ORIGINAL ARTICLE

Cephalometric variables predicting the long-term success or failure of combined rapid maxillary expansion and facial mask therapy

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The aim of this study was to select a model of cephalometric variables to predict the results of early treatment of Class III malocclusion with rapid maxillary expansion and facemask therapy followed by comprehensive treatment with fixed appliances. Lateral cephalograms of 42 patients (20 boys, 22 girls) with Class III malocclusion were analyzed at the start of treatment (mean age 8 years 6 months ± 2 years, at stage I in cervical vertebral maturation). All patients were reevaluated after a mean period of 6 years 6 months (at stage IV or V in cervical vertebral maturation) that included active treatment plus retention. At this time, the sample was divided into 2 groups according to occlusal criteria: a successful group (30 patients) and an unsuccessful group (12 patients). Discriminant analysis was applied to select pretreatment predictive variables of long-term treatment outcome. Stepwise variable selection of the cephalometric measurements at the first observation identified 3 predictive variables. Orthopedic treatment of Class III malocclusion might be unfavorable over the long term when a patient's pretreatment cephalometric records exhibit a long mandibular ramus (ie, increased posterior facial height), an acute cranial base angle, and a steep mandibular plane angle. On the basis of the equation generated by the multivariate statistical method, the outcome of interceptive orthopedic treatment for each new patient with Class III malocclusion can be predicted with a probability error of 16.7%. (Am J Orthod Dentofacial Orthop 2004;126:16-22)

The decision-making process for treating Class III malocclusion is characterized by a fundamental binary choice that is faced by all clinicians: either orthopedic treatment of the malocclusion in the growing patient or delayed intervention in terms of corrective jaw surgery at the end of the active growth period. Regardless of the treatment choice, a functional and esthetic treatment result that is stable over the long term is the desired outcome.

At the clinical level, several factors are involved in the critical decision concerning the timing of intervention. As shown by previous clinical studies, a number of treatment approaches in the early mixed dentition (eg, rapid maxillary expansion combined with a facemask,[1-5] the orthopedic chincup,[6-9] and the FR-3 appliance of Fränkel[10-12]) are efficient in managing Class III problems. Many limitations exist, however, regarding the use of these approaches, including the need for adequate patient compliance and parental support.[13] In addition, sometimes these appliances must be worn for more than just 1 period, because of the severity of the disharmony and the tendency toward the reemergence of the Class III growth pattern (at least partially) in some patients, especially during adolescence.[5]

On the other hand, the clinician might elect not to intervene until the end of the active growth period. Improvements in surgical techniques during the last 2 decades have made most types of corrective jaw surgery for maxillary skeletal retrusion and mandibular skeletal protrusion relatively routine. The benefits of delaying active intervention until the end of adolescence include knowledge of the full extent of the malocclusion, which is particularly useful in instances of severe sagittal and vertical imbalances. The anteroposterior relationship in an untreated person with Class III malocclusion might worsen during the adolescent growth period.[14] Furthermore, treatment planning might be easier and more efficient when all permanent teeth, except perhaps the third molars, have erupted into occlusion. Obviously, there are risks inherent with any type of surgical intervention, especially temporary or permanent paresthesia. Additionally, the negative psy-

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chological impact of having a Class III malocclusion during the juvenile and adolescent periods might be important enough to warrant earlier intervention.[15]

Recent data on the long-term effects of rapid maxillary expansion and protraction therapy seem to indicate that, on average, the outcome of orthopedic treatment of Class III malocclusion is favorable when it is started before the pubertal growth spurt.[5,16] Three quarters of Class III patients who receive orthopedic treatment maintain a positive overjet after postpubertal skeletal maturation. The literature also agrees on the recommendation that overcorrecting the Class III skeletal discrepancy with orthopedic appliances is advisable.[5,13,17] Patients corrected to positive overjets of 4 to 5 mm or greater during the orthopedic phase of treatment generally can sustain favorable long-term outcomes.[5] Furthermore, increased patient self-esteem and parental satisfaction related to the early rapid improvement of facial esthetics typically is observed after orthopedic intervention in juvenile patients with Class III malocclusion.

