Craniofacial heterogeneity of prepubertal Korean and European-American subjects with Class III malocclusions: Procrustes, EDMA, and cephalometric analyses

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The purpose of this study is to determine whether there is a difference in craniofacial morphology in subjects of diverse ethnic origin with untreated Class III malocclusions, and thus to examine the validity of using similar therapeutic protocols in their orthodontic management. Lateral cephalographs of 142 Korean and European-American children aged 5 to 11 years were traced, and homologous cranial, midfacial, and mandibular landmarks were digitized. Procrustes analysis and Euclidean Distance Matrix Analysis (EDMA) were performed to identify size-corrected differences of the three craniofacial configurations, and bivariate analysis to determine statistical differences between 42 cephalometric parameters. Procrustes analysis indicated statistical significance for each configuration of landmarks; these results were confirmed by EDMA and cephalometry. Korean children appear to develop Class III malocclusions because of smaller anterior cranial base and midfacial dimensions, exacerbated by a large and less favorable mandibular morphology. Therefore, morphologic diversity of craniofacial components, presumably due to heterochrony during development, contributes to distinctive facial profiles associated with Class III malocclusions. Ethnic heterogeneity may need to be taken into account in the orthodontic management of Class III malocclusions.
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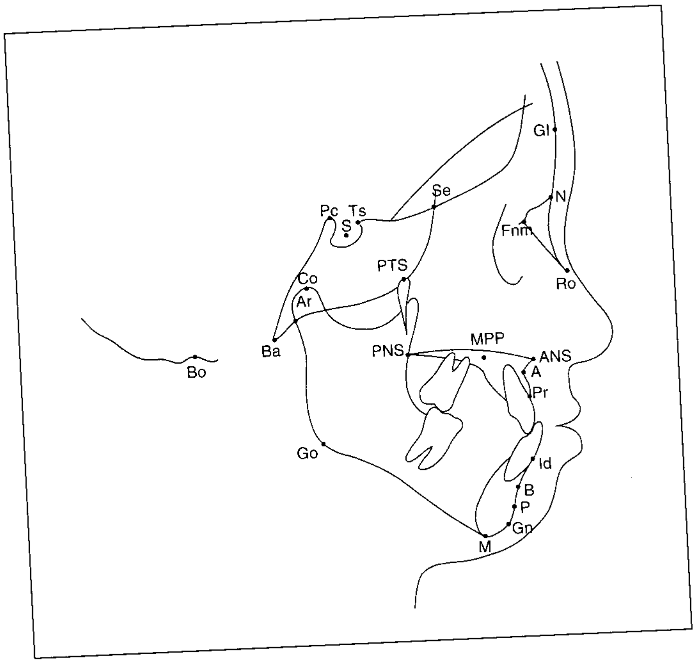
Analysis of craniofacial morphology is essential in orthodontic evaluation and clinical treatments. There is limited information in the English-language orthodontic literature concerning the morphology of untreated individuals with Class III malocclusions, presumably because of the relatively low prevalence of this malocclusion in European-American populations. However, the prevalence of Class III malocclusions has been observed previously to be higher in Asian populations: for example, as high as 19% in Hong Kong Cantonese children.[1] Similarly, Tang[2] reported that some 15% of male Hong Kong Chinese males exhibited Class III malocclusions, while 20% of Hong Kong Chinese adults had such malocclusions.[3] In an earlier study, Johnson et al[4] discovered that 23% of Chinese children had Angle Class III malocclusions. Later, Woon et al[5] reported a higher prevalence of Class III malocclusions among Chinese and Malay high school children compared to their Indian counterparts, suggesting that an edge-to-edge incisor relationship might be the norm for those two ethnic groups. These findings were supported by Lew et al[6] who found that Chinese schoolchildren have a higher incidence of Class III malocclusions compared with Caucasians.

Although the prevalence of Angle Class III molar relationship among the Japanese has not been studied in detail, estimates of the frequencies of anterior crossbite and edge-to-edge incisal relationships in Japanese range from 2.3% to 13.0% and 2.7% to 7.4%, respectively.[7-9] If the frequency of occurrence of these two manifestations of Class III malocclusions are combined, a substantial percentage of the Japanese population have characteristics of Class III malocclusion. Therefore, it appears that Class III malocclusions are prevalent to a greater degree in Asian populations than in European-American populations, and this information stresses the need to establish well-balanced facial norms for Asian patients. Assessment of occlusal disharmonies and indicators of relative facial attractiveness could provide clinicians with guidelines for the establishment of treatment priorities in children of Asian origin.[10]

In an early study, Kameda[11] noted that mandibular protrusion and bimaxillary protrusion accounted for about 50% of orthodontic patients in Japan and that improvements in the Begg technique were required to treat such Japanese malocclusions. However, the role of craniofacial components in the etiology of the Asian Class III profile has not been fully investigated. Miyajima et al[12] have made some progress in this regard; in a comprehensive cross-sectional study of 1,376 Japanese females, they reported maxillary retrusion with respect to the cranial base allied with a protrusive mandible. Earlier, Chan[13] had suggested that a significantly shorter sella-nasion length accounts for the high incidence of Class III malocclusion in the Cantonese; and in a study of skeletal types of Chinese Class III malocclusions, Zeng[14] described six different groups. In the management of such patients, Ritucci and Nanda[15] found that chin-cup therapy causes a closing of the cranial angle nasion-sella-basion (N-S-Ba) inhibits posterior growth of basion and imposes a vertical growth tendency on nasion and sella. Therefore, a putative role for the cranial base in the emergence of Asian Class III malocclusions can be advocated. Support for such a notion has been established in experimental animal studies,[16-19] as well as in studies on human subjects.[20-22]

