Morphometry of the Midfacial Complex in Subjects With Class III Malocclusions: Procrustes, Euclidean, and Cephalometric Analyses

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The purpose of this study was to determine whether the morphology of the midface differed in subjects with a retrognathic midfacial appearance (Class III malocclusions) using a combination of morphometric and cephalometric analyses. After obtaining appropriate consent, lateral cephalographs of 133 children of European-American descent, ages 5–11 years, were compared: 73 had Class III malocclusion, 60 had normal (Class I) occlusion. The cephalographs were traced and subdivided into seven age- and sex-matched groups. Average geometries based upon seven nodes (pterygoid point, PTS; rhinion, RO; posterior nasal spine, PNS; midpalatal point, MPP; anterior nasal spine, ANS; subspinale, A; prosthion, Pr), scaled to an equivalent size, were compared using a Procrustes routine. Euclidean distance matrix analysis (EDMA) was employed to localize differences in morphology. Bivariate analyses on unscaled data utilizing nine linear and six angular measurements were also undertaken. Results from Procrustes and EDMA analyses indicated that although the overall midfacial configurations differed statistically ($P < 0.05$), only about half of the seven age sub-groups maintained significance. Similarly, only four of the nine linear measures (PNS-MPP, MPP-ANS, A-Pr and PTS-RO) and two of the six angular parameters (PTS-RO-ANS and ANS-A-Pr) tested were significantly different ($P < 0.05$). Therefore, midfacial morphometric variability and morphological diversity may mask statistical differences. It is concluded that the midface may be the defining craniofacial component in the final appearance of Class III malocclusions compared to other craniofacial components, including the cranial base and mandible. Clin. Anat. 11:162–170, 1998.   © 1998 Wiley-Liss, Inc.