A feasible improvement in clinical decision-making when the treatment of a new patient with a Class III malocclusion is being planned would be the ability to detect at the individual level a few pretreatment skeletal characteristics to use as predictors of successful or unsuccessful orthopedic correction of the disharmony. A multivariate approach to cephalometric data for predictive purposes has been recommended by Johnston[18] and used for differential diagnosis by Kowalski et al.[19,20] In fact, discriminant analysis had been used previously in several studies, many of which focused on identifying predictive variables for the results of orthodontic or orthopedic correction of Class III malocclusion.[21-25] Battagel[21] analyzed dentoskeletal and soft tissue pretreatment measurements to forecast relapse in patients with Class III malocclusion treated by nonextraction techniques in the mixed and permanent dentitions. Stensland et al[22] also used discriminant analysis to predict the short-term outcome of early orthopedic therapy of Class III malocclusion.

In a study by Franchi et al,[23] dental casts and lateral cephalograms of Class III patients treated with functional appliances (ie, removable mandibular retractors) were analyzed to derive predictive variables for the outcome of this type of Class III treatment. Three variables with predictive value were identified. Subjects having wider mandibular arches (assessed on casts), a more upward and forward inclination of the mandibular condyle in relation to the cranial base, and a larger angle between the mandibular and palatal planes had unsatisfactory long-term treatment outcomes. Vertical and transverse measurements played a major role in determining the destiny of early functional treatment of Class III malocclusion.

Tahmina et al[24] examined a rather large sample of patients (N = 56) with mandibular prognathism and anterior crossbite who were treated mainly with chincups. These patients were reevaluated after completing pubertal growth and assigned to 2 groups: a "stable" group and an "unstable" group. Three pretreatment cephalometric variables had the highest predictive power in terms of discriminating between the 2 groups: gonial angle, nasion-A-pogonion angle, and ramus plane to sella-nasion angle. Patients with larger values for these 3 measurements before treatment belonged to the unstable group at the end of the observation period. The degree of inclination of the ramus to the corpus in the mandible, together with the degree of mandibular protrusion, seemed to be key factors for determining the long-term outcome of chincup therapy in growing Class III patients.

The sizes of the apical bases for the maxilla and the mandible, along with the gonial angle and mandibular ramus and body dimensions, were the discriminating factors between good and poor responders to early Class III treatment in the investigation by Zentner et al.[25] Conventional orthodontic treatment with various commonly used removable and fixed appliances and their combinations was carried out in this study. No postretention evaluation of the patients was provided.

Thus, several previous studies of Class III treatments have identified specific morphologic variables as predictors of subsequent favorable or unfavorable treatment results. The aim of the present study was to select some cephalometric variables predictive for the long-term outcome of orthopedic treatment of Class III patients, by means of a specific treatment protocol (rapid maxillary expansion and facemask [RME/FM] therapy, followed by a phase with fixed appliances). As in previous similar investigations,[21-25] a multivariate statistical procedure (discriminant analysis) was used to identify the model of pretreatment variables for prediction.

MATERIAL AND METHODS

The parent sample consisted of the cephalometric records of 102 Class III patients treated with RME/FM therapy followed by comprehensive, preadjusted, edgewise therapy. Of these, all patients who satisfied the following inclusion criteria were selected for the final group: (1) European-American ancestry (white); (2) Class III malocclusion at the time of the first observation (T1), characterized by an anterior crossbite or edge-to-edge incisal relationship and a Wits appraisal[26] of −1.5 mm or less; (3) no permanent teeth congenitally missing or extracted before or during treatment; (4) cephalograms of

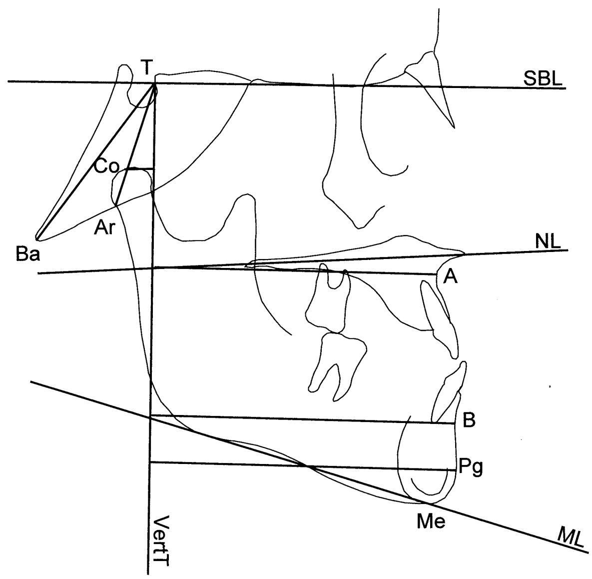

Fig 1. Cephalometric analysis: linear measurements for assessing sagittal relationships and angular measurements for assessing cranial base angulation and vertical relationships. See text for definitions of abbreviations.