For the midfacial components of Class III malocclusions, Lew and Foong[23] analyzed the maxillary skeletal base using angular (S-N–point A/S-N–point B) as well as linear (points A and B to the nasion perpendicular) criteria. They reported normal anteroposterior maxillary position in Chinese adults. In contrast, Murata et al[24] suggested that skeletal Class III malocclusions in Japanese females are a combination of a retrusive maxilla and a larger, prognathic mandible. In this respect, Oda et al[25] found that application of chin-cup therapy restrained growth in overall mandibular length, mandibular body length, and ramus height in Japanese girls with Class III malocclusions. Similarly, Ritucci and Nanda[15] found that chin-cup therapy significantly inhibited anterior and posterior vertical maxillary growth, and growth of upper anterior face height, in Japanese girls. More recently, Shanker et al[26] found that correction of Class III malocclusions in Chinese children treated with maxillary protraction therapy was due to skeletal maxillary advancement. But such changes often are not maintainable.[24,27] Therefore, the contribution of the midfacial complex in the development of Class III malocclusions appears to be critical.[28]

The morphologic differences for Korean children with Class III malocclusion have not been considered extensively in the orthodontic literature. Recently, Yang[29] discovered that some 49% of orthodontic patients in Korea sought treatment for Class III malocclusions, but there are very few studies of Korean craniofacial morphology, although Chung et al[30] have undertaken a preliminary study of skull foramina in Koreans. Therefore, the overall aim of the present study is to compare Korean and European-American children he landmarks used in y superimposed on a aphic tracing of a Ko- d with a Class III maloc- he definitions are found



with Class III malocclusions, providing preliminary data on ethnically diverse Class III subjects. The specific purpose is to test the null hypothesis that craniofacial morphology does not differ in subjects of diverse ethnic origin who exhibit similar Class III malocclusions. In the event that the null hypothesis is rejected, developmental mechanisms responsible for morphologic heterogeneity may be formulated and differences in therapeutic requirements more clearly delineated.

Method and materials

After obtaining appropriate consent, 73 pretreatment lateral cephalographs of European-American subjects, 5 to 11 years of age, with a Class III malocclusion were retrieved.[31] An additional 69 cephalographs of untreated Korean subjects with a similar Class III malocclusion were obtained from a Korean orthodontic practice. The total sample included an approximately equal number of age-matched boys and girls with a negative history of airway problems and no obvious vertical skeletal problems.

It was presumed that all radiographs were taken from subjects exhibiting left-right symmetry and that the central x-ray passed along the transmeatal axis while the teeth were in occlusion. The magnification of each film was standardized to 8%. The chronologic age was assumed to match the developmental age in this study as carpal ages were unavailable. Each lateral cephalograph was traced on frosted acetate film (0.03 inches thick) and checked by one investigator (GDS). Digitization of landmark coordinates from cephalographs taped to a light box of uniform brightness was achieved using appropriate software and a digitizing tablet (Numonics).

Nine homologous cranial base landmarks, seven homologous landmarks of the midfacial complex, and eight homologous mandibular landmarks were identified and digitized (Fig 1):

1. A—Subspinale (point of maximum concavity inferior to the anterior nasal spine on maxillary alveolus)
2. ANS—Anterior nasal spine (anterior-most point on anterior nasal spine)
3. Ar—Articulare (intersection of the condyle and the posterior cranial base)

4. B—Supramentale (point B, the deepest point on mandibular alveolus)
5. Ba—Basion (lowest point on the anterior border of foramen magnum)
6. Bo—Bolton point (highest point behind the occipital condyle)
7. Co—Condylion (superior-most point on mandibular condyle)
8. Fnm—Frontonasomaxillary suture
9. Gl—Glabella (anterior-most point on the frontal bone in the horizontal plane)
10. Gn—Gnathion (most anteroinferior point on mandibular symphysis)
11. Go—Gonion (midpoint at angle of mandible)
12. Id—Infradentale (most anterosuperior point on mandibular alveolus)
13. M—Menton (inferior-most point on mandibular symphysis)
14. MPP—Midpalatal point (the point midway between the outlines of the nasal and oral palatal surfaces)
15. N—Nasion (most anterior point on frontonasal suture)
16. P—Pogonion (most anterior point on mandibular symphysis)
17. Pc—Posterior clinoid process (most superior point)
18. PNS—Posterior nasal spine (most posterior point on posterior nasal spine)
19. Pr—Prosthion (anteroinferior point of maxillary incisor alveolus)
20. PTS—(Most superior point on outline of pterygomaxillary fissure)
21. Pt—(Most inferior point on outline of pterygomaxillary fissure)
22. Ro—Rhinion (most inferior point on tip of nasal bone)
23. S—Sella (center of sella turcica)
24. Se—Sphenoidale (intersection of the greater wings of the sphenoid and the anterior cranial base)
25. Ts—Tubercullum sellae (most anterior point of sella turcica)

These landmarks permitted the formation of configurations encompassing the three craniofacial regions to be studied, ie, the cranial base, the midface, and the mandible. The rationale of selection was that preference was given to landmarks that encompass developmental sites and were located in the midsagittal plane where possible.[32,33] All films were digitized twice, and any landmarks that showed a discrepancy of greater than 1% on duplicate digitization were deemed to be identified unreliably and were excluded from the final analyses.