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INTRODUCTION

A greater understanding of the growth of the maxillary complex is required to comprehend how departure from normal growth patterns leads to the formation of Class III craniofacial profiles with retrognathic midfacial appearances. Typically, Class III malocclusions exhibit an altered molar occlusion with a horizontal discrepancy between the maxilla and mandible such that the mandible appears protrusive when the teeth are in occlusion (Fig. 1a). De Alba et al. (1979a) studied the relationship between active growth and induced anatomic changes of the midface, employing photoelastic cephalometry, and reported that orthodontic biomechanics affected the zygomaticotempo-ral, zygomaticofrontal, and frontomaxillary sutures. Later, De Alba et al. (1979b) reported counterclockwise palatal and maxillary rotations in Class III photoelastic models. Similarly, using human autopsy material, Melsen and Melsen (1982) suggested that remodeling processes of the palatal bones reflect different functional and intrinsic growth patterns and that the center for spatial changes of the maxillary
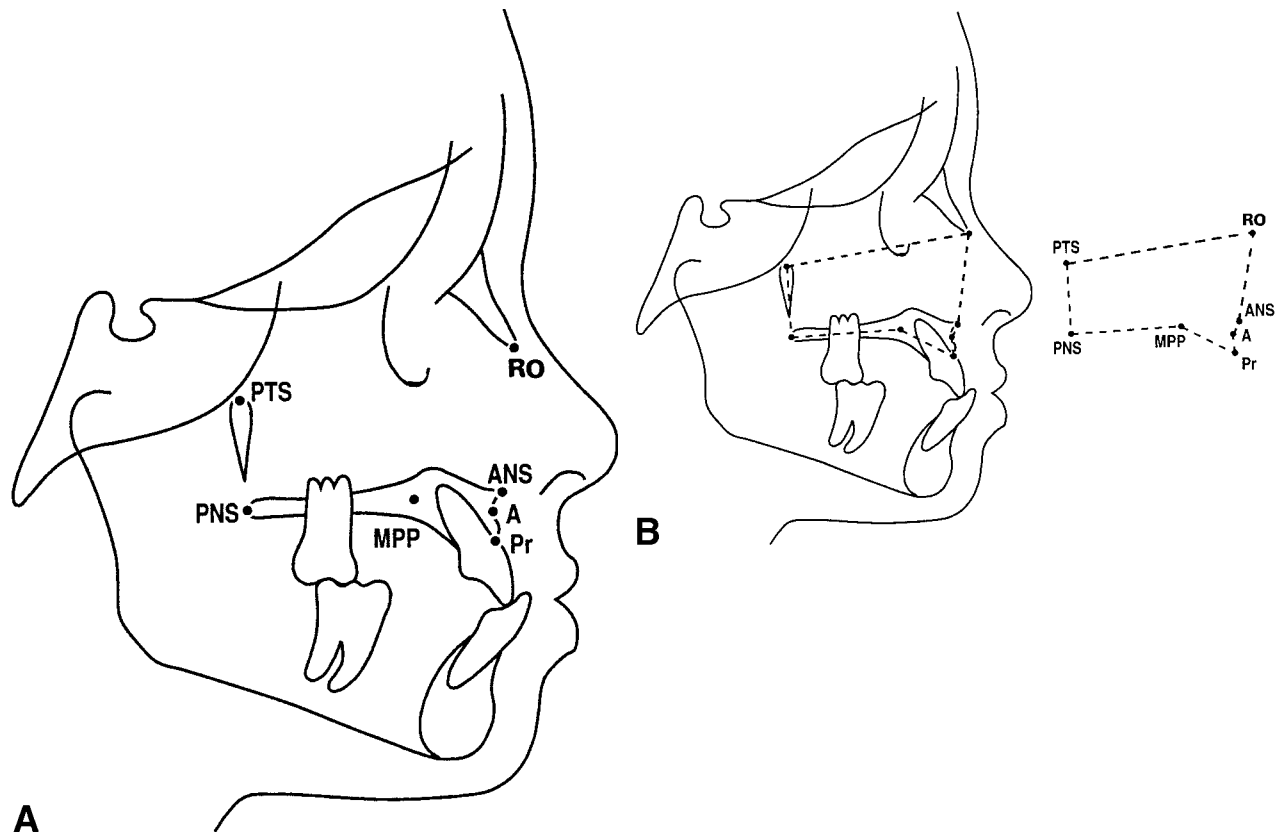
Fig. 1. (**a**) Homologous landmarks employed for the construction of a seven-noded geometry to define the midfacial complex. A, subspinale: point of maximum concavity inferior to the anterior nasal spine on maxillary alveolus; ANS, anterior nasal spine: anteriormost point on anterior nasal spine; MPP, midpalatal point: midpoint between outlines of the nasal and oral palatal surfaces and the point of maximal palatal oral curvature; RO, rhinion: inferiormost point on tip of nasal bone; PNS, posterior nasal spine: posteriormost point on posterior nasal spine; Pr, prosthion: antero-inferior point of maxillary incisor alveolus; PTS, pterygoid point: superiormost point on outline of pterygoid fissure. (**b**) Midfacial geometry derived from the seven homologous landmarks employed superimposed on a tracing of a Class III cephalograph, and shown separately. A: subspinale; ANS: anterior nasal spine; MPP: midpalatal point; RO: rhinion; PNS: posterior nasal spine; Pr: prosthion; PTS: pterygoid point.

complex could be localized in the palatomaxillary complex.

Later studies (e.g., Mooney and Siegel, 1986; Tollaro et al., 1994) suggested that midfacial profiles are established early in fetal development and are maintained postnatally. It has been suggested that sutures of the midface, in particular the transverse palatine suture, may be important in the growth of the bony palate (King and Scheiderman, 1993; Njio and Kjaer, 1993), but Iseri and Solow (1995) recommend great caution in the interpretation of clinical treatment analyses based upon superimposition of the bony palate for growth studies. For Class III malocclusions, Williams and Andersen (1986) suggest that no single morphological trait for Class III malocclusions can be isolated because of the existence of different skeletal combinations. Therefore, the relationship between occlusion and craniofacial morphology remains unclear

(Siriwat and Jarabak, 1985; Keeling et al., 1989), and in a more recent longitudinal study, Nanda and Ghosh (1995) raised questions about growth prediction and its applications because of individual variation in growth pattern.

