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Morphological parameters as predictors of successful correction of Class III malocclusion

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SUMMARY The aim of the study was to assess pre-treatment cephalometric parameters and measurements of the size of the apical bases as predictors of successful orthodontic correction of Class III malocclusions.

Pre- and post-treatment lateral cephalograms and study models of 80 completed Class III subjects were examined to obtain 23 cephalometric parameters taken mainly from the analyses of McNamara and Schwarz, and to measure the size of the apical bases. Success of occlusal correction was evaluated as the percentage change of peer assessment rating score during treatment, which was used as the dependent variable in multivariate statistical analyses testing the predictive value of the parameters assessed.

No improvement in the Class III skeletal pattern occurred during treatment and the treatment effects were confined to dentoalveolar changes. With the exception of the percentage midfacial length/mandibular length ratio, the net sum of maxillary and mandibular length differences, the mandibular ramus height/mandibular body length ratio and the gonion angle, most cephalometric parameters of pre-treatment craniofacial morphology assessed were poor predictors of successful correction of Class III malocclusions. Assessment of the size relationship of the maxillary and mandibular apical bases was the strongest predictor of occlusal correction achieved and may serve as a valuable diagnostic addition in the prediction of successful treatment outcome.

Introduction

Although the prevalence of Class III malocclusions in Europe is relatively low (Haynes, 1970; Thilander and Myrberg, 1973; Keß *et al*., 1991), their treatment represents a considerable clinical challenge which is related both to potential complications occurring during treatment and to reliable prognosis of treatment outcome. The contemporary approach to treatment of Class III malocclusions, without orthognathic surgery, includes growth modification aimed at promoting maxillary and restraining mandibular growth, and/or dentoalveolar compensation or 'camouflage' of skeletal discrepancy by differential movement of teeth on their bony bases into acceptable occlusion (Proffit, 2000). In-depth studies of the literature (Dermaut and Aelbers, 1996) suggest, however, that the so-called orthopaedic or skeletal effects of growth modification, if at all attainable, appear to be transient and of limited clinical significance, and indicate that dentoalveolar compensation might be the more likely outcome of successful treatment of Class III malocclusions. It is also recognized that the degree of dentoalveolar compensation achieved during the course of treatment is an essential component of the correction of Class III malocclusions, and may have both favourable and adverse effects on treatment success (Berg, 1979; Stensland *et al*., 1988). Therefore, it would be highly desirable to have, at the stage of treatment planning, knowledge of morphological characteristics rendering any individual Class III malocclusion as either favourable or untenable for successful dentoalveolar compensation.

Some investigations have addressed the issues of prognosis of treatment success (Franchi *et al*., 1997) or prediction of post-treatment relapse

(Battagel, 1993a, 1994) in Class III malocclusions by testing the predictive significance of pre-treatment morphological parameters. The results of these studies unveil a relatively high predictive value of some cephalometric parameters, such as the inclination of the condylar axis, the angle between the maxillary and mandibular planes (Franchi *et al.*, 1997), the inclination of the upper incisors to the maxillary plane, the distances of labrale superius to soft tissue nasion and of labrale inferius to the sella vertical line (Battagel, 1993a, 1994). An acceptable predictive value of selected pre-treatment measurements on study models, such as the width of the mandibular arch (Franchi *et al.*, 1997) and the number of anterior teeth in crossbite (Battagel, 1993a, 1994) has also been substantiated statistically. Use of these measurements as predictors is, however, applicable only to strictly specified groups of patients (Battagel, 1993a, 1994; Franchi *et al.*, 1997).

It has been suggested that among cephalometric variables, those expressing craniofacial relationships as positions and proportions tend to be of greater predictive significance for the future craniofacial morphological appearance (Johnston, 1968). Several parameters characterizing relative size and position of the bony bases have been introduced into cephalometric analyses such as, for instance, comparison of maxillary and mandibular length measurements with each other and with standard values (Schwarz, 1961; McNamara, 1984), and their use in the diagnostic assessment of the feasibility of orthodontic correction has been advocated (Proffit, 1991). Statistical verification of such measurements is, however, almost completely lacking.

