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Scientific Section

Comparison of Mandibular Morphology in Korean and European-American Children with Class III Malocclusions using Finite-Element Morphometry

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Abstract. *The purpose of this study was to determine whether the morphology of the mandible differed in subjects of diverse ethnic origin exhibiting Class III malocclusions. Lateral cephalographs of 147 children of either Korean or European-American descent aged between 5 and 11 years were compared. The cephalographs were subdivided into seven age- and sex-matched groups, traced, and eight mandibular homologous landmarks digitized. Average mandibular geometries, scaled to an equivalent size, were computed using Procrustes superimposition and subjected to ANOVA. Graphical analysis using a colour-coded finite element (FEM) programme was used to localize differences in morphology. Results indicated that the overall mean Korean and European-American mandibular configurations differed statistically ($P < 0.001$) and statistical difference was maintained at all age-wise comparisons. Comparing Korean and European-American Class III mandibular configurations for local size-change, FEM analysis revealed that the Korean condylar and mental regions generally were smaller (≈15–20 per cent decrease in size, respectively). However, an antero-posterior increase in the size of the mandibular corpus was most apparent in the incisor alveolus region (≈35 per cent increase in size). For shape-change, the Korean and European-American mandibular configurations were fairly isotropic except in the symphyseal and incisor alveolus regions. Dissimilarities in mandibular morphology are identifiable particularly in the dento-alveolar regions in subjects of diverse ethnic origin exhibiting Class III malocclusions. These differences may reflect genetic and/or environmental influences that might determine the severity and prevalence of the condition, and its subsequent clinical management.*

Index words: Class III, Craniofacial, Finite element, Korean, Mandible, Malocclusion.

Introduction

Individuals with Class III malocclusions are more likely to seek evaluation than those with mandibular deficiencies (Proffit *et al*., 1990). Recently, there has been renewed interest in the management of this condition, but population norms derived from one sub-population may not be valid for others of differing ethnicity (Lew *et al*., 1993). Indeed, it has been noted that Chinese school children and adults have a higher incidence of Class III malocclusion compared to Caucasians (Mak, 1969; Johnson *et al*., 1978; Woon *et al*., 1989; Lew *et al*., 1993; Tang 1994a,b). Similarly, in studies of the prevalence of Class III relationship in the Japanese, estimates of the frequencies of anterior crossbite and edge-to-edge incisal relationships range from 2 to 13 per cent and 2 to 7 per cent, respectively (Endo, 1971; Susami *et al*., 1972; Kitai *et al*., 1989). Moreover, Yang (1990) discovered that about half of the orthodontic patients presenting for treatment in South Korea exhibited Class III malocclusions. These studies highlight the need to establish well-balanced facial norms for the establishment of treatment in children of Southeast (SE) Asian origins (Soh and Lew, 1992).

In children of SE Asian origins, different skeletal patterns exist even in those with normal occlusions (Shen *et al*., 1996). Indeed, Chang and Huang (1998) noted that certain cases of Class I occlusion exhibited an underlying Class III character in young Chinese adults. Class III malocclusions

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are believed to be the result of excessive growth of the mandible with respect to the maxilla and/or cranial base (Sugawara and Mitani, 1997), but Karlsen (1998) noted mandibular skeletal protrusion was associated with forward positioning of the mandible relative to the anterior cranial base, and this may yield a Class III relationship without involving any morphological changes of the mandible. Although anterior displacement of the mandible may play a part (Kerr and Ten Have, 1988), it is unclear whether Class III malocclusion is caused by variations in mandibular position, mandibular size, or a combination of the two (Kerr *et al.*, 1994).