The purpose of this study is to investigate the morphological differences within the midfacial complex of subjects with normal occlusion and those with a retrognathic midfacial profile associated with Class III malocclusions. Typically, cephalometry involves the direct measurement of linear distances and angles from lateral cephalographs. Cephalometric analysis, however, suffers from deficiencies in that registration points may not remain stationary during growth and are not corrected for size. Thus an individual may display a greater absolute length compared to a smaller subject, when in fact this value may be less if it is normalized for size. In contrast, new geometric morpho-

metrics depend upon the analysis of parameters derived from landmarks of size-scaled configurations irrespective of registration. In view of the shortcomings of conventional cephalometrics (Moyers and Bookstein, 1979), this study will employ a combination of morphometric (Singh et al., 1997a,b,c) and cephalometric techniques to test the hypothesis that the midface creates the characteristic difference between subjects with a normal occlusion and those with a retrognathic midfacial appearance associated with Class III malocclusions. In the event that the null hypothesis is vindicated, the role of other craniofacial developmental parameters such as the cranial base and mandible also might be more clearly comprehended.

MATERIALS AND METHODS

Sample

The samples used in this study were derived from a total of 133 children of European-American descent between the ages of 5–11 years. Seventy-three subjects with Class III molar occlusion (Guyer et al., 1986) were compared to 60 children with a normal Class I molar relationship. The total sample included approximately equal numbers of male and female children, with negative history of airway problems and no obvious vertical jaw discrepancies. The total sample comprised seven age-matched (5, 6, 7, 8, 9, 10, 11 years) and sex-matched groups for each occlusal type (Class I, Class III). The chronological age was assumed to match developmental age in this study as carpal radiographs were unavailable.

Each lateral cephalograph used in this study was standardized to an 8% enlargement. It was presumed that all subjects showed left-right symmetry and that the central X-ray passed along the transmeatal axis while the teeth were in occlusion. Each lateral cephalograph was traced on frosted acetate film (0.03″ thick) and checked by one investigator (GDS). To increase the reliability of the landmarks selected, cephalographs were taped to a light box of uniform brightness in a darkened room and digitization of landmarks was achieved using a cross-wires cursor. Seven homologous midfacial landmarks were identified and digitized (Fig. 1a, Table 1), employing appropriate software and a digitizing table (Numonics, Montgomeryville, PA). These landmarks showed a discrepancy of <1% on duplicate digitization and were deemed to be reliably identified.

Morphometric and Statistical Analysis

To determine whether landmark configurations differed between the two occlusal types, a Procrustes routine was implemented on an Amiga 3000. A mean

TABLE 1. Homologous Landmarks Digitized From Lateral Cephalographs*

A	Subspinale:	point of maximum concavity inferior to the anterior nasal spine on maxillary alveolus
ANS	Anterior nasal spine:	anteriormost point on anterior nasal spine
MPP	Midpalatal point:	point midway between the outlines of the nasal and oral palatal surfaces
RO	Rhinion:	inferiormost point on tip of nasal bone
PNS	Posterior nasal spine:	posteriormost point on posterior nasal spine
Pr	Prosthion:	antero-inferior point of maxillary incisor alveolus
PTS	Pterygoid point:	superiormost point on lateral outline of pterygoid fissure

Linear distances (mm)	Angular measurements (°)
PNS—MPP	PNS—MPP—ANS
MPP—ANS	PNS—ANS—A
PNS—ANS	PNS—ANS—Pr
ANS—A	ANS—PNS—Pr
ANS—Pr	ANS—A—Pr
PNS—Pr	PTS—RO—ANS
A—Pr	
PTS—RO	
RO—ANS	

*Landmarks were employed to construct seven-noded midfacial geometries for Procrustes and EDMA analyses. Linear distances (mm) and angular measures (°) that were subjected to conventional bivariate analysis are also defined.