Although the potential importance of the size of the apical bases and their spatial relationship for the success of the dentoalveolar compensation of the abnormal skeletal base relationship might appear obvious (Rees, 1953), it has not been examined in detail. A recent study (Zentner and Doll, 2001), in which a specifically designed method (Sergl *et al.*, 1996) of assessment of the apical bases was employed, showed their significance for the success of orthodontic correction of Class III malocclusions and suggested introduction of this measurement as a valuable addition to cephalometric parameters in the search for reliable predictors of treatment outcome.

The purpose of this retrospective evaluation of 80 treated Class III malocclusion patients was to test the predictive value of a number of pre-treatment cephalometric parameters and of the measurements of the size of the apical bases for the outcome of orthodontic correction of this type of malocclusion.

Materials and methods

Data collection

Pre- (T1) and post-treatment (T2) study models and lateral cephalograms of 80 orthodontically treated Class III subjects were used in this study. The average age of the patients at the start of treatment was 10.85 ± 4.65 years, the entire treatment including the retention phase lasted 60.50 ± 27.77 months. In all patients a Class III base relationship had been diagnosed before treatment, and only conventional orthodontic treatment by means of various commonly used removable and fixed appliance types and their combinations was carried out. The material of the study also contained cases in which conventional orthodontic treatment had resulted in an obvious failure and had been either discontinued for this reason or the original treatment plan changed to a combined orthodontic–surgical approach. For the purpose of this investigation, study models and cephalograms obtained from these cases at the stage of treatment discontinuation or change of the treatment plan were evaluated as 'post-treatment' (T2) records.

The outlines of the maxillary (ABU) and mandibular (ABL) apical bases in the sagittal and transverse planes were drawn and measured in a standardized manner on T1 and T2 study models using a purpose-designed apparatus as described and discussed in detail elsewhere (Zentner and Doll, 2001), and the surface areas of ABU and ABL outlines (Figure 1) and the percentage relationship between the ABU and ABL areas, designated as the apical base ratio (ABR), were obtained. The dentition at the start

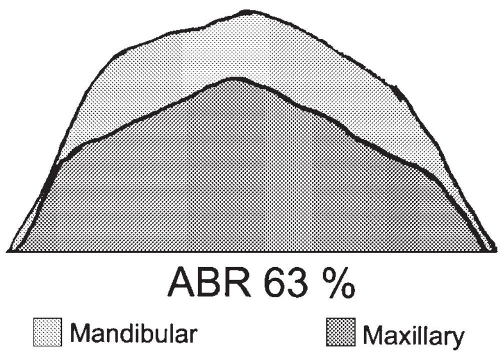

Figure 1 Superimposition of drawings of the outline areas of the apical bases typical for Class III malocclusion.

and completion of treatment was assessed on T1 and T2 study models using the peer assessment rating (PAR) index (Richmond *et al*., 1992). Occlusal changes during treatment were estimated both as the percentage change between the index scores from T1–T2 and by assignment of each treatment case into one of the three improvement categories (1, 'worse–no different'; 2, 'improved'; 3, 'greatly improved') using a standard nomogram (Richmond *et al*., 1992). T1 and T2 cephalograms were traced by hand and measurements were carried out on 23 cephalometric parameters taken mainly from McNamara (1984) and Schwarz (1961) analyses (Figure 2, Table 1).

When any one of the above methods was applied, the measurements were always gained by one and the same investigator in order to exclude interindividual variation. Measurement reproducibility was examined in preliminary trials taking into consideration the recommendations of Battagel (1993b), and was rated as good. Pooled standard deviations calculated for apical base surface areas were 12.38 mm^2, for PAR scores 0.66 points, for linear cephalometric measurements 0.90 mm, and for angular cephalometric measurements 0.38 degrees.