From the digitized landmarks, 26 linear distances (mm) and 16 craniofacial angles (degrees) between coordinates were calculated (Table 1). For statistical analysis, the mean parameter of each Korean and European-American Class III group was compared using paired t tests. In each instance, the null hypothesis was that the Korean and European-American Class III means were not significantly different.

Table 1 Linear distances and angular measurements calculated from the homologous landmarks digitized from lateral cephalographs

Linear distances	Angular measurements
Cranial	
N-S	N-Se-S
N-Se	N-Pc-Bo
Se-S	N-S-Ba
N-Pc	N-S-Ar
Pc-Bo	Gl-N-Ro
S-Ba	
S-Ar	
Gl-N	
N-Ro	
Midfacial	
PTS-Ro	PTS-Ro-ANS
Ro-ANS	PNS-MPP-ANS
PNS-ANS	PNS-ANS-A
PNS-MPP	PNS-ANS-Pr
MPP-ANS	ANS-A-Pr
PNS-Pr	ANS-PNS-Pr
ANS-Pr	
ANS-A	
A-Pr	
Mandibular	
Co-Gn	Co-Gn-B
Go-Gn	Co-Go-Gn
Go-M	Ar-Go-M
Co-Go	Id-Gn-Go
Ar-Go	Id-M-Go
Gn-B	
Id-Gn	
Id-M	

Table 2 Summary of mean craniofacial distance measures (mean mm ± SD)

	Korean	European-American	Significance
Cranial lengths			
N-S	65.82 ± 1.77	69.68 ± 1.84	$P < 0.010$
N-Se	37.84 ± 1.86	43.44 ± 1.23	$P < 0.001$
Se-S	28.18 ± 0.85	26.31 ± 0.65	$P < 0.001$
N-Pc	70.18 ± 1.56	73.71 ± 1.82	$P < 0.010$
Pc-Bo	53.86 ± 3.39	48.47 ± 2.98	$P < 0.001$
S-Ba	44.24 ± 2.24	43.91 ± 1.78	NS
S-Ar	31.07 ± 1.73	30.69 ± 1.51	NS
Gl-N	17.82 ± 1.46	13.38 ± 1.43	$P < 0.001$
N-Ro	24.36 ± 1.82	21.34 ± 1.41	$P < 0.010$
Midfacial lengths			
PTS-Ro	46.83 ± 0.70	49.63 ± 0.62	$P < 0.001$
Ro-ANS	24.86 ± 0.10	24.71 ± 0.21	NS
PNS-ANS	39.93 ± 0.79	41.71 ± 0.64	$P < 0.001$
PNS-MPP	21.76 ± 0.60	19.84 ± 0.92	$P < 0.010$
MPP-ANS	18.27 ± 0.92	20.32 ± 1.54	$P < 0.010$
ANS-A	5.11 ± 0.59	5.61 ± 0.26	NS
ANS-Pr	12.87 ± 1.82	12.14 ± 1.37	$P < 0.050$
PNS-Pr	41.04 ± 0.60	41.32 ± 0.55	NS
A-Pr	8.39 ± 1.28	7.89 ± 0.94	$P < 0.050$
Mandibular lengths			
Co-Gn	113.42 ± 0.53	106.65 ± 0.42	$P < 0.001$
Go-Gn	75.61 ± 0.70	75.89 ± 0.76	NS
Go-M	71.52 ± 0.76	71.69 ± 0.84	NS
Co-Go	53.86 ± 0.54	53.98 ± 0.84	NS
Ar-Go	44.68 ± 0.62	42.74 ± 0.79	$P < 0.001$
Gn-B	16.22 ± 0.08	19.19 ± 0.08	$P < 0.001$
Id-Gn	28.31 ± 0.93	27.44 ± 0.85	NS
Id-M	31.24 ± 0.97	29.52 ± 0.79	$P < 0.010$

17 of 26 (65%) parameters are statistically significant.
See text for definitions.

In view of the intrinsic deficiencies of cephalometry, the sample was also subjected to geometric morphometric procedures to determine whether mean craniofacial configurations differed between the two ethnic groups. An average thirteen-noded geometry for the cranial base of each ethnic group was determined with a generalized orthogonal Procrustes analysis[21] implemented on an Amiga 3000. Similarly, average seven- and eight-noded geometries for the midface and mandibular complex respectively, were determined. Therefore, all craniofacial configurations were scaled to an equivalent size and registered with respect to one another. Each craniofacial mean geometry was compared statistically to the other ethnic group average using analysis of variance (ANOVA). In each instance, the null hypothesis was that the mean Korean and European-American configurations were not significantly different. The total sample also was divided into seven age-matched groups and subjected to ANOVA. Residuals and corresponding F values were computed, tabulated, and compared. Full details of this method are available.[21]

To meet the concerns regarding the robustness of Procrustes analysis, and the likelihood of inequality of the variance-covariance matrices of the samples, the mean craniofacial configurations were also compared using Euclidean Distance Matrix Analysis (EDMA). The EDMA has been successfully employed in several biologic and clinical studies.[34-36] Using a newer EDMA procedure,[37] the assumption of equality of variance-covariance matrices is avoided. Therefore, distances between each of the homologous landmarks in the three craniofacial regions were calculated and EDMA matrices were formed for the Korean and European-American Class III configurations. The corresponding linear distances were compared as ratios, and the statistical significance of form difference was tested by the nonparametric bootstrap method.[34,37]