seven-node geometry for each occlusal group was determined (Fig. 1b), using a generalized orthogonal Procrustes analysis (Gower, 1975; Rohlf and Slice, 1990; Singh et al., 1997a). ("Procrustes" refers to the Greek giant who would stretch or shorten victims to fit a bed and is now used in the context of superimposition methods.) Following this method, every object's coordinates were translated, rotated, and scaled repeatedly until the least-squares fit of all configurations was no longer improved. Therefore, all configurations were scaled to an equivalent size and registered with respect to one another. The mean geometry of each Class I group was also compared statistically with that of the age-matched Class III group, using an analysis of variance (Gower, 1975). In each instance, the null hypothesis was that the Class I and Class III means were not significantly different. Residuals (the set of vectors connecting the landmarks of a specimen to corresponding landmarks in the consensus configuration after Procrustes fit) and corresponding F values were computed, tabulated, and compared.

The samples were also compared using Euclidean distance matrix analysis (EDMA) to meet the concerns expressed by Lele (1993) regarding the robustness of Procrustes analysis and the likelihood of inequality of

the variance-covariance matrices. EDMA is a coordinate-free, statistical procedure for the comparison of two forms using all possible linear distances between homologous landmarks. It is a method for the statistical analysis of full matrices of all interlandmark distances, by averaging elementwise within samples, and then comparing those averages between samples by computing the ratios of corresponding mean distances (Lele and Richtsmeier, 1991). The form matrix generated thus allows determination of the way the two shapes differ by identifying those linear distances that are the most and least different among the shapes being compared (Lele and Richtsmeier, 1991; Ayoub et al., 1994). EDMA has been successfully employed in several biological and clinical studies (e.g., Lele and Richtsmeier, 1991; Ayoub et al., 1994, 1995). Using this new procedure, the assumption of equality of variance-covariance matrices is avoided (Lele and Cole, 1996). Therefore, distances between each of the seven homologous landmarks were calculated and EDMA matrices formed for the Class I and Class III configurations. The corresponding linear distances were compared as ratios and statistical significance of shape difference was tested by the nonparametric bootstrap method (Lele and Richtsmeier, 1991).

Finally, nine unscaled linear distances (mm) between coordinates were measured as well as six midfacial angles (°). By employing bivariate statistical analysis (paired t-tests), the battery of linear and angular parameters delineated was analyzed.

RESULTS

Residuals computed from the Procrustes analysis for the two occlusal types were tabulated and compared using a F distribution. A statistically significant difference between the Class I and Class III midfacial configurations occurred at the $P < 0.05$ level (Table 2). When the Class III sample was decomposed into seven age- and sex-matched groups and compared to the equivalent Class I groups, the midfacial configurations were also found to be significantly different at

ages 7, 9, and 10, marginal at age 5, but not significant at ages 6, 8, and 11 years.

Comparison of the two occlusal types employing EDMA corroborated statistical significance at the $P < 0.05$ level, showing differences in both size and shape. The EDMA analysis revealed that the differences in morphology arose from reductions in horizontal and vertical facial lengths posteriorly and increased vertical facial lengths anteriorly (Table 3). For example, a form difference for PTS-RO of 0.93 and 0.94 for PNS-PTS indicates a decrease in length between the pterygoid point and rhinion, and between the posterior nasal spine and the pterygoid point for the Class III configuration. Generally, size and shape change were apparent in the posterior regions, but highly localized changes of the maxillary alveolus anteriorly were evident. In contrast, the pan-midfacial parameters such as Pr-PTS, Pr-PNS, and ANS-PNS showed remarkable degrees of uniformity (Table 3), suggesting that there is little difference between the two mean configurations for these particular ratios.

Results of the bivariate tests carried out on the two occlusal types are presented in Tables 4a,b. Bivariate analysis indicated that the midface length (PTS-RO) was longer in the Class III sample (99.2 mm compared to 95.6 mm) and remained so in each of the age groups tested, but no difference was found in anterior midface height (RO-ANS). Similarly, no differences were identified in total alveolar length (PNS-Pr). The posterior palatal length (PNS-MPP) was shorter in Class III than in Class I (39.7 mm vs. 40.2 mm) and remained so at each age group, but the anterior palatal length (MPP-ANS) was longer (40.6 mm vs. 37.9 mm). Therefore, no difference in total palatal length (PNS-ANS) was detected. Most of the linear distance values decreased with age (Table 4a).