Data analysis

Two models of multivariate statistical analysis (Backhaus *et al*., 1994) were employed to evaluate

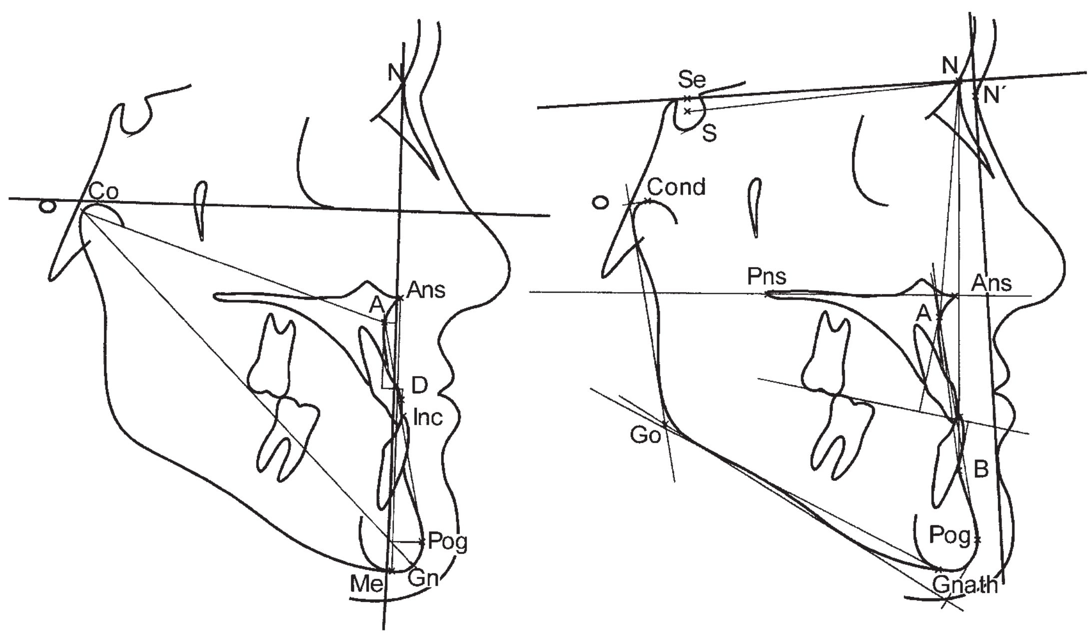

Figure 2 Drawing of the cephalometric parameters assessed. (**Left**) Measurements using McNamara analysis. (**Right**) Measurements using Schwarz analysis. For measurements definition see Table 1. Terms and definitions as in the original descriptions of the analyses (McNamara, 1984; Schwarz, 1961).

Table 1 Abbreviations and definition of the parameters assessed in T1 and T2 study models and lateral cephalograms.[a]

Parameters	Definition
Dentoalveolar	
PAR score	Peer Assessment Rating Index value
%PAR	PAR score percentage change T1–T2
ABU	Maxillary apical base (mm^2)
ABL	Mandibular apical base (mm^2)
ABR	Apical base relationship as per cent ratio ABU/ABL
$\underline{1}$ to A	Maxillary dental as distance from facial surface of upper incisor to point A vertical line drawn as perpendicular to Frankfort horizontal ◇
$\bar{1}$ to A-Pog	Mandibular dental as distance from lower incision to A-Pog line ◇
Sagittal	
ANB<	ANB angle
Wits	Wits appraisal
Max S	Maxillary skeletal as distance from nasion perpendicular to point A ◇
Mand S	Mandibular skeletal as distance from pogonion to nasion perpendicular ◇
F<	Angle between N-Se und N-A lines ○
AB<	Anterior angle between maxillary plane and A–B line ○
MM<	Anterior angle between maxillary plane and A-Pog line ○
Maxillary and mandibular length	
Co-A	Midfacial length as distance from Co to A ◇
Co-Gn	Mandibular length as distance from Co to Gn ◇
MMR	Midfacial length/mandibular length ratio (Co-A to Co-Gn in per cent)
Mand L	Mandibular body length as distance from Go to intersection of Pog perpendicular to tangent to inferior border of the mandible ○
Max L	Maxillary length as distance from Pns to intersection of A perpendicular to maxillary plane ○
Mand Diff	Difference between measured Mand L and individual standard which is calculated as length of N-Se + 3 mm; positive value—mandibular length excess, negative value—mandibular length deficiency ○
Max Diff	Difference between measured Max L and individual standard which is calculated as ⅔ of mandibular length individual standard; positive value—maxillary length excess, negative value—maxillary length deficiency ○
Sum Diff	Net sum of Max Diff and Mand Diff
Vertical	
Go<	Gonion angle ○
ANS-Me	Lower anterior facial height as distance from Ans to Me ◇
B<	Angle between maxillary and mandibular planes ○
I<	Angle between maxillary plane and soft tissue nasion perpendicular to N-Se ○
RH	Mandibular ramus height as distance from Go to intersection of Cond perpendicular and line tangent to posterior border of the ramus ○
RH/Mand L	Mandibular ramus height/mandibular body length ratio ○