Results

Cranial base

Linear measures. The total anterior cranial base length (N-S) was longer in the European-American children compared to the Korean children ($P < 0.01$) (Table 2). The major contribution to this difference in length arose from the longer anterior cranial base length subcomponent N-Se ($P < 0.001$) because the anterior cranial base sublength Se-S was actually shorter in the European-Americans ($P < 0.001$). The anterior cranial base length N-Pc, however, remained longer in the European-Americans ($P < 0.001$). In contrast, while the posterior cranial base length Pc-Bo was shorter in the European-Americans

Table 3 Summary of mean craniofacial angular measurements (mean degrees ± SD)

	Korean	European-American	Significance
Cranial angles			
N-Se-S	173.07 ± 1.55	174.61 ± 1.30	NS
N-Pc-Bo	133.79 ± 1.88	128.44 ± 2.85	$P < 0.010$
N-S-Ba	127.53 ± 2.27	126.62 ± 2.23	NS
N-S-Ar	123.11 ± 2.42	120.44 ± 1.71	$P < 0.050$
Gl-N-Ro	152.46 ± 3.00	138.39 ± 1.91	$P < 0.001$
Midfacial angles			
PTS-Ro-ANS	75.23 ± 1.91	73.31 ± 1.54	NS
PNS-MPP-ANS	172.07 ± 3.11	177.43 ± 1.27	$P < 0.010$
PNS-ANS-A	63.38 ± 3.92	49.07 ± 5.59	$P < 0.001$
PNS-ANS-Pr	84.54 ± 3.85	79.69 ± 4.00	$P < 0.010$
ANS-PNS-Pr	18.18 ± 2.51	16.76 ± 1.79	$P < 0.050$
ANS-A-Pr	143.90 ± 8.93	127.78 ± 10.10	$P < 0.001$
Mandibular angles			
Co-Go-Gn	122.05 ± 1.65	123.85 ± 1.28	$P < 0.010$
Ar-Go-M	130.43 ± 2.17	133.15 ± 1.67	$P < 0.010$
Co-Gn-B	54.10 ± 3.54	51.64 ± 3.39	$P < 0.001$
Id-Gn-Go	80.04 ± 1.59	77.38 ± 1.91	$P < 0.001$
Id-M-Go	86.22 ± 1.38	84.46 ± 2.05	$P < 0.010$

13 of 16 (81%) parameters were statistically significant.
See text for definitions.

($P < 0.001$), other parameters of posterior cranial base length (eg, S-Ba and S-Ar) were not statistically different. For the cranial vault, however, both the superior and inferior frontonasal heights, Gl-N and N-Ro, were longer in Korean children ($P < 0.001$ and $P < 0.01$, respectively).

Angular measures. While the anterior cranial base angulation marginally failed to reach statistical difference when the two samples were compared (Table 3), the posterior cranial base angulation N-S-Ar was more acute in the European-American children ($P < 0.05$). Similarly, the posterior cranial base angulation N-Pc-Bo was more acute in the European-Americans ($P < 0.01$). For the cranial vault, however, the frontonasal angulation Gl-N-Ro was flatter in the Korean children and more acute in their European-American counterparts ($P < 0.001$).

Procrustes analysis. When the mean cranial base configurations were compared (Fig 2), the European-American cranial base was found to be signifi-

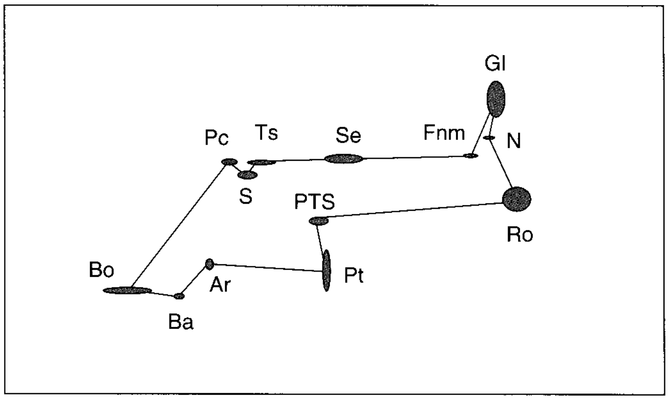


Fig 2 Procrustes analysis of the cranial base of Korean and European-American children with Class III malocclusions. Despite the size of the 95% confidence ellipsoids at glabella and rhinion, statistical significance was maintained.

Table 4 Procrustes analysis of mean cranial base, midface, and mandibular configurations of European-American and Korean Class III subjects

	Age (y)							
	5	6	7	8	9	10	11	Total
Cranial base								
Residual	0.0041	0.0028	0.0055	0.0031	0.0048	0.0041	0.0039	0.0027
F value	3.97	3.31	6.71	4.83	7.33	4.54	2.56	7.89
$P <$	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005
Midface								
Residual	0.0030	0.0001	0.0021	0.0006	0.0024	0.0013	0.0011	0.0011
F value	2.51	1.07	2.38	0.93	3.37	1.19	0.67	3.12
$P <$	0.001	0.01	0.001	0.05	0.05	0.01	NS	0.01
Mandible								
Residual	0.0005	0.0003	0.0006	0.0002	0.0004	0.0005	0.0007	0.0002
F value	1.11	0.88	2.57	0.93	1.65	1.75	1.85	4.71
$P <$	0.01	0.05	0.001	0.05	0.001	0.01	0.001	0.001

cantly different from the Korean equivalent ($P < 0.005$). Indeed, when the sample was divided into seven age groups (5 to 11 years), statistical significance was maintained for all age groups (Table 4).

EDMA. When the mean cranial base configurations were compared, the European-American cranial base was found to be significantly different from the Korean counterpart ($P < 0.01$). This difference arises partly because of change in shape and partly because of size. Table 5a shows that marked changes were most notable for the posterior cranial base at Bo-Ba (0.66) and for anterior cranial base at Fnm-Se (1.17). The results of the form matrix showed very good concordance with the cranial distance measures.