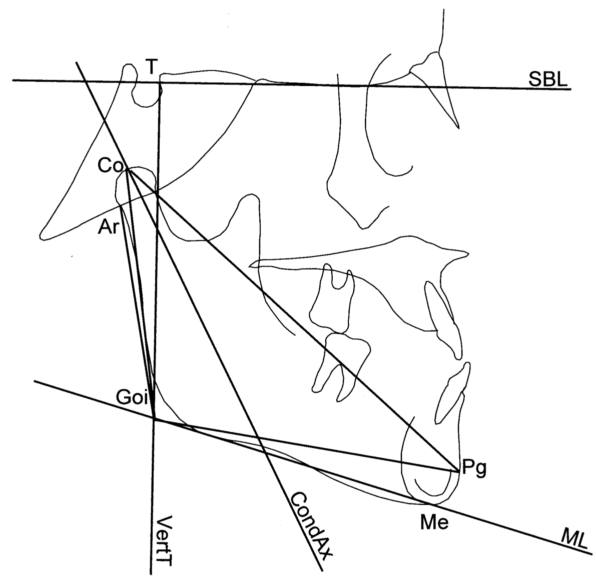

Fig 2. Cephalometric analysis: linear measurements for assessing mandibular dimensions and angular measurements for assessing condylar inclination. See text for definitions of abbreviations.

adequate quality available before the RME/FM therapy (T1) and at the long-term observation after the 2-phase treatment (T2); and (5) prepubertal skeletal maturation at T1, according to the cervical vertebral maturation method[27] (CVMS), performed with cephalometric software (Dr Ceph 7.2, FYI Technologies, Duluth, Ga), of CVMS I and with postpubertal skeletal maturation at the final observation (T2) (CVMS IV or V).

From the parent sample of 102 patients, 42 patients (22 girls, 20 boys) who satisfied the inclusionary criteria were selected. Mean age at the time of first observation was 8 years 6 months ± 2 years. Orthopedic treatment of the malocclusion was with RME/FM therapy. The mean active treatment period was approximately 1 year. During this period, the children wore the facemask at least 16 hours per day (nighttime included). The degree of cooperation was acceptable in all patients. Active treatment was discontinued when a positive overjet had been achieved. Later, all patients underwent a period of treatment with fixed appliances to refine and detail the occlusion after the permanent teeth (with the exception of the third molars) had erupted.

The lateral cephalograms of all patients were analyzed and standardized to 8% of radiographic enlargement. The cephalometric analysis (Figs 1 and 2) was based on a previously described basicranial reference system[23] comprising 2 perpendicular lines, and it was performed with cephalometric software (Dentofacial Planner, Dentofacial Software, Toronto, Ontario, Canada). The 2 lines were the stable basicranial line (SBL; passing through the superior point of the anterior wall of the sella turcica at the junction with tuberculum sellae, point T, and tangent to the lamina cribrosa of the ethmoid) and the vertical T line (VertT; perpendicular to SBL and passing through point T).

The following landmarks were used: point A (A), point B (B), pogonion (Pg), menton (Me), gonial intersection (Goi), articulare (Ar), condylion (Co), center of the condyle (Cs) (ie, a point equidistant from the anterior, posterior, and superior borders of the condylar head), basion (Ba), anterior nasal spine (ANS), and posterior nasal spine (PNS). The definitions of all landmarks correspond to those given by Björk,[28] Ødegaard,[29] and Riolo et al.[30]

The following measurements were performed (Figs 1 and 2): linear measurements for assessing sagittal relationships: A-VertT, B-VertT, Pg-VertT, Co-VertT; linear measurements for assessing mandibular dimensions: Co-Pg, Co-Goi, Goi-Pg; angular measurements for assessing cranial base angulation: Ba-T-SBL, Ar-T-SBL; angular measurements for assessing vertical relationships: nasal line (NL)-SBL, mandibular line (ML)-SBL, NL-ML, gonial angle (Ar-Goi-Me); and angular measurements for assessing condylar inclination: condylar axis (CondAx)-SBL and CondAx-ML (CondAx is a line passing through point condylion and