[a]Parameters from McNamara analysis are marked by ◇, and those from Schwarz analysis by ○.

the association between the pre-treatment morphological parameters, assigned as the independent variables, and the percentage change from the pre- to the post-treatment PAR scores (%PAR), assigned as the dependent variable characterizing the treatment outcome. Step 1 of model 1 comprised calculations of Pearson product moment correlations between each individual independent variable and %PAR. Variables shown by these calculations as statistically significant were included in step 2 which consisted of best subsets regression analysis. In model 2, as step 1, forward stepwise regression analyses were carried out for the dentoalveolar, sagittal, maxillary and mandibular length, and vertical groups of the independent variables, to which these variables were assigned in accordance with the craniofacial morphological features they characterized (Table 1). Subsequently, significant variables from each group in step 1 were pooled and subjected to multiple linear regression analysis in step 2.

Additional multiple linear regression analyses testing each morphological parameter as the dependent variables and age, age squared and age cubed as the independent variables were performed. As no influence of age on the morphological measurements obtained from the material of the study was found, patients' age was excluded from further data evaluation. Differences between groups of variables were tested for statistical significance using the two sample unpaired *t*-test or, in the absence of normal data distribution, the Mann–Whitney rank sum test. Mean values and standard deviations were calculated for data presentation. All calculations were carried out using the SigmaStat® 2.0 statistical program (Jandel Scientific Software, San Rafael, CA, USA). The level of statistical significance was set at $P < 0.05$.

Results

Plotting of the individual T1 PAR scores against T2 PAR scores using the standard nomogram resulted in assignment of 10 from a total of 80 assessed treatment cases to category 1 ('worse–no different'). This category contained in particular those patients in which conventional orthodontic treatment had resulted in an obvious failure and had been discontinued or the treatment plan had been changed to a combined orthodontic–surgical approach. Thirty cases were assigned to category 2 ('improved') and 40 cases included in category 3 ('greatly improved').

Table 2 shows the mean values and standard deviations calculated for each parameter for the total material and each of the three improvement categories. Noticeable in particular were the %PAR from T1–T2, which in categories 2 and 3 comprised a statistically significant reduction of 63.60 and 83.80 per cent, respectively, whilst in category 1, in contrast, there was an average increase of PAR scores amounting to 18.80 per cent.

The results of the multivariate statistical analyses are shown in Table 3. From the 27 morphological parameters tested in step 1 of model 1, only ABR, MMR, Go< and RH/Mand L correlated significantly with %PAR. The best subsets regression analysis in step 2 resulted in a statistically significant regression function with $r^2 = 0.137$ identifying ABR and Go< as covariates with significant influence on the outcome of %PAR. In step 1, model 2, only ABR among the dentoalveolar parameters, MMR and Sum Diff among the maxillary and mandibular length parameters, RH/Mand L among the vertical parameters were significantly associated with %PAR, but none of the sagittal parameters. When these variables were pooled and subjected to the multiple linear regression analysis in step 2, ABR, MMR and Sum Diff were the covariates significantly influencing the outcome of %PAR ($r^2 = 0.190$).