Because of the tendency toward relapse in treated Class III cases, individual variation in growth and treatment response need to be assessed pre-operatively (Ngan *et al.*, 1997). Kocadereli (1998) believes that initiation of treatment at an early age is beneficial for the treatment of Class III cases. Indeed, Franchi and Baccetti (1998) describe a Class III case treated in the primary dentition, but Sugawara and Mitani (1997) are of the opinion that inherited prognathic characteristics of Class III malocclusion seldom are altered through chincap appliances. Given the wide range of clinical presentations of Class III malocclusions, the application of similar treatment modalities requires further investigation. In previous studies (Singh *et al.*, 1998a, 1999), geometric morphometrics were employed to investigate the notion that heterogeneic developmental mechanisms might be responsible for the craniofacial phenotypic diversity of Class III malocclusions. The aim of this current study is to determine whether the morphology of the mandible differs in subjects of diverse ethnic origin with Class III malocclusions. Rejection of the null hypothesis, that mandibular morphology is similar across different racial types, would raise the premise that genetic and/or environmental factors are responsible for mandibular phenotypes that might need to be taken into account prior to the initiation of treatment modalities.

TABLE 1 *The number of European-American subjects in each group between 5 and 11 years with Angle Class III molar malocclusion is illustrated. Similarly, the number of Korean subjects obtained from a private orthodontic practice are also shown. The total sample included an approximately equal number of males and females*

Age (years)	Korean	European-American
5	7	9
6	14	7
7	14	10
8	14	10
9	9	17
10	9	11
11	6	10
Total	73	74

Materials and methods

After obtaining ethical permission, pretreatment lateral cephalographs of 74 European-American subjects aged between 5 and 11 years with Angle's Class III molar malocclusion were retrieved (Guyer *et al.*, 1986). A further 73 cephalographs of untreated Korean subjects with a similar Class III molar relationship also were obtained from a Korean orthodontic practice. The total sample included an approximately equal number of age-matched males and females with negative history of airway problems and no obvious vertical skeletal problems (Table 1). It was presumed that all radiographs were taken from subjects exhibiting left-right symmetry and that the central X-ray passed along the trans-meatal axis when the teeth were in occlusion. The magnification of each film was standardized to 8 per cent. The chronological age was assumed to match developmental age in this study as carpal ages were unavailable.

Each lateral cephalograph was traced on frosted acetate film (0·03-inch thick) and checked by one investigator (GDS). Digitization of landmark co-ordinates from cephalographs taped to a light box of uniform brightness was achieved using appropriate software and a digitising tablet (Numonics Inc., Montgomeryville, PA). Eight homologous mandibular landmarks were identified and digitized (Figure 1). These landmarks encompassed the lateral profile of the mandible and permitted the construction of the mandibular configurations to be studied. For the x, y co-ordinates of the landmarks, the digitization error was <1 per cent on duplicate digitization ($P > 0{\cdot}05$). Therefore, the landmarks were deemed to be identified reliably and further analyses warranted.

For statistical analysis, a Procrustes method was employed to determine the variance around each landmark and express it as a root-mean square. Therefore, each overall sample was subjected to Procrustes superimposition and each group was represented as a mean and variance. The Procrustes routine was implemented on an Amiga 3000 computer, and an average eight-noded geometry for each age group was determined using a generalized orthogonal Procrustes analysis (Gower, 1975). Following this method, every object's co-ordinates were translated, rotated and scaled iteratively until the least-squares fit of all configurations was no longer improved. Therefore, all configurations were registered with respect to one another and, as a result of this procedure, geometric mandibular configurations were scaled to equivalent areas, avoiding problems introduced by differences in size. To determine whether mandibular landmark configurations differed between ethnic types and at each age interval, each European-American group mean geometry was compared statistically to the age-matched Korean group average geometry using ANOVA (Gower, 1975). In each instance, the null hypothesis was that the European-American mean was not significantly different from the Korean average. Residuals and corresponding F values were computed, tabulated, and compared.

In order to demonstrate sources of heterogeneic mandibular morphology, a finite element morphometry (FEM) analysis was undertaken that incorporated a spline interpolation function (Bookstein, 1991). Based on this approach, differences can be described graphically as a size- and/or shape-change (e.g. Singh *et al.*, 1997a,b, 1998b). The FEM software was written in 'C' and implemented on an Amiga 3000 computer. The overall mean European-American configuration was taken as the initial geometry, and this configuration was compared to the overall Korean mean. Size-change variables were computed as the product of the principal extensions, while shape-change measures were calculated as the ratio of the greater divided by the lesser principal extension. The mean geometries at each age interval also were compared (≈10 subjects per group; ≈5 males, ≈5 females per group). Therefore, eight comparisons were generated in total and deformation values were computed for at least 2000 points per geometry for graphical display. A log-linear interpolation of the size- and shape-values was used to generate a colour map. These form-change measures then were colour-mapped into each European-American configuration to provide graphical displays of geometrical change for the overall and each age-wise comparison.