For the maxillary alveolus parameters, no differences in height were detected for ANS-A or for ANS-Pr, but the subspinale height (A-Pr) was longer in the Class III sample (15.8 mm vs. 14.2 mm). The angulation of the midface (PTS-RO-ANS) also was found to be more acute in the Class III sample ($\approx 73°$

TABLE 2. Procrustes Analysis of Mean Midfacial Configurations of Normal (Class I) and Midfacially Retruded (Class III) Subjects

Age (yr)	5	6	7	8	9	10	11	TF[a]
n	19	14	17	19	26	19	19	133
Residual	0.0008	0.0012	0.0019	0.0003	0.0012	0.0011	0.0007	0.0006
F value	0.8310	0.7810	1.4826	0.3624	2.1346	1.0688	0.7386	1.8685
P value	0.05	N.S.[b]	0.01	N.S.[b]	<0.01	<0.01	N.S.[b]	<0.05

[a]Represents total combined Class I and Class III comparison that is significantly different at the $P < 0.05$ level. When the total sample is decomposed into age subgroups, age 7, 9, and 10 years maintain statistical difference, whereas at age 5 the Class I and Class III comparison marginally fails to reach statistical significance at the $P < 0.05$ level.
[b]Subgroups at ages 6, 8, and 11 years are statistically not significant (N.S.).

TABLE 3. Comparison of Mean, Normal (Class I: numerator) With Mean Midfacially Retrusive (Class III: denominator) Midfacial Configurations*

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	0.118	0.000					
ANS	0.197	0.095	0.000				
MPP	0.607	0.498	0.410	0.000			
PNS	0.886	0.801	0.808	0.803	0.000		
PTS	0.687	0.647	0.699	0.887	0.386	0.000	
RO	0.331	0.270	0.319	0.583	0.560	0.381	0.000

Form difference matrix (sorted)

PTS	RO	0.933
PNS	PTS	0.939
PNS	RO	0.953
A	ANS	0.979
A	PTS	0.982
A	PNS	0.988
ANS	PTS	0.991
A	MPP	0.993
Pr	PTS	0.999
Pr	PNS	1.001
MPP	PTS	1.001
ANS	PNS	1.001
ANS	MPP	1.001
Pr	MPP	1.007
Pr	ANS	1.018
MPP	RO	1.022
MPP	PNS	1.027
ANS	RO	1.060
A	RO	1.053
Pr	RO	1.078
Pr	A	1.102

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

*Euclidean Distance Matrix Analysis employed 100 bootstraps.

vs. $\approx 76°$), but no differences in palatal plane angle (PNS-MPP-ANS), alveolar plane angle (PNS-ANS-Pr), anterior alveolar angle (ANS-PNS-Pr), or subspinale plane angle (PNS-ANS-A) were demonstrable (Table 4b). In contrast, the upper alveolar angulation (ANS-A-Pr) was found to be more acute in the Class III sample ($\approx 128°$ vs. $\approx 137°$). Generally speaking, the morphometric and cephalometric analyses employed show corroboration.

DISCUSSION

Moyers and Bookstein (1979) commented upon the inappropriateness of conventional cephalometrics. Therefore, in this study a combination of morphometric and cephalometric analyses was employed to inves-

tigate the morphology of the midface in subjects with Class III malocclusions. Variation for the cephalometric parameters was evident, and this is perhaps not surprising as the data were not normalized. Indeed, the unreliability of cephalometric parameters spanning curved surfaces is evident, as some linear distance measures appeared to decrease with increasing age, probably because the linear distances were the shortest distances between two digitized points and did not necessarily reflect the true (curved) length. This shows one shortcoming of conventional cephalometrics when three-dimensional data are compressed into two. Nevertheless, one might also argue that apparent antero-posterior shortening may be due to postnatal remodeling despite proliferative processes at developmental sites such as sutures.