Subsequently, a comparison of the mean values calculated for the variables ABR, MMR, Sum Diff, RH/Mand L and Go< at T1 was carried out between the three improvement categories. The difference between ABR in category 1 and ABR values in categories 2 and 3 were statistically significant ($P < 0.01$), whilst ABR values in categories 2 and 3 did not differ significantly. MMR in category 1 was significantly different from MMR in categories 2 and 3 ($P < 0.05$), whilst the latter two did not differ from each other. No statistically significant differences were found between the Sum Diff values in each individual improvement category. RH/Mand L in category 3 showed statistically significant differences from RH/Mand L values calculated for categories 1 ($P < 0.05$) and 2 ($P < 0.01$), whereas the latter two did not differ significantly from each other. When Go< values were compared, only the difference between categories 2 and 3 was significant at $P < 0.05$.

Discussion

Apart from the diagnosis of mesial base relationship before treatment and the use of orthodontic treatment means without orthognathic surgery, no other selection criteria were applied when cases were included in the material of this study. The subjects were treated by conventional orthodontics using various removable and fixed appliances and their combinations, including reverse headgear. However, no attempts were

Table 2 Mean values and standard deviations calculated for the parameters assessed.

Parameter	Total material		PAR category 1		PAR category 2		PAR category 3	
	T1	T2	T1	T2	T1	T2	T1	T2
PAR score	31.75 ± 12.00	11.53 ± 12.41***	33.90 ± 14.44	36.50 ± 14.08	25.30 ± 11.32	10.07 ± 7.67***	36.05 ± 9.81	6.38 ± 5.79***
%PAR	–	63.40 ± 42.30	–	–18.80 ± 69.60	–	63.60 ± 15.40	–	83.80 ± 13.30
ABU	848.23 ± 181.54	803.51 ± 204.26	838.97 ± 199.08	788.85 ± 193.04	796.19 ± 159.28	788.28 ± 180.31	889.57 ± 186.78	813.90 ± 219.39
ABL	1056.09 ± 204.53	951.33 ± 243.45**	1202.32 ± 288.54	1135.19 ± 333.90	982.61 ± 162.20	917.11 ± 209.92	1074.65 ± 189.66	927.27 ± 198.16**
ABR	80.79 ± 11.79	85.32 ± 14.56*	70.48 ± 13.29	70.90 ± 10.88	81.12 ± 9.68	86.83 ± 13.69	83.12 ± 11.76	87.50 ± 14.26
$\underline{1}$ to A	4.54 ± 2.52	6.38 ± 2.32***	4.03 ± 1.64	4.65 ± 2.14	5.22 ± 2.33	6.94 ± 2.38**	4.16 ± 2.75	6.40 ± 2.14***
$\overline{1}$ to A-Pog	3.77 ± 2.64	3.28 ± 2.65	4.35 ± 3.77	4.05 ± 3.93	3.82 ± 2.12	3.78 ± 2.50	3.60 ± 2.72	2.69 ± 2.30
ANB<	–0.49 ± 2.78	–0.77 ± 2.81	–2.75 ± 3.12	–2.75 ± 2.72	0.38 ± 2.42	–0.81 ± 2.52	–0.58 ± 2.67	–0.22 ± 2.87