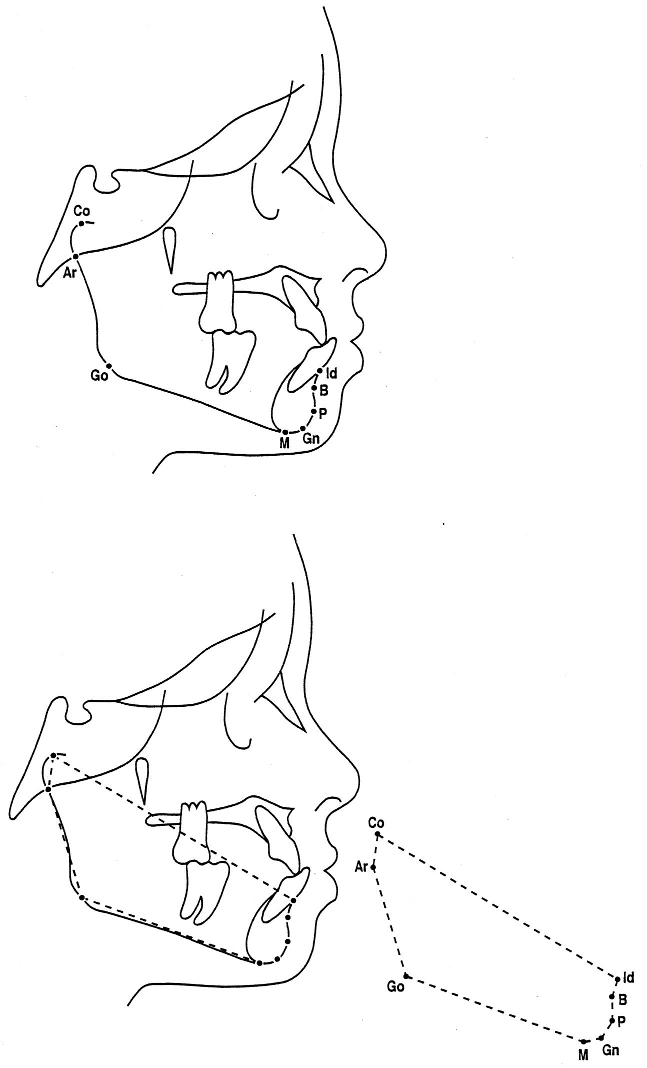

FIG. 1 Mandibular landmarks superimposed on a lateral cephalographic tracing of a Class III profile. Ar, articulare (posterior intersection of condylar head and posterior cranial base); B, supramentale (point B, deepest point on mandibular alveolus); Co, condylion (superior-most point on mandibular condyle);Gn, gnathion (most anterior-inferior point on mandibular symphysis); Go, gonion (midpoint at angle of mandible); Id, infradentale (most antero-superior point on mandibular alveolus); M, menton (inferior-most point on mandibular symphysis);P, pogonion (anterior-most point on mandibular symphysis).

Results

Table 2 shows the residuals from the overall Procrustes analysis and those at each age when compared using an F distribution. Statistically significant differences between the European-American and Korean mandibular configurations occurred at $P < 0{\cdot}001$ for the total sample. When the total sample was decomposed over seven age intervals, the comparisons maintained statistical significance at all age groups tested.