In the surgical treatment of skeletal Class III relationships, maxillary advancements are employed in up to 40% of cases (Bailey et al., 1995). It has been suggested also that early correction of the Class III occlusal relationship might establish a more favorable craniofacial growth pattern (Tollaro et al., 1996). But Zeng (1993) identified some six different Class III subtypes in Chinese patients, with the severity of the malocclusion varying according to craniofacial morphologic parameters. Similarly, Martone et al. (1992) suggest that different headforms establish lines of craniofacial growth resulting in anatomic subgroupings of Class III malocclusions. Clinically, Collet and West (1993) consider that facial type plays an important role in the formulation of orthodontic treatments. Using scaled data, the mean Class I and Class III configurations were found to differ on the whole, but this finding did not hold for the age subsamples. It is perhaps not surprising, therefore, that in our current study Procrustes analysis demonstrated that only half of the age groups were statistically different, whereas the other groups failed to reach statistical significance at the $P < 0.05$ level. These results presumably reflect the diversity of the Class III midfacial morphology. In spite of the above limitations, statistical significance was maintained for the total Class I and Class III sample, warranting further mathematical analysis.

Results from the EDMA indicated reduced midfacial length and height posteriorly, with some pan-facial reductions also evident (e.g., PNS-RO). These differences suggest developmental changes initiated at the pterygo-maxillary sutures. Tanne et al. (1995) suggested that the center of rotation of the nasomaxillary complex is located on the posterosuperior ridge of the pterygomaxillary fissure registered in the sagittal plane, as Melsen and Melsen (1982) had confirmed the significance of this developmental site. Chang et al. (1993) also suggested that the posterior part of the face

TABLE 4. Distances and Angles*

(a) Linear distances (mm)

Age (yr)	n	PNS-MPP	MPP-ANS	PNS-ANS	ANS-A	ANS-Pr	PNS-Pr	A-Pr	PTS-RO	RO-ANS
Class I										
5	10	40.14	42.01	85.29	11.74	26.39	82.81	15.83	97.86	48.57
6	7	40.54	42	85.73	10.76	24.45	81.66	15.06	95.77	47.84
7	7	42.49	39.25	85.02	11.13	23.69	83.93	13.83	93.08	46.18
8	9	42.49	36.18	81.97	11.32	21.84	80.7	12.62	97.12	49.99
9	9	42.9	35.96	82.1	11.82	24	80.52	14.09	94.05	49.46
10	9	42.79	36.88	82.96	11.25	21.02	82.63	12.92	95.76	49.03
11	9	42.98	33.25	79.38	10.87	23.45	80.23	14.94	95.37	50.43
Total	**60**	**40.2**	**37.93**	**83.21**	**11.27**	**23.55**	**81.78**	**14.18**	**95.57**	**48.79**
std		0.12	0.32	0.23	0.04	0.17	0.13	0.12	0.16	0.14
Class III										
5	9	37.31	45	85.22	11.23	28.86	84.02	19.18	100.51	46.45
6	7	39.32	40	82.63	1 1.63	27.55	83.7	17.46	100.17	47.32
7	10	37.29	44.99	85.2	11 .64	22.96	80.98	13.85	100.64	50.07
8	10	41.18	38.52	82.89	11. 03	22.73	82.1	14.8	98.18	49.93
9	17	41.91	38.08	83.26	11.4 1	23.41	82.82	15.34	99.35	48.47
10	10	39.84	39.53	82.51	10.1	22.22	83.09	15.26	98.29	51.55
11	10	40.89	38.09	82.16	11.37	22.17	81.65	14.48	97.57	52.14
Total	**73**	**39.7**	**40.63**	**83.41**	**11.2**	**24.28**	**82.62**	**15.77**	**99.24**	**49.42**
std		0.18	0.31	0.13	0.05	0.27	0.11	0.18	0.12	0.21
P		**<0.01**	**<0.05**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**<0.05**	**<0.01**	**N.S.**