Wits	–6.44 ± 3.02	–5.40 ± 3.54*	–7.40 ± 3.41	–7.05 ± 3.00	–6.13 ± 2.88	–5.40 ± 3.88	–6.44 ± 3.05	–4.97 ± 3.36*
Max S	–1.28 ± 3.40	–1.29 ± 4.20	–2.25 ± 2.79	–2.20 ± 3.95	–1.75 ± 3.29	–2.67 ± 3.73	–0.69 ± 3.57	0.00 ± 4.30
Mand S	–1.74 ± 5.19	–0.29 ± 7.40	1.35 ± 5.24	3.55 ± 6.44	–3.32 ± 6.09	–3.57 ± 6.41	–1.34 ± 4.00	1.25 ± 7.52
F<	83.24 ± 4.07	83.76 ± 4.13	81.10 ± 2.47	82.15 ± 3.69	83.37 ± 3.00	82.95 ± 3.62	83.68 ± 4.91	84.80 ± 4.41
AB<	90.35 ± 6.29	90.15 ± 6.14	84.00 ± 8.53	83.85 ± 9.61	92.80 ± 6.22	91.25 ± 4.87	90.10 ± 4.42	90.92 ± 5.04
MM<	90.62 ± 6.15	88.85 ± 5.88*	84.55 ± 8.72	82.75 ± 7.83	92.66 ± 6.14	89.87 ± 5.05	90.61 ± 4.29	89.63 ± 5.07
Co–A	81.56 ± 5.88	87.18 ± 6.67***	80.10 ± 6.87	84.55 ± 6.45	83.22 ± 5.56	87.80 ± 7.17**	80.69 ± 5.71	87.39 ± 6.34***
Co–Gn	109.76 ± 9.46	120.07 ± 9.07***	111.80 ± 10.34	118.75 ± 10.44	111.03 ± 10.38	120.92 ± 9.34***	108.29 ± 8.48	119.76 ± 8.68***
MMR	74.30 ± 3.73	72.60 ± 4.25**	71.70 ± 2.92	71.30 ± 5.54	75.00 ± 3.75	72.60 ± 4.29*	74.50 ± 3.69	72.90 ± 3.89*
Mand L	71.21 ± 6.07	78.34 ± 6.19***	71.20 ± 7.22	75.42 ± 5.98	70.97 ± 6.20	77.40 ± 5.10***	71.39 ± 5.82	79.82 ± 6.72***
Max L	44.42 ± 3.99	47.37 ± 3.87***	43.50 ± 3.73	46.40 ± 3.57	44.93 ± 4.39	47.05 ± 3.45*	44.26 ± 3.79	47.86 ± 4.25***
Mand Diff	2.53 ± 5.01	6.33 ± 5.43***	2.95 ± 5.36	5.48 ± 4.78	1.51 ± 5.18	4.25 ± 5.49	3.19 ± 4.79	8.15 ± 5.01***
Max Diff	–1.37 ± 3.27	–0.69 ± 2.96	–1.87 ± 2.31	–0.45 ± 2.88	–1.19 ± 3.95	–1.84 ± 2.96	–1.37 ± 2.97	0.13 ± 2.75*
Sum Diff	3.93 ± 4.20	7.09 ± 4.79***	4.82 ± 4.81	6.36 ± 5.38	2.69 ± 3.57	6.10 ± 4.73**	4.63 ± 4.36	8.03 ± 4.62**
Go<	130.31 ± 5.68	128.82 ± 5.52	130.65 ± 3.71	130.50 ± 3.76	131.90 ± 6.11	130.65 ± 5.55	129.04 ± 5.54	127.00 ± 5.37
ANS–Me	62.06 ± 7.40	68.42 ± 8.28***	61.15 ± 7.61	65.65 ± 12.41	64.85 ± 8.26	70.12 ± 8.71*	60.20 ± 6.09	67.83 ± 6.46***
B<	28.43 ± 6.00	27.22 ± 6.38	25.45 ± 7.79	24.15 ± 7.36	29.47 ± 6.98	28.40 ± 7.17	28.40 ± 4.42	27.10 ± 5.28
I<	85.57 ± 3.22	86.05 ± 4.22	83.00 ± 2.35	83.20 ± 3.85	86.35 ± 3.23	86.71 ± 5.11	85.63 ± 3.12	86.28 ± 3.26
RH	52.94 ± 6.11	59.37 ± 6.28	54.70 ± 5.99	60.00 ± 6.23	54.15 ± 6.56	59.42 ± 6.41**	51.60 ± 5.63	59.17 ± 6.34***
RH/Mand L	0.74 ± 0.06	0.76 ± 0.08	0.77 ± 0.06	0.80 ± 0.06	0.76 ± 0.06	0.77 ± 0.08	0.72 ± 0.06	0.74 ± 0.08

Statistically significant differences between the individual parameters at T1 and T2: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 3 Results of the multivariate statistical analyses.