Comparing the overall European-American and Korean mandibular configurations for size-change graphically, FEM revealed that a localized area of negative allometry was discernible for the Korean configuration, with its epicentre based between the condylar head and neck regions (Figure 2a; ≈ 15 per cent decrease in size). Similarly, a region of negative allometry was localized between B and Gn in the mental region with an epicentre based around P. A decrease in size of ≈ 20 per cent was evident in that region (Figure 2a). In contrast, antero-posterior stretching of the mandibular corpus was evident for the Korean configuration with a large degree of positive allometry demonstrable at Id (35 per cent increase in size).

Decomposition of the sample into the seven age- and sex-matched groups revealed that a similar pattern of size-change emerged at ages 5–11 years (Figure 2b–h). The Korean condylar region showed a decreased size at ages 5 and 9 years, whereas it was largely isometric (invariant with respect to local size change) in the other age groups. Similarly, for all age groups (Figures 2b–h), the Korean mental region exhibited a negative allometry (≈ 25–30 per cent decrease in size), although the epicentre of the diminution varied in its location in that region. In contrast, corpus elongation was evident in all configurations, varying between 10–40 per cent increase in size. Invariably, the mandibular incisor alveolus showed positive allometry (≈ 20–80 per cent increase in size) in all Korean age groups tested.

For shape-change, the overall Korean Class III mandibular nodal mesh was predominantly isotropic, with evidence of anisotropy restricted to areas in the anterior-most regions of the mandibular configuration (Figure 3a). Perhaps not surprisingly, shape changes in the 5–11 year old age groups were remarkably similar (Figures 3b–h). The

TABLE 2 *Procrustes analysis of mean mandibular configurations of European-American and Korean Class III subjects. When the total sample is decomposed into seven age groups, all groups maintain statistical significance*

Age (years)	5	6	7	8	9	10	11	Total
Residual	0·0005	0·0002	0·0006	0·0002	0·0004	0·0004	0·0007	0·0007
F-value	1·11	0·88	2·57	0·93	1·65	1·75	1·85	2·37
$P <$	0·01	0·05	0·001	0·05	0·001	0·01	0·001	0·001