Table I. Descriptive statistics for all cephalometric variables at T1

	Total group (n = 42)		Successful group (n = 30)		Unsuccessful group (n = 12)	
Cephalometric variables	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
A-VertT (mm)	62.8	3.9	62.0	3.7	64.8	3.9
B-VertT (mm)	61.4	5.6	60.0	5.2	65.0	5.1
Pg-VertT (mm)	72.4	7.2	70.6	6.5	77.0	7.1
Co-VertT (mm)	17.1	3.2	17.0	3.4	17.3	2.9
Ba-T-SBL (°)	56.5	3.8	55.9	4.0	58.1	2.8
Ar-T-SBL (°)	60.3	4.5	60.1	4.8	61.0	3.6
NL-SBL (°)	−1.0	3.9	−0.8	4.1	−1.5	3.5
ML-SBL (°)	26.7	6.4	26.7	7.0	26.8	4.7
NL-ML (°)	25.7	4.8	25.9	4.7	25.3	5.1
Co-Pg (mm)	109.7	8.0	107.4	6.9	115.5	7.9
Co-Goi (mm)	53.2	5.0	51.7	4.2	56.8	5.3
Goi-Pg (mm)	71.3	6.5	70.1	5.8	74.3	7.4
Ar-Goi-Me (°)	128.1	5.7	128.2	5.3	128.0	6.9
CondAx-SBL (°)	138.3	8.2	139.3	9.1	135.8	4.4
CondAx-ML (°)	165.1	7.0	165.8	6.8	163.5	7.3
Wits (mm)	−4.8	1.9	−4.7	1.9	−5.1	2.1
Overjet (mm)	−1.9	1.5	−2.2	1.5	−1.1	1.0
Overbite (mm)	0.2	1.6	0.4	1.8	−0.4	0.7
Molar relationship (mm)	3.8	1.7	3.7	1.7	4.2	1-7

point Cs). Wits appraisal and the measurements for overjet, overbite, and molar relationship completed the analysis.

The assessment of the method error for the cephalometric measurements was performed with Dahlberg's formula[31] on 20 repeated measurements selected randomly from the total of the observations. The errors were between 0.1 and 0.8 mm for the linear measurements and between 0.2° and 0.9° for the angular measurements.

The patients were reevaluated after a mean period of 6 years 6 months (mean age at T2: 15 years ± 1 year 10 months) on the basis of their postretention occlusions. All patients were analyzed after completing their pubertal peak in mandibular growth (CVMS IV or V). At this time, failure of treatment was defined as "the concurrent presence of Class III permanent molar relationship and negative overjet." According to this rationale, the sample was divided into 2 groups, successful (SG) or unsuccessful (USG); SG comprised 30 patients (14 male, 16 female), and USG comprised 12 patients (6 male, 6 female).

Data analysis

Discriminant analysis was applied to cephalometric values of the 42 patients at the time of the first observation (T1). To arrive at the best model for discrimination, the first phase of the analysis was to select the most important variables for group separation between SG and USG. Therefore, stepwise variable selection was used to identify "good" predictor variables. Forward selection procedure with *F-to-enter* and *F-to-remove* equal to 4 was chosen. When the smallest set of significant discriminant variables was selected, the predictive power (classificative power) of the model was tested with discriminant analysis. This last procedure provides a method to forecast into which group a new patient is most likely to fall. Unstandardized discriminant function coefficients are calculated for each previously selected variable together with a constant. This calculation leads to an equation that will assign a score to each patient. A "mean score" for each of the 2 groups is given. Halfway between these scores is the dividing value (critical score) that establishes to which of the 2 groups a patient belongs. Statistical computations were performed with statistical software (SPSS for Windows 10.0.0; SPSS, Chicago, Ill).

RESULTS

Descriptive statistics for all cephalometric variables at the first observation (T1), for both the total sample and the 2 groups in the final sample (SG, n = 30; USG, n = 12), are listed in Table I. Normal distribution for the values of all cephalometric variables was verified in both groups with the Shapiro-Wilk test. Coefficients for normality ranged from 0.93 to 0.98 in SG, and from 0.86 to 0.97 for USG, and they did not reach statistical significance for any variable examined in either group.