(b) Angular measures (degrees)

Age (yr)	n	PNS-MPP-ANS	PNS-ANS-A	PNS-ANS-Pr	ANS-PNS-Pr	ANS-A-Pr	PTS-RO-ANS
Class I							
5	10	177.91	56.11	75.68	17.98	146.04	75.66
6	7	179.58	49.93	72.24	16.56	141.95	78.71
7	7	175.35	58.76	79.35	16.11	142.97	76.82
8	9	176.14	53.35	78.98	15.41	131.55	74.33
9	9	178.16	53.43	77.79	16.93	135.4	74.92
10	9	174.88	49.87	81.79	14.58	128.66	76.62
11	9	170.99	54.42	83.62	16.88	129.99	74.65
Total	**60**	**176.14**	**53.7**	**78.49**	**16.35**	**136.65**	**75.95**
std		2.82	3.18	3.77	1.11	6.97	1.54
Class III							
5	9	177.05	53.58	77.83	19.62	141.81	75.71
6	7	179.24	59.59	82.65	19.05	141.81	72.44
7	10	177.79	43.41	71.68	15.61	128.24	73.78
8	10	175.71	46.85	80.11	15.83	122.61	73.7
9	17	176.74	46.77	80.82	16.21	121.34	71.43
10	10	178.85	47.71	83.76	15.42	121.01	71.67
11	10	176.59	45.54	80.91	15.55	117.6	74.42
Total	**73**	**177.42**	**49.06**	**79.68**	**16.75**	**127.77**	**73.31**
std		1.27	5.59	3.99	1.78	10.09	1.54
P		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**<0.01**	**<0.05**

*N.S. = not significant.

has a greater potentiality for change, presumably influenced by the pterygo-maxillary sutures. Indeed, the pterygomaxillary fissure is the target of intermaxillary biomechanics, producing disarticulation and osteogenesis at the palatomaxillary and pterygopalatine sutures (Vardimon et al., 1994). Employing an implant technique, Iseri and Solow (1995) noted that pterygomaxillare was relocated postero-inferiorly by surface remodeling during normal growth. Therefore, it appears that developmental deficiency localized at the pterygo-maxillary sutures affects the final midfacial morphology. For the Class III subject in the present study, the primary developmental problem is apparently localized foreshortening of the PTS-RO parameter (Table 3). But subjects were not grouped on the basis of dolicho- or brachycephalic facial types. If it is accepted that there are Class III subtypes, presumably this diversity within the Class III grouping will be reflected as morphologic variation in our findings.

In contrast to the findings for EDMA, bivariate analysis indicated that the midface length (PTS-RO) was longer in the Class III sample (99.2 mm vs. 95.6 mm), but the angulation of the midface (PTS-RO-ANS) was found to be more acute in the Class III

sample ($\approx 73°$ vs. $\approx 76°$). In the growing child, Williams and Andersen (1986) suggest that maxillary retrognathism is masked by angular analysis because reduction in length of the anterior cranial base subsequently affects the position of nasion. This notion contrasts with the findings of our current study that suggest that the angulation of the midface could exacerbate the Class III profile, as no difference in anterior midface height (RO-ANS) was found. Our contention is supported by the earlier findings of Rak (1989) who describes a negative difference in the position of the apical base of the jaws and concavity of the osseous profile accompanied by diminished convexity of the soft tissue profile in boys and girls with Class III malocclusions. But, PTS-RO is longer for Class III than Class I at the outset and remains so. The Class I sample appears to start smaller than Class III, unexpectedly. Presumably, PTS and RO are not ideal landmarks to interpret antero-posterior midfacial elongation because their spatial organization is nonsagittal. As the PTS-RO plane is parallel in the horizontal axis to the anterior cranial base, growth deficiency of the posterior part of the midfacial configuration (at pterygomaxillary suture complex, transverse palatine suture, etc.) could be developmentally compensated for by elongation of the anterior part of midfacial configuration by anterior translatory displacement of the midfacial complex due to growth of the anterior cranial base (e.g., at the spheno-ethmoidal synchondrosis). Nevertheless, a long PTS-RO measurement might exacerbate the Class III midfacial profile when one takes into account the palato-alveolar morphology.