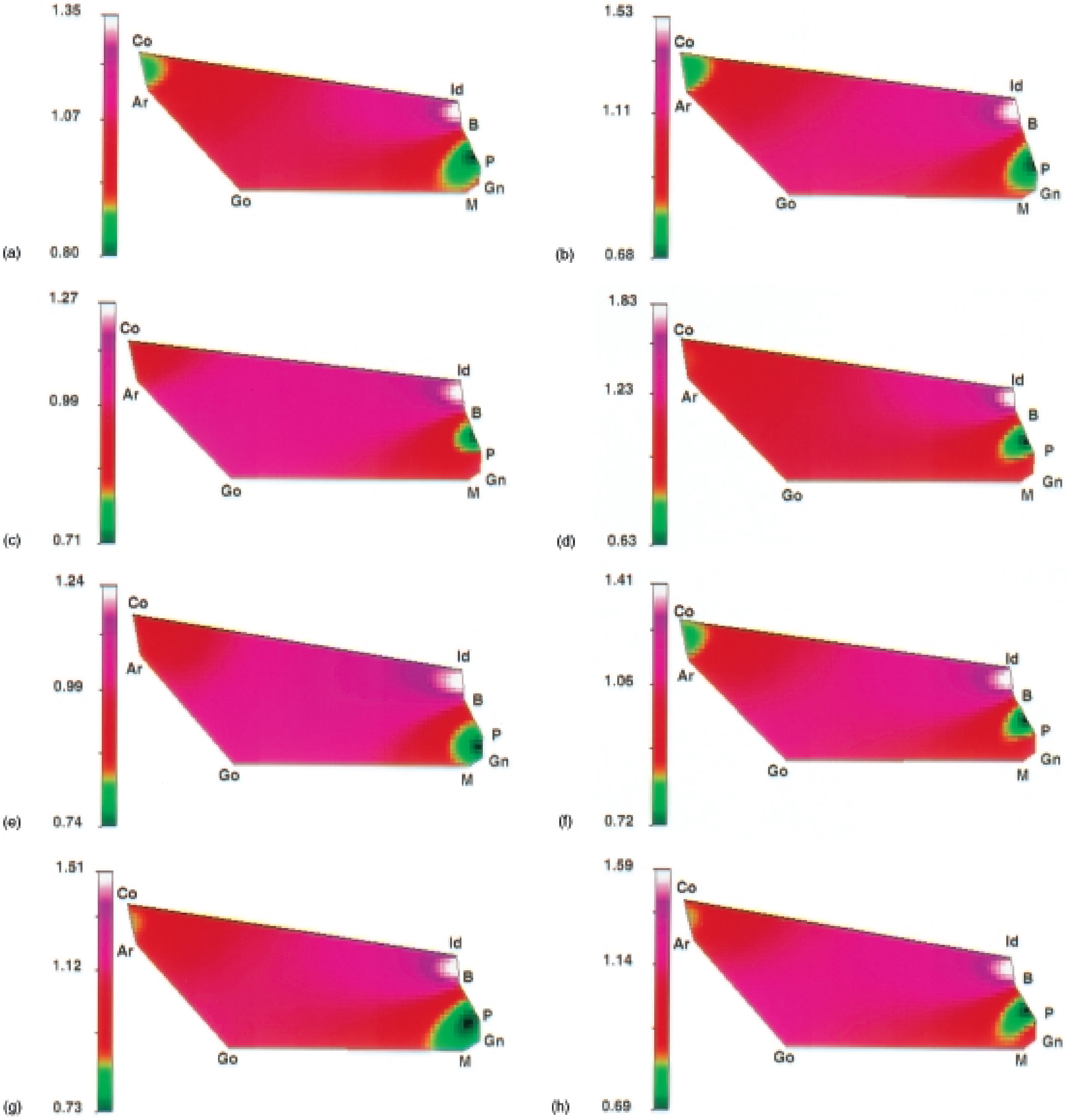

FIG. 2 Comparison of European-American and Korean mandibular configurations for size-change. The colour scale bar indicates the degree of size-change. (a) Overall comparison. In the condylar region between Co and Ar, a decrease in size of ≈ 20 per cent is evident. The mandibular ramus and corpus, however, show a moderate increase in size (≈ 5–10 per cent), but ≈ 30 per cent increase in size is visible at the incisor alveolus at Id. In contrast, in the symphysis/mental region between B and M a decrease in size (≈ 15 per cent) is discernible. (b) Age 5 years. Between Co and Ar, a decrease in size of ≈ 30 per cent is visible. The ramus and corpus show ≈ 10–25 per cent increase in size, rising to ≈ 50 per cent in the incisor alveolus region at Id. The symphysis/mental region shows a decrease in size (≈ 20 per cent). (c) Age 6 years. Co and Ar is predominantly isometric (no size change). An increase in size of ≈ 10–20 per cent is seen, however, extending across the ramus and corpus. The anterior aspect of incisor alveolar region shows ≈ 25 per cent increase in size while the anterior-most region of the symphysis shows a ≈ 20 per cent decrease in size. (d) Age 7 years. The condyle, ramus, and corpus show mild increase in size, and as the incisor alveolus region is reached an increase in size of ≈ 80 per cent is seen. The anterior aspect of the symphysis region, however, shows a decrease in size (≈ 30 per cent). (e) Age 8 years. The condylar region between Co and Ar is predominantly isometric. An increase in size of ≈ 10–20 per cent is seen extending across the ramus and corpus with the anterior aspect of the incisor alveolar region showing > 20 per cent increase in size. In contrast, the anterior-most region of the symphysis shows a ≈ 20 per cent decrease in size. (f) Age 9 years. Between Co and Ar shows a decrease in size of ≈ 20 per cent is found. In contrast, the ramus and corpus show increases in size of ≈ 5–25 per cent with the incisor alveolar region showing ≈ 40 per cent increase in size at Id. Similar to the other groups, between B and P the symphysis shows a ≈ 20 per cent decrease in size. (g) Age 10 years. The condylar region between Co and Ar is predominantly isometric while the ramus and corpus show increases in size of ≈ 10–25 per cent. Similarly, the incisor alveolar region shows ≈ 50 per cent increase in size. In contrast, the anterior-most parts of the symphysis/mental region show negative allometry (≈ 20 per cent decrease in size). (h) Age 11 years. The condylar region is predominantly isometric while an increase in size of ≈ 15–40 per cent is seen extending across the ramus and corpus. The anterior aspect of the incisor alveolar region shows ≈ 55 per cent increase in size. In contrast, the anterior-most region of the symphysis shows a ≈ 25 per cent decrease in size.