Statistical tests	Significant variables		
Model 1			
Step 1: Pearson product moment correlation	ABR	$r = 0.299$	$P < 0.01$
	MMR	$r = 0.252$	$P < 0.05$
	Go<	$r = 0.238$	$P < 0.05$
	RH/Mand L	$r = 0.254$	$P < 0.05$
Step 2: best subsets regression analysis	ABR, Go<; $r^2 = 0.137$, $P < 0.05$		
Model 2			
Step 1: forward stepwise regression analysis	*Dentoalveolar*		
	ABR; $r^2 = 0.090$, $P < 0.01$		
	Sagittal		
	none		
	Maxillary and mandibular length		
	MMR, Sum Diff; $r^2 = 0.141$, $P < 0.01$		
	Vertical		
	RH/Mand L; $r^2 = 0.064$, $P < 0.05$		
Step 2: multiple linear regression	ABR, MMR, Sum Diff; $r^2 = 0.190$, $P < 0.05$		

made to discriminate between the effects of different appliances nor were the cases selected on the basis of any specific Class III morphological criteria, such as, for instance, the degree of maxillary deficiency or mandibular excess.

It was intended by these means and by the inclusion of failed treatment cases, to achieve as realistically as possible an assessment of the potential significance of the morphological parameters for the success of orthodontic correction, which undoubtedly is also strongly influenced by other factors such as the patient's individual growth during treatment, varying effectiveness of different treatment strategies, the clinician's expertise and patient compliance. Although it is recognized that the age of Class III patients during treatment may have a significant effect on its success because of the amount of growth during treatment (Stensland *et al.*, 1988), age and, correspondingly, gender were excluded from the data analysis of the present study because, as described above, separate preliminary assessment of potential associations between age and other variables had not revealed any significant relationships.

Treatment results were quantitatively evaluated using the PAR Index which has been specifically designed for such purposes (Richmond *et al.*, 1992), extensively tested and frequently applied in various studies. The employment of this index was considered as advantageous because of its suitability for categorization of treatment outcome. The apparatus used for the measurements of the apical base areas has been designed and tested specifically for the purpose of clinical orthodontic research issues (Sergl *et al.*, 1996). The most notable sources of error of this method are potential inaccuracies during fabrication of impressions and study models and imprecise localization of the reference points on the models (Zentner and Doll, 2001). Repeated measurements on identical study models revealed, however, an acceptably high reproducibility showing a pooled standard deviation below 2.0 per cent of the mean values. Therefore, this method compares favourably with other conventional orthodontic diagnostic measurements on radiographs and study models.

Examination of the mean pre- and post-treatment values calculated for the sagittal parameters (Table 2) suggests that with the exception of Wits appraisal, no measurable improvement of the Class III skeletal pattern occurred during treatment both in the total material and the individual improvement categories. Although a statistically significant favourable reduction of Wits appraisal values was revealed for the total material and category 3, on its own this measurement is of limited clinical significance, especially as the extent of the reduction was far from exceeding two standard deviations, which has been suggested as a criterion denoting clinical significance of cephalometric changes (Aelbers and Dermaut, 1996). In addition, the parameters MMR and Sum Diff (Table 2), which reflect the differential growth of the skeletal bases, in general also exhibited statistically significant changes toward consolidation of a Class III skeletal pattern when their T1 and T2 values were compared. Considering the above and the occurrence of a statistically significant increase of the measurement 1 to point A in the total material and categories 2 and 3, which on the grounds of its extent is more likely to qualify for clinical significance, it appears that overall treatment effects in the present sample were primarily dentoalveolar rather than skeletal. In contrast to the combined skeletal and dentoalveolar treatment effects reported on a group of younger Class III patients by Stensland *et al.* (1988), this finding is in agreement with Brodie's statement (1938) that correction of Class III malocclusions is mostly restricted to changes in the alveolar processes, which was recently confirmed by a review of the relevant literature (Dermaut and Aelbers, 1996).