Midface

Linear measures. The midface length PTS-Ro was found to be longer in the European-American children ($P < 0.001$), but there was no difference in midface height Ro-ANS between the two groups of children (see Table 2). The palatal length PNS-ANS, however, was found to be shorter in the Korean children ($P < 0.001$). This finding depended on the palatal sublength MPP-ANS being longer in the European-Americans ($P < 0.01$) because the palatal sublength PNS-MPP was found to be shorter in European-American children ($P < 0.01$). While there were no differences in the alveolar length PNS-Pr, the alveolar height ANS-Pr was found to be longer in the Korean children ($P < 0.05$). Similarly, the subspinale height A-Pr was shorter in the European-American children ($P < 0.05$).

Angular measures. The results are summarized in Table 3. The palatal angle PNS-MPP-ANS was more acute in the Korean children ($P < 0.01$), but the subspinale angle PNS-ANS-A was more obtuse ($P < 0.001$). Similarly, the alveolar angle PNS-ANS-Pr was more obtuse in the Koreans ($P < 0.01$). These findings were reflected in the anterior alveolar angle ANS-PNS-Pr being more acute in the European-Americans ($P < 0.05$). Not sur-

Table 5a EDMA analysis with European-Americans as the numerator and Koreans as the denominator

Form matrix for numerator sample

PTS	0.000												
Pt	0.107	0.000											
Ro	0.412	0.407	0.000										
N	0.426	0.383	0.145	0.000									
Gl	0.504	0.450	0.222	0.091	0.000								
Fnm	0.370	0.331	0.132	0.057	0.145	0.000							
Se	0.233	0.135	0.363	0.294	0.343	0.254	0.000						
Ts	0.263	0.165	0.520	0.453	0.494	0.414	0.160	0.000					
S	0.246	0.156	0.532	0.473	0.518	0.431	0.179	0.034	0.000				
Pc	0.290	0.200	0.567	0.500	0.540	0.461	0.207	0.048	0.044	0.000			
Bo	0.358	0.367	0.765	0.750	0.813	0.699	0.474	0.356	0.322	0.328	0.000		
Ba	0.286	0.309	0.697	0.691	0.759	0.638	0.427	0.330	0.295	0.311	0.079	0.000	
Ar	0.219	0.223	0.621	0.606	0.671	0.554	0.337	0.243	0.208	0.230	0.145	0.091	0.

Form matrix for denominator sample

PTS	0.000												
Pt	0.131	0.000											
Ro	0.387	0.369	0.000										
N	0.438	0.369	0.165	0.000									
Gl	0.543	0.456	0.279	0.121	0.000								
Fnm	0.383	0.317	0.145	0.055	0.170	0.000							
Se	0.275	0.155	0.322	0.257	0.319	0.216	0.000						
Ts	0.283	0.163	0.481	0.425	0.475	0.384	0.168	0.000					
S	0.274	0.162	0.497	0.448	0.502	0.406	0.191	0.030	0.000				
Pc	0.315	0.206	0.535	0.478	0.524	0.438	0.222	0.054	0.044	0.000			
Bo	0.396	0.410	0.770	0.778	0.854	0.727	0.535	0.397	0.367	0.366	0.000		
Ba	0.277	0.306	0.656	0.675	0.759	0.623	0.444	0.329	0.301	0.313	0.119	0.000	
Ar	0.224	0.222	0.584	0.590	0.670	0.539	0.353	0.239	0.211	0.227	0.188	0.092	0.0

Form difference matrix (sorted)

Bo-Ba	0.658	N-Gl	0.753	Bo-Ar	0.770
Ro-Gl	0.796	PTS-Pt	0.820	PTS-Se	0.846
Gl-Fnm	0.850	Pt-Se	0.873	Ts-Pc	0.874
Ro-N	0.876	S-Bo	0.878	Se-Bo	0.888
Pt-Bo	0.895	Pc-Bo	0.897	Ts-Bo	0.897
PTS-S	0.900	PTS-Bo	0.905	Ro-Fnm	0.913
PTS-Pc	0.921	PTS-Gl	0.929	PTS-Ts	0.930
Se-S	0.935	Se-Pc	0.936	Se-Ts	0.951
Gl-Bo	0.953	Se-Ar	0.954	Fnm-Bo	0.962
Pt-S	0.963	Se-Ba	0.963	PTS-Fnm	0.964
N-Bo	0.965	PTS-N	0.971	Pt-Pc	0.972
PTS-Ar	0.981	S-Ba	0.982	Ba-Ar	0.985
Pt-Gl	0.986	S-Ar	0.989	Ro-Bo	0.993
Pc-Ba	0.995	Gl-Ba	0.999	Gl-Ar	1.001
Ts-Ba	1.001	Pt-Ar	1.004	Pt-Ts	1.010
Pt-Ba	1.010	Pc-Ar	1.011	S-Pc	1.014
Ts-Ar	1.017	N-Ba	1.024	Fnm-Ba	1.025
N-Ar	1.027	Fnm-Ar	1.029	N-Fnm	1.029
Gl-Pc	1.031	PTS-Ba	1.032	Gl-S	1.032
Pt-N	1.038	Gl-Ts	1.040	Pt-Fnm	1.046
N-Pc	1.047	Fnm-Pc	1.053	N-S	1.055
Ro-Pc	1.060	Ro-Ba	1.061	Fnm-S	1.061
Ro-Ar	1.063	PTS-Ro	1.065	N-Ts	1.067
Ro-S	1.071	Gl-Se	1.075	Fnm-Ts	1.076
Ro-Ts	1.081	Pt-Ro	1.102	Ro-Se	1.125
N-Se	1.145	Ts-S	1.165	Fnm-Se	1.173

Probability that forms are the same: $P < 0.010$.