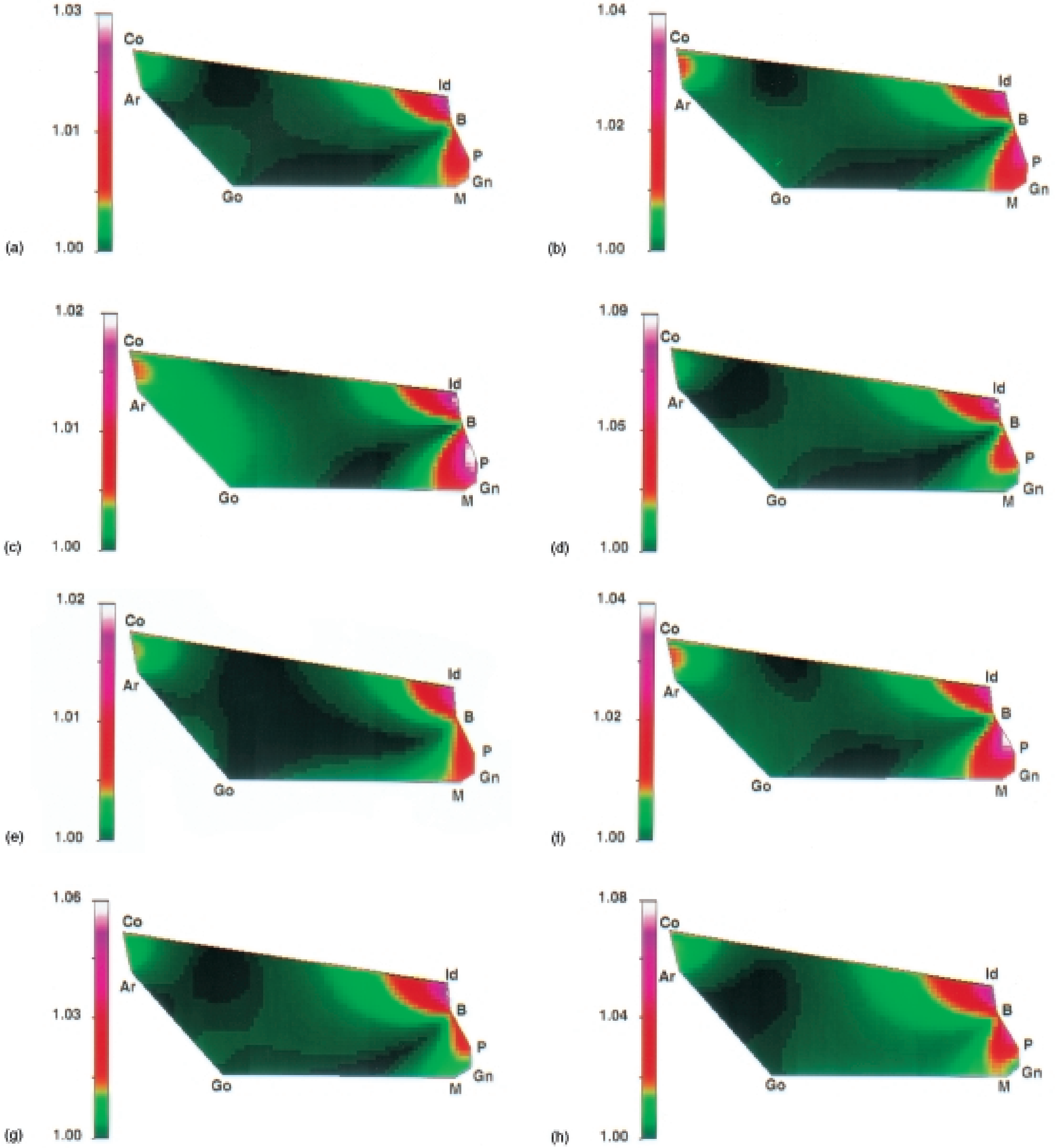

FIG. 3 Comparison of European-American and Korean mandibular configurations for shape-change. The colour scale bar indicates the degree of shape-change. (a) Overall comparison. The vast majority of the configuration is isotropic, with low levels of anisotropy in the anterior-most part of the symphysis/mental region, extending from Id to M. (b) Age 5 years. Anisotropy is restricted to a small, localised area of the condylar region. Although low levels of anisotropy are discernible in the anterior-most part of the symphysis/mental region, the vast majority of the configuration is isotropic. (c) Age 6 years. Anisotropy is restricted to a small, localised area of the condylar region. Low levels of anisotropy are discernible in the anterior-most part of the symphysis/mental region, but most of the configuration is isotropic. (d) Age 7 years. Anisotropy is restricted to a small, localised area of the antero-superior parts of the symphysis/mental region, but the vast majority of the configuration is isotropic. (e) Age 8 years. Some minor anisotropy is evident for the condylar region and low levels of anisotropy are discernible in the anterior-most part of the symphysis/mental region. The remainder of the configuration, however, is isotropic. (f) Age 9 years. Anistropy is restricted to a small, localised area of the condylar region. Low levels of anisotropy are discernible in the anterior-most part of the symphsis/mental region, but most of the configuration is isotropic. (g) Age 10 years. Some anisotropy is discernible in the antero-superior parts of the symphysis/mental region, but the majority of the configuration is isotropic. (h) Age 11 years. Similar to the 10-year-olds, low levels of anistropy are discernible in the antero-superior parts of the symphysis/mental region, but the majority of the configuration is isotropic.

TABLE 3 *FEM analysis comparing Korean and European-American Class III mandibular nodal values for size and shape change*

	Co	Ar	M	Gn	P	B	Id
Size	0·923	1·051	0·911	0·908	0·837	1·195	1·314
Shape	1·002	1·000	1·005	1·005	1·011	1·018	1·021