Multivariate analyses are powerful statistical techniques able to overcome potential problems of confounding (Backhaus *et al.*, 1994) which is frequently encountered in clinical orthodontic research. Aiming for a more rigorous examination of the predictive capacity of the morphological parameters assessed, two multivariate statistical approaches were employed. Under the conditions of the present study both statistical models showed associations between the treatment outcome and some morphological parameters before treatment. Although the individual parameters disclosed by either model as the variables of statistically significant predictive value for treatment outcome were not completely identical (Table 3), essentially they are very similar as they appear to characterize the same strictly confined aspects of craniofacial morphology.

In detail, two parameters describing the relative size of the maxillary and mandibular basal bone and apical bases, i.e. MMR and ABR, respectively, as well as two parameters characterizing mandibular morphology in the vertical plane, i.e. Go< and RH/Mand L were associated with %PAR in step 1 of model 1. Two of these, namely ABR and Go<, together were able to explain 13.7 per cent of occlusal improvement as shown by the r^2 value calculated in step 2. Similarly, next to ABR, MMR and RH/Mand L the variable Sum Diff, which also describes the length discrepancy of the maxillary and mandibular bases, was significantly associated with %PAR in step 1 of model 2. The combination of ABR, MMR and Sum Diff as covariates showed the highest predictive value explaining 19.0 per cent of occlusal improvement achieved during treatment. As a statistically significant covariate in both multivariate statistical models, ABR appeared to be the strongest predictor among all variables tested, and on its own was able to explain 8.9 per cent of occlusal correction achieved.

These findings, which in part parallel the results of other studies reporting the high predictive value of the pre-treatment size of the mandibular body and angle (Stensland *et al.*, 1988), and the width of the mandibular arch (Franchi *et al.*, 1997) indicate a reasonably high predictive value of these parameters for treatment outcome and suggest their usefulness as diagnostic measures of the feasibility of orthodontic correction of Class III malocclusions.

Pre-treatment values of the parameters ABR and MMR in category 1 were statistically significantly different from those in categories 2 and 3, whilst RH/Mand L values in category 3 differed significantly from the corresponding measurements in categories 1 and 2. This provides additional evidence for their merit as diagnostic predictors of the feasibility of orthodontic correction of Class III malocclusions. Conceivably, a potential numerical threshold value of these parameters might exist which might denote an unfavourable pre-treatment morphology jeopardizing attempts at successful correction of the malocclusion. In the sample in this study, such values would presumably be located below 81 per cent for ABR, 74 per cent for MMR and above 0.72 for RH/Mand L, as shown by the comparison of the corresponding T1 values from the different PAR categories

(Table 2). This consideration, which warrants further investigation, is supported by the findings of another study (Zentner and Doll, 2001), that after arbitrary assignment of Class III cases into groups of varying degrees of ABR, both the corresponding T1 and T2 PAR scores and their reduction showed conspicuous differences between the groups. In addition, it was shown in that investigation that the extent of occlusal discrepancy as reflected by PAR scores was markedly related to T1 and T2 ABR values, and the PAR score reduction correlated with the ABR values both before and after treatment.

These findings underline the necessity of a thorough clinical assessment and quantitative evaluation of the size relationship of the apical bases using either the method described or a similar procedure. Assessment of the apical bases should be added to cephalometric parameters as a predictive variable when future investigations of treatment progress and prognosis are planned, and its validity tested especially on borderline treatment cases. It may be possible and desirable to obtain in future studies further fundamental data and baselines for this diagnostic measurement which may serve as a valuable adjunct to cephalometry and conventional model analysis, and be used as a helpful predictor of treatment outcome.

Conclusions

The findings of the present study suggest that:

1. No measurable improvement of Class III skeletal pattern took place during treatment and the treatment effects were confined to dentoalveolar changes.
2. With the exception of the percentage midfacial length/mandibular length ratio (Co-A:Co-Gn), the net sum of maxillary and mandibular length differences (Sum Diff), the mandibular ramus height/mandibular body length ratio (RH/Mand L) and the gonion angle, all other cephalometric parameters of pre-treatment craniofacial morphology tested were negligible as predictors of successful correction of Class III malocclusions.
3. Assessment of the size ratio of the maxillary and mandibular apical bases was the strongest predictor of occlusal correction achieved and may serve as a valuable diagnostic addition in the prediction of successful treatment outcome.

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