognathia of the jaws (s-n-ss, s-n-pg, s-n-sm) could be more affected by the position of sella and nasion than the variables showing the sagittal jaw relationship (ss-n-sm, ss-n-pg), which may be the reason why the sagittal jaw relationship was the only significant measurement, especially when the craniofacial morphology was not yet fully developed in prepubertal children in the present study.[12,13,16,27] Instead, children with upper spine deviations or decreased Atlas dorsal arch height had more backward growth prediction signs in the symphysis and border of the mandible.

Table IV. Significant associations between upper cervical spine morphology and craniofacial morphology, including growth prediction signs in the total group

	Fusion			Posterior arch deficiency			Upper spine deviations		
			95% CI			95% CI			95% CI
	P	OR	Lower-Upper	P	OR	Lower-Upper	P	OR	Lower-Upper
Sagittal jaw relationship									
ss-n-sm	*	0.366	0.154-0.871	NS			NS		
ss-n-pg	*	0.486	0.242-0.975	NS			NS		
Growth prediction signs									
Mn canal	NS			*	0.420	0.193-0.912	**	0.330	0.151-0.720
Mn border	NS			NS			*	0.517	0.294-0.907
Symphysis	NS			NS			*	0.573	0.347-0.946

Notes: Upper spine deviations: either fusions or posterior arch deficiency. Logistic regression analysis, adjusted for the effect of age, gender and ethnic group.
CI, confidence interval; *Mn Canal*, curvature of the mandibular canal; *Mn Border*, lower border of the mandible; *NS*, not significant.
$^{*}P < 0.05$, $^{**}P < 0.01$.

Table V. Significant associations between Atlas dimensions and craniofacial morphology, including growth prediction signs in the total group

	Dorsal arch height				Posterior neural arch height				Width (A-P)			
			95% CI				95% CI				95% CI	
Variables	P	Co	Lower	Upper	P	Co	Lower	Upper	P	Co	Lower	Upper
Posterior cranial fossa												
s-d	NS				***	0.144	0.076	0.211	***	0.523	0.283	0.763
s-iop	NS				NS				**	0.283	0.109	0.456
Sagittal dimensions												
s-n-pg	*	0.127	0.008	0.246	NS				NS			
Growth prediction signs												
LAFH (sp-gn)	*	0.145	0.024	0.267	*	0.060	0.013	0.106	**	0.278	0.107	0.449
Con head	*	0.432	0.072	0.792	NS				NS			
Mn border	*	0.416	0.014	0.818	NS				NS			
Symphysis	*	0.441	0.097	0.785	NS				NS			

Note: Multiple linear regression analysis, adjusted for the effect of age, gender and ethnic group.
A-P, anterior-posterior; *CI*, confidence interval; Co, regression coefficient; Con Head, inclination of the condylar head; Mn Border, lower border of the mandible; NS, not significant.
$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.0001$.

Björk has addressed difficulties in finding single cephalometric variables to predict the growth at an early age, because the pattern recorded at a juvenile age may well have changed by adolescence.[12,13] By contrast, the structural growth prediction signs are characterized as a consequence of rotation and remodeling of the jaws.[12,13] Thus, growth prediction signs rather than cephalometric variables represented the pattern and growth of the jaws and presented significant associations with upper cervical spine morphology in the present study.

The reliability of the growth prediction signs and its predictive power has been questioned.[28,29] Leslie et al[29] criticized the predictive power of the method proposed by Skieller et al[13] and reported that the method did not predict the mandibular rotation in patients with moderate malocclusion. However, they analyzed the rotation on anatomic structures, such as nasion-sella-line and mandibular plane, and true rotation was not measured.[12,13] In a recent study, the growth prediction signs reflected the craniofacial morphology and jaw divergency, and backward growth prediction signs showed associations with morphologic deviations in the upper spine and decreased Atlas dimensions.[3]

Moreover, associations between the Atlas and the posterior cranial fossa dimensions were found in the present study. In previous studies, dimensions of the Atlas and occipitalization were associated with the surrounding bony structures, including the posterior cranial fossa and the posterior cranial base.[21,30] Developmental disorders in the posterior cranial fossa area were also suggested to account for deviant cranial base morphology in skeletal Class III.[1,27,31]

An explanation regarding the associations between upper cervical spine and craniofacial morphology through the posterior cranial fossa and the cranial base could be found in early embryogenesis. Upper cervical spine and the posterior cranial fossa are derived from the same developmental origin of the notochord.[14] In a prenatal study, Kjaer[14,15] illustrated that the notochord influences the development of the upper spine and basilar part of the occipital bone. The notochord is extended to the sella throughout the upper spine field and the posterior cranial base.[14,15,32] The cranial base is directly attached to the jaws, and it is closely related to the development and rotations of the jaws.[27,31,32] Therefore, upper cervical spine, posterior cranial fossa, cranial base, and the jaws are developmentally connected, and the posterior cranial fossa and the posterior cranial base may act as a developing link between the upper cervical spine and the jaws.

The posterior synchondrosis of the Atlas fuses by the age of 5 years, and the ossification becomes mature by the age of 8 years.[33,34] If anomalies develop during the ossification process, such as cleft of the posterior arch or dehescience, it could be found on lateral cephalograms, routinely taken for orthodontic diagnosis, considering the timing of the first visit of patients with Class III malocclusion.[33,34] The Class III malocclusion is usually found in deciduous dentition, and predicting jaw growth and rotation is critical in treatment success.[1,2] Retrognathia of the maxilla or backward rotation of the jaws has been reported to be a factor that may jeopardize the long-term success of the Class III malocclusion treatment.[10-13] In the present study, morphologic deviations in the upper spine and decreased Atlas dorsal height were significantly associated with these morphologic characteristics.

It would be a clear advantage for patient selection and treatment planning if it could be possible to predict the prognosis before orthodontic treatment of children with Class III malocclusion. Considering that upper spine morphology can be evaluated at an early age and is significantly associated with jaw growth and morphology,[3-7] it may be valuable to include upper spine morphology in addition to the growth prediction signs by Björk[12] in orthodontic diagnosis and treatment planning for growing children with Class III malocclusion. If morphologic deviations in the upper spine or decreased Atlas dimensions are found on lateral cephalograms of young children with Class III malocclusion, it may suggest that the vertical dimensions of the jaws need to be controlled carefully during early orthodontic treatment, and late treatment in combination with orthognathic surgery may be considered.

CONCLUSIONS

In the craniofacial morphology, only the inclination of the maxilla and the shape of the posterior cranial fossa were significantly different between the 2 ethnic groups. There was no significant difference in the upper cervical spine morphology and Atlas dimensions between the groups. In the total group, fusion of the upper cervical spine was significantly associated with the sagittal jaw relationship, and the total upper spine deviations were significantly associated with some growth prediction signs. Atlas dimensions were significantly associated with prognathia of the mandible, the posterior cranial fossa, and some growth prediction signs. The results may be considered in treatment planning for growing Class III children.

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