majority of the configurations were isotropic, with evidence of anisotropy localized between an area extending from the mandibular incisor alveolus over the anterior-most part of the symphyseal/mental region. Table 3 summarizes nodal values for size- and shape-change using FEM to compare European-American and Korean mandibular configurations. It appears that mandibular phenotypic diversity in Korean and European-American children arises predominantly from a combination of corpus/alveolar elongation and mental diminution.

Discussion

Geometric morphometrics permit a rigorous analysis of shape- and size-change. For example, Richtsmeier and Cheverud (1986), and Lozanoff and Diewert (1989) note that decomposition of morphological integration is possible using FEM. Therefore, the application of FEM is warranted in the analysis of craniofacial growth (Motoyoshi *et al*., 1989). In this study, sexes were combined due to the relatively small sample size. Combining sexes in the 5–11-year age range generally is satisfactory because of only the modest sexual dimorphism of craniofacial structures present at these prepubertal ages (Riolo *et al*., 1974). Furthermore, the present study is based upon a cross-sectional sample of randomly selected Korean children and these have been compared with their European-American counterparts (Guyer *et al*., 1986). While acknowledging that classification of Class III malocclusions may be based upon skeletal pattern, incisor relationships, molar occlusions, and cephalometric parameters, in this current study children exhibiting a molar Class III malocclusions were deployed for geometric morphometric investigation. In addition to these assumptions, automated landmark detection was not possible in this study. Indeed, landmarks on the inferior border of the mandible, gonial and symphyseal regions were employed even though opinion is emerging that resorption might produce high variance at these sites and that landmarks at more stable sites such as nerve foraminae might be preferable. Despite these limitations, morphological differences were detectable using FEM, presumably reflecting genetic and/or environmental influences on mandibular heterogeneity.