Table 5b EDMA analysis of the midface using the European-American sample as the numerator and the Korean sample as the denominator, employing 100 bootstraps

Form matrix for numerator sample

Pr	0.000						
A	0.130	0.000					
ANS	0.201	0.093	0.000				
MPP	0.611	0.495	0.411	0.000			
PNS	0.886	0.791	0.809	0.825	0.000		
PTS	0.686	0.636	0.693	0.888	0.363	0.000	
Ro	0.357	0.284	0.338	0.596	0.533	0.356	0.000

Form matrix for denominator sample

Pr	0.000						
A	0.140	0.000					
ANS	0.216	0.086	0.000				
MPP	0.635	0.504	0.420	0.000			
PNS	0.905	0.803	0.796	0.792	0.000		
PTS	0.693	0.641	0.675	0.867	0.377	0.000	
Ro	0.350	0.275	0.309	0.588	0.560	0.368	0.000

Form difference matrix (sorted)

Pr-A	0.929	A-PTS	0.992
Pr-ANS	0.931	MPP-Ro	1.015
PNS-Ro	0.952	ANS-PNS	1.016
Pr-MPP	0.963	Pr-Ro	1.021
PNS-PTS	0.964	MPP-PTS	1.024
PTS-Ro	0.967	ANS-PTS	1.027
ANS-MPP	0.978	MPP-PNS	1.042
Pr-PNS	0.979	A-Ro	1.033
A-MPP	0.982	A-ANS	1.076
A-PNS	0.985	ANS-Ro	1.093
Pr-PTS	0.990		

Probability that forms are the same: $P < 0.05$.

prisingly, therefore, the upper alveolar angulation ANS-A-Pr was found to be more acute in European-American children compared to their Korean counterparts ($P < 0.001$).

Procrustes analysis. When the mean midface configurations were compared (Fig 3), the European-American midface was found to be significantly different from the Korean equivalent ($P < 0.005$). Indeed, when the sample was divided into seven age groups (5 to 11 years), statistical significance was maintained for almost all age groups (see Table 4).

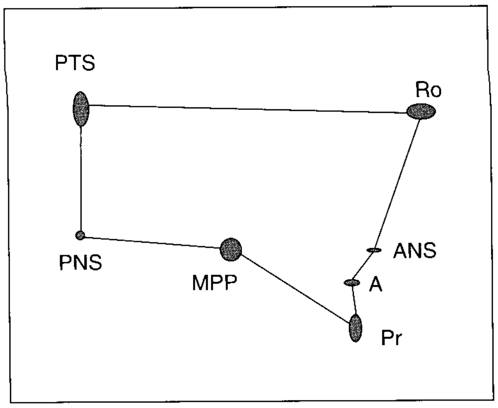


Fig 3 Procrustes analysis of the midface of Korean and European-American children with Class III malocclusions. Note the 95% confidence ellipsoids at pterygomaxillare, rhinion, and midpalatal point.

EDMA. When the mean midface configurations were compared, the European-American midface was found to be significantly different from the Korean counterpart ($P < 0.05$). This difference arises partly because of change in shape and partly because of change in size. Table 5b shows that marked changes were most notable for the maxillary alveolus at Pr-A (0.93) and for the nasopalatal complex (Ro-ANS, 1.09). The results of the form matrix showed concordance with the midfacial distance measures.

Mandible

Linear measures. While the mandibular length Co-Gn was found to be longer in the Korean children ($P < 0.001$), there were no differences in the corpus lengths Go-Gn or Go-M (see Table 2). The ramus length Ar-Go, however, was shorter in the European-American children ($P < 0.001$). In contrast, the supramentale length Gn-B was greater in the European-American children ($P < 0.001$), but the symphyseal height Id-M compensated for this, being taller in their Korean counterparts ($P < 0.01$).

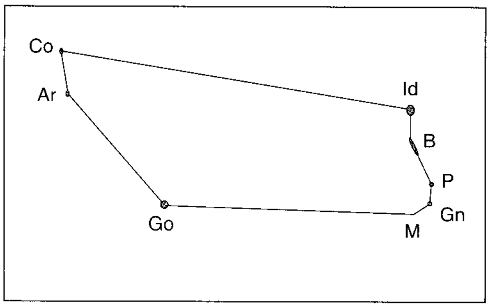


Fig 4 Procrustes analysis of the mandible of Korean and European-American children with Class III malocclusions. Note the small 95% confidence ellipsoids at the landmarks employed.

Angular measures. While the mandibular angle Co-Gn-B was more acute in the European-American children ($P < 0.001$), the mandibular angles Co-Go-Gn and Ar-Go-M were found to be more acute in the Koreans ($P < 0.01$ and $P < 0.01$, respectively). In contrast, the mental angle Id-Gn-Go was more acute in the European-Americans ($P < 0.001$), as was the symphyseal angle Id-M-Go ($P < 0.01$). These results are summarized in Table 3.

Procrustes analysis. When the mean mandibular configurations were compared (Fig 4), the European-American mandible was found to be significantly different from the Korean equivalent ($P < 0.001$). Indeed, when the sample was divided into seven age groups (5 to 11 years), statistical significance was maintained for all age groups (see Table 4).