It has been suggested that the transverse palatine suture, in particular, may be important in growth of the palate (King and Scheiderman, 1993; Njio and Kjaer, 1993). In our current study, we found that the posterior palatal length (PNS-MPP) was shorter in the Class III sample (39.7 mm vs. 40.2 mm), but the anterior palatal length (MPP-ANS) was longer (40.6 mm vs. 37.9 mm). Therefore, no difference in the total palatal length (PNS-ANS) was detected. Although reduced posterior palatal lengths could be due to deficient proliferation at the transverse palatine suture, this reduction appears to be compensated by increased proliferation at the maxillary-premaxillary suture. Takada et al. (1993) reported that the dentofacial morphology in young female children treated with maxillary protraction headgear (when applied shortly before or during the pubertal growth spurt) exhibited increased maxillary length. In younger children with a deciduous dentition and Class III malocclusions, Chang et al. (1992) reported a shorter maxillary length in association with more posteriorly positioned maxilla, but Yamada (1990) found no significant differences in maxillary dimensions among older children with Class I and Class III malocclusions. Therefore, it is possible that palatal developmental compensation is a feature during the morphogenesis of the midfacial complex. The landmarks PNS and MPP encompass the transverse palatine suture. Hence growth deficiency could occur at that suture in the development of Class III malocclusions.

Fleury et al. (1994) advocate that the entire cephalometric parameters and specifically the alveolar inclinations have to be taken into account when treating skeletal sagittal discrepancies. For the maxillary alveolus parameters, no differences in height were detected for ANS-A or for ANS-Pr, but the subspinale height (A-Pr) was longer in the Class III sample (15.8 mm vs. 14.2 mm). The upper alveolar angulation (ANS-A-Pr) was found to be more acute in the Class III sample ($\approx 128°$ vs. $\approx 137°$). Employing EDMA we also found an increase in size of the anterior maxillary alveolus. Taken together, these results are in accord with Iseri and Solow (1995) who reported relocation of subspinale and ANS antero- inferiorly. Therefore, it appears that developmental dental compensation is one feature of the Class III sample in this particular study and supports the notion of Fleury et al. (1994) that compensatory alveolar angulation should be maintained during treatments. The only significant difference is the angulation of the incisor as indicated by ANS-A-Pr and perhaps it is not surprising that it is more acute in Class III subjects. This acute angulation of the incisors could exacerbate the Class III midfacial profile, as PTS-RO appears to be longer than in the Class I groups.

In summary, in this study it appears that the midface is much more variable in its contribution to the appearance of Class III malocclusions than other craniofacial components, e.g., the cranial base (Singh et al., 1997a,b,c). This finding presumably relates to the subclasses found within the Class III grouping. Dibbets (1996) suggests that the midface is the deciding craniofacial component for classifying the Class III patient and our current findings support this notion. Overall, it appears that the variability of the midfacial complex in Class III malocclusions is due to developmental deficiency at the transverse palatine suture, but that acute angulation of the maxillary incisors may act as a compensatory occlusal mechanism for the shorter maxilla relative to the longer mandible. The elongation of the anterior part of the midface could be a further attempt to compensate for the midfacial deficiency. That differences in parameters of normal and maxillary-retrognathic children were found to be marginal is in accord with the notion that sagittal and vertical dental and skeletal maxillary relationships are

only partly reflected in the face (Bittner and Pancherz, 1990). Indeed, Gasson and Lavergne (1977a) found no connection between variation of maxillary rotation and growth of the cranial base. Interaction between the maxillary and mandibular complexes, however, may play a more important role in the vertical and sagittal relationships of both jaws (Gasson and Lavergne, 1977b). Therefore, the final facial profile may also depend upon other craniofacial parameters such as cranial base morphology and mandibular allometry as well as soft tissue morphology. These topics will form the premises and subjects of further studies.

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