In this current study it was found that mandibular morphology differs significantly when Korean and European-American Class III configurations are compared using FEM. In previous studies of Class III malocclusions, mandibular dimensions often are measured using linear analysis. For example, Chang *et al*. (1992) found mandibular length significantly greater in Chinese children with Class III malocclusion. Other evidence, however, contrasts with such generic findings. It has been reported that the European-American mandibular ramus is shorter than that of Korean children, while there are no significant differences in corpus lengths when analysing size-incorporated data (Singh *et al*., 1998a). Using scaled data in this current study, size differences were discerned and morphological differences localized using FEM. Obradovic *et al*. (1992) note that thickness of the cortical plates vary within the mandibular ramus, a finding that might help explain putative genetic factors and epigenetic remodelling that predispose to the prognathic mandibular appearance. Importantly, our results support the view that the skeletal framework for Class III malocclusions is established before the prepubertal growth period (Sugawara and Mitani, 1997).

It is not known whether treatment-induced changes reported after early treatment of Class III occlusions are maintained during the pubertal growth period. The distance from the condyle to the chin (effective mandibular length) increased significantly less in a group of Japanese prepubertal females treated with chincup therapy (Deguchi and McNamara, 1999). Similarly, orthopaedic treatment of Class III malocclusion induces favourable size- and shape-changes of the mandible in children at the early mixed dentition stage (Baccetti *et al*., 1998), and significantly smaller increments in mandibular total length can be achieved in children with Class III malocclusions undergoing very early treatment (Baccetti and Tollaro, 1998). Similarly, in Korean children, mandibular growth was inhibited with maxillary protraction (Sung and Baik, 1998). Yet, the effect of the pubertal growth spurt of the mandible in these patients remains unknown. With combined palatal expansion and facemask therapy, correction of the Class III condition was due more to the maxilla than the mandible (Nartallo-Turley and Turley, 1998), reflecting the view that inherited prognathic characteristics of Class III seldom are altered through chincap appliances (Sugawara and Mitani, 1997). Indeed, some correction of Class III correction can be lost because of mandibular growth (Williams *et al*., 1997). Therefore, anticipation of pubertal growth of the mandible is an essential step stage in the successful management of Class III malocclusions in the actively growing patient, an orthodontic paradigm that appears to remain elusive.

Dento-alveolar effects contribute to the correction of Class III malocclusion (Williams *et al*., 1997). For example, the mandibular incisors moved posteriorly with Delaire mask therapy (Kilicoglu and Kirlic, 1998), while the mandible rotated posteriorly. However, there is some evidence in support of the notion that European-American children have a better developed mental symphyseal region when compared to their Korean counterparts (Singh *et al*., 1998a, 1999). Indeed, the inclination of lower incisors and mandibular symphysis may differ (Nojima *et al*., 1998). Dental compensation with proclination of maxillary incisors in Southern Chinese children following maxillary expansion and protraction helps camouflage the Class III relationship, but some relapse has been noted (Ngan *et al*., 1998). Ngan *et al*. (1997) suggest that treatments initiated at the time of initial eruption of the upper central incisors might help to maintain the corrected occlusions after completion of treatment. Some patients, however, revert back to a negative overjet because of excessive horizontal mandibular growth that was not compensated by proclination of the upper incisors (Ngan *et al*., 1997). Kameda (1992) noted that some 50 per cent of Japanese orthodontic patients had mandibular protrusion and bimaxillary protrusion. Therefore, bimaxillary protrusion of the mandibular incisors is a likely feature of the Korean Class III mandible and this feature might increase the severity and prevalence of an anterior crossbite.

In conclusion, the phenotypic diversity of mandibular 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. Although changes in occlusion in SE Asian children might indicate environmental influences (Corruccini and Lee, 1984), the variation in mandibular phenotypic features of patients with untreated Class III malocclusions also suggests that genetic factors might have an influence on the morphologic characteristics of this malocclusion (Katoh *et al*., 1998). Class III malocclusion is characterized by several developmental features and molecular genetic investigations of this particular craniofacial anomaly hold much promise for establishing a genetic method for the diagnosis of Class III malocclusion, enabling treatment far earlier than currently possible.

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