EDMA. The European-American mandible was found to be significantly different from the Korean counterpart ($P < 0.01$). This difference arises because of change in shape and size. Table 5c shows that marked changes were most notable for the mandibular alveolus at B-Id (0.69) and for the symphyseal region at P-B (1.27). The results of the form matrix showed good concordance with the mandibular distance measures.

In summary, 17 of 26 linear distances (65%) and 13 of 16 angular measures (81%) were statistically different. In addition, almost all Procrustes superimpositions demonstrated statistical difference, and this was largely corroborated by EDMA. Therefore, significant changes are discernible when craniofacial features of prepubertal Korean children with Class III malocclusions are compared with their European-American counterparts.

Table 5c EDMA analysis of the mandible with the European-American sample as the numerator and the Korean sample as the denominator, employing 100 bootstraps

Form matrix for numerator sample

M	0.000							
Gn	0.037	0.000						
P	0.071	0.043	0.000					
B	0.155	0.140	0.100	0.000				
Id	0.215	0.200	0.159	0.061	0.000			
Co	0.819	0.840	0.827	0.761	0.741	0.000		
Ar	0.771	0.794	0.785	0.728	0.716	0.093	0.000	
Go	0.523	0.554	0.558	0.534	0.546	0.394	0.312	0.000

Form matrix for denominator sample

M	0.000							
Gn	0.039	0.000						
P	0.074	0.042	0.000					
B	0.140	0.118	0.079	0.000				
Id	0.228	0.207	0.167	0.089	0.000			
Co	0.810	0.828	0.816	0.767	0.738	0.000		
Ar	0.772	0.792	0.784	0.741	0.720	0.076	0.000	
Go	0.522	0.552	0.558	0.542	0.560	0.393	0.326	0.000

Form difference matrix (sorted)

B-Id	0.686				
M-Id	0.945	B-Co	0.992	Id-Co	1.005
M-Gn	0.954	Id-Ar	0.994	M-Co	1.011
P-Id	0.957	M-Ar	0.998	P-Co	1.013
Ar-Go	0.958	P-Go	1.001	Gn-Co	1.014
M-P	0.962	P-Ar	1.001	Gn-P	1.030
Gn-Id	0.969	Co-Go	1.002	M-B	1.105
Id-Go	0.976	Gn-Ar	1.002	Gn-B	1.184
B-Ar	0.983	M-Go	1.002	Co-Ar	1.217
B-Go	0.985	Gn-Go	1.004	P-B	1.267

Probability that forms are the same: $P < 0.01$.

Discussion

Given the greater prevalence of Class III malocclusions in Asian populations and the requirement to achieve well-balanced facial norms for these patients, analysis of the Korean craniofacial complex is warranted. Assessment of occlusal disharmonies and indicators of relative facial attractiveness could provide clinicians with guidelines for the establishment of treatment priorities in children of Asian origins.[10] In a preliminary study, Park et al[38] noted horizontal and vertical craniofacial differences between American-Caucasian and Korean subjects.

The present study is based on a cross-sectional sample of randomly selected Korean children exhibiting molar Class III malocclusions compared with their European-American counterparts.[31] While acknowledging that classification of Class III malocclusions may be based on incisor relationships, molar occlusions, and cephalometric parameters *inter alia,* the aim of this study is to provide preliminary data of Korean children with Class III malocclusions as a foundation for further geometric morphometric studies.[20–39] Moreover, the phenotypic diversity of craniofacial components noted in this study may represent an additional factor in the orthodontic management of Class III malocclusions and presumably arises due to heterochrony during development. Lozanoff,[16] Lozanoff et al,[17,18] and Ma and Lozanoff[19] showed that crucial events during murine anterior base morphogenesis determine the midfacial profile and have delineated developmental sites within the cranial complex that may be responsible for such morphologic outcomes. Similarly, the cranial base plays a critical role in the development of the retruded midfacial appearance associated in humans with Class III malocclusions.[20–22]

In this study, Koreans with Class III malocclusions were found to have ostensibly smaller anterior cranial base dimensions in comparison with their European-American counterparts. This finding parallels that of Chan,[13] who suggested that a significantly shorter sella-nasion length accounts for the high incidence of Class III malocclusions in the Cantonese. In the present study, it appears that the increased anterior cranial base length in European-American children arises from maintenance of growth activities at the sphenoethmoidal synchondrosis. In contrast, further posteriorly, it is likely that growth activities persist longer in prepubertal Korean children, considering that their posterior cranial base dimensions are larger than their European-American counterparts. Our study reflects the report of Masaki,[40] who noted a longer posterior cranial base length but shorter anterior cranial base in Japanese boys and girls compared to Caucasians. These findings lead us to hypothesize that earlier closure of the spheno-occipital synchondrosis may occur in European-American children; but the timing of puberty could complicate this apparently simple deduction in the postpubertal period. In European-Americans, the cranial base appears to show less orthocephalization, ie, deficient flattening in the anteroposterior plane,[20–22] and, allied with earlier closure of the spheno-occipital synchondrosis, may be one factor leading to morphologic heterogeneity of the cranial base. Thus, differences in facial appearance may become apparent when comparing European-Americans to Koreans with Class III malocclusions.

For the midfacial complex, it was found that the horizontal midfacial length (PTS-Ro) was longer in the European-Americans compared to their Korean counterparts. This observation is not surprising, given the flattened facial profile commonly associated with some ethnic groups of Southeast Asia. For example, Murata et al[24] suggested that skeletal Class III malocclusion in Japanese females is due to a retrusive maxilla in combination with a larger, prognathic mandible. One developmental site responsible for such midfacial heterogeneity may be the pterygomaxillary suture; earlier closure in Korean child may herald the foundation of a midface that is ostensibly deficient in the horizontal axis when compared to the equivalent European-American child. That the anteroposterior midfacial length PTS-Ro is significant is supported by the finding that midfacial heights were similar in the Korean and European-American children studied. In contrast, palatal lengths also were longer in the European-Americans. The relative palatal deficiency in Koreans might arise from cessation of growth activities at the premaxillary-maxillary suture. Early synostosis in the growing Korean child is suggested by the finding that the palatal sublength MPP-ANS is longer in their European-American counterparts. Not surprisingly, therefore, Shanker et al[26] found that correction of Class III malocclusions in Chinese children treated with maxillary protraction therapy was due to skeletal maxillary advancement. Therefore, the Class III midfacially retrusive appearance of the Korean child may also be dependent on midfacial form,[28] and exacerbated, given the shorter anterior cranial base noted above.

Evidence for developmental compensation, nevertheless, is also revealed by the present study. It was found that the Korean children had taller maxillary alveolar processes, and this additional growth may represent an attempt by the maxillary incisors to regain a positive overjet in the developing dentition. Dental compensation appears to be more marked in the Korean child, and at first sight the reasons for this are not evident. However, clues are gleaned from a study of their comparative palatal morphology. It appears that the Korean palatal plane angle is more acute, and this concept is reinforced by the finding that an obtuse palatoalveolar angle (PNS-ANS-A) is evident in Korean children. Therefore, while the European-American maxillary alveolus is less compensatory, alveolar angulation is more obtuse in the Koreans, and this angulation may contribute to the flatter facial profile associated with these children. Therefore, it appears that European-American Class III malocclusions are more strongly influenced by a cranial base that exhibits deficient orthocephalization[20-22] rather than by midfacial morphology, whereas the Korean appearance is influenced predominantly by a shorter cranial base and midface, but a higher degree of dental compensation. Therefore, the good results achieved with maxillary protraction in Korean children with Class III malocclusions[41] may have been related to this dental compensation tendency.

In the study of malocclusions, the mandible often is an important component. Murata et al[24] suggested that skeletal Class III malocclusion is due to a larger, prognathic mandible in Japanese females (who were found to have larger Go-P and Ar-Go dimensions in linear analysis). Not surprisingly, therefore, we also found that mandibular morphology makes a significant contribution to the Korean and European-American Class III profiles. In the Koreans, mandibular parameters were larger, and these increased dimensions may exacerbate the Class III profile when the comorphology of the cranial base and midface are taken into consideration. Similarly, in the analysis of the Class III deciduous dentition in Chinese children, Chang et al[42] found mandibular length significantly greater and the mandible positioned further forward. Such relative mandibular hyperplasia presumably emanates from a proliferative condylar cartilage that may be directive in its nature.

Other evidence, however, refutes such simplistic explanations. The present study found the European-American ramus to be shorter than that of Korean children, while there were no significant differences in corpus lengths. But the Korean children were characterized by more acute mandibular angles; smaller mandibular angles presumably would contribute to the expression of mandibular prognathism. Therefore, the shape of the mandible, presumably determined by genetic inheritance and epigenetic remodeling, may be one factor that predisposes to the prognathic mandibular appearance. Given the comorphology of the Korean cranial base and midface, the degree of mandibular prognathism is relatively greater compared to European-American counterparts. Yet, other subcomponents also may contribute to this facial appearance.

There is some evidence in support of the notion that European-American children have a better-developed mental symphyseal region compared to their Korean counterparts. This symphyseal difference is indicated by the finding that angle Co-Gn-B was more acute in the European-Americans and supported further by the finding that the symphyseal angles Id-Gn-Go and Id-M-Go also were more acute in the European-American children. Such findings add quantitative support to the observation that the Korean profile is similar to other Asian populations that feature a more flattened facial profile. Further evidence for this notion stems from the findings of the frontonasal parameters analyzed in this study. The Korean children were typified by obtuse frontonasal angles that appear to contribute to a distinctive facial profile. Differences in frontal bone morphology have been studied by Hoyte,[43] who found that virtually all sagittal increase of the anterior cranial base, except increasing frontal bone thickness, is completed by 7 years of age. Less postnatal deposition may occur in the Korean child and, allied with differences in nasal morphology that still require determination, may yield the facial appearance typified by Korean children.

In view of the above findings, ideal occlusal relationships and well-balanced facial harmony may not be obtained when orthodontic management protocols are based on Western norms in the treatment of Korean children with Class III malocclusions. Indeed, Park et al[44] managed Korean mandibular prognathic patients with a combination of surgical procedures in collaboration with orthodontic treatment to yield good postoperative results.

In summary, Class III malocclusion appears to develop in Korean children because of smaller anterior cranial base and midfacial dimensions, exacerbated by a large and less favorable mandibular morphology. For the European-American child with Class III malocclusion, the craniofacial morphology is typified by deficient orthocephalization of the cranial base[20-22] and exacerbated by a prominent mandible and symphyseal morphology.[39] Such craniofacial heterogeneity in Class III malocclusions has been noted in other ethnic groups also, and this preliminary study corroborates well with other cephalometric studies. Given the wide range of clinical presentations of Class III malocclusions, therefore, the application of similar treatment modalities requires further validation. Future work will employ more sophisticated geometric morphometrics as well as molecular genetics to unravel the heterogeneic developmental mechanisms responsible for the phenotypic diversity of Class III malocclusions.

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