Stepwise variable selection generated a 3-variable model that produced the most efficient separation

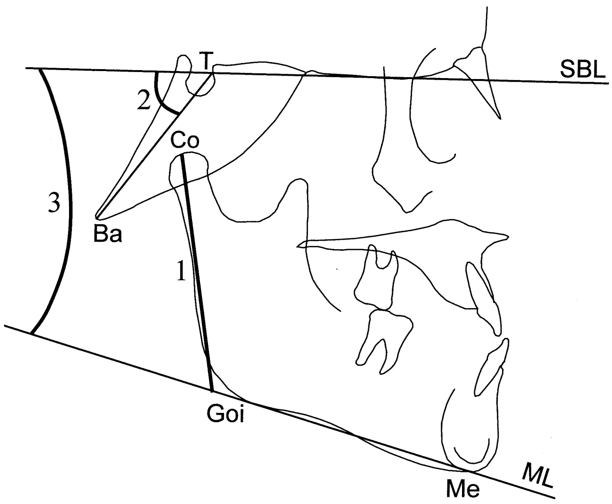

Fig 3. Predictive measurements for early orthopedic treatment of Class III malocclusion. *1*, Length of the mandibular ramus (Co-Goi); *2*, angulation of cranial base, measured as posterior angle between Ba-T and SBL; *3*, inclination of mandibular plane to cranial base (ML-SBL).

Table II. Stepwise variable selection procedure

Variables in model	*F-to-remove = 4*	*Variables not in model*	*F-to-enter = 4*
Co-Goi	24.509	Wits	0.006
Ba-T-SBL	9.724	Overbite	3.297
ML-SBL	7.297	Overjet	2.645
		Molar relationship	0.417
		Co-VertT	0.029
		A-VertT	0.081
		B-VertT	1.472
		Pg-VertT	0.871
		NL-SBL	0.018
		Ar-Goi	1.871
		CondAx-SBL	0.224
		Co-Pg	0.050
		Condax-ML	0.060
		NL-ML	0.018
		Goi-Pg	0.131
		Ar-T-SBL	2.321

Wilks's lambda = 0.564.

between the 2 groups (SG vs USG). The variables selected were length of the mandibular ramus (Co-Goi); angulation of the cranial base, measured as the posterior angle between Ba-T and the SBL; and inclination of the mandibular plane to the cranial base (ML-SBL) (Fig 3 and Table II). The classificative power of the selected 3-variable model was 83.33% (Table III). Only 1 of 5 patients in each group was not classified correctly. Unstandardized discriminant function coefficients of the selected variables, together with a calculated constant (Table IV), led to the following equation, which provides individual scores for assigning a new patient to SG or USG (Equation 1):

Table III. Discriminant analysis, classification results

Group	*No. of cases*	*Predicted group membership*			
		1		*2*	
		n	*%*	*n*	*%*
Group 1 (success)	30	26	86.7	4	13.3
Group 2 (failure)	12	3	25.0	9	75.0

Percentage of cases correctly classified: 83.33%.

Table IV. Discriminant function

Predictive variables	*Unstandardized canonical discriminant function coefficients*
Co-Goi	0.282
Ba-T-SBL	0.205
ML-SBL	0.120
Constant	−29.784

Individual score = $0.282_{(\text{Co-Goi})} + 0.205_{(\text{Ba-T-SBL})} + 0.120_{(\text{ML-SBL})} - 29.784$. Discriminant scores for group means (group centroids): successful group = −0.542; unsuccessful group = 1.355; critical score = 0.4065.

$$\text{Individual Score} = 0.282_{(\text{Co-Goi})} + 0.205_{(\text{Ba-T-SBL})} + 0.12_{(\text{ML-SBL})} - 29.784 \quad (1)$$

The critical score (the value dividing SG from USG) is 0.4065; ie, the mean value of the group centroids of the 2 groups (Table IV). Each new patient with Class III malocclusion that has a score lower than the critical score will be treated successfully with RME/FM therapy. Conversely, each new patient with Class III malocclusion with a score higher than the critical score can be predicted to respond poorly to orthopedic treatment. The predictive power of the selected model was tested successfully on a separate group of Class III patients treated with the same protocol.

DISCUSSION

The possibility to predict at an early stage the long-term outcome of orthopedic intervention in Class III skeletal disharmony might play a substantial role in enhancing the diagnostic and prognostic abilities of the contemporary orthodontist. This study attempted to identify a series of cephalometric variables with significant power for the pretreatment categorization of Class

III patients with regard to the effectiveness of an orthopedic treatment protocol and the long-term stability of treatment results. More specifically, our findings pertain to the predictability of outcome of Class III orthopedic treatment with a standardized protocol—RME/FM therapy followed by a comprehensive phase with fixed appliances.

In this study, "outcome" was considered as the result of active treatment plus a period of posttreatment observation. All patients completed orthopedic treatment of Class III malocclusion with the RME/FM protocol before the start of the pubertal peak in mandibular growth. The long-term evaluation of treatment results took place about 6.5 years after the start of treatment (at approximately 16 years of age), that is, after the pubertal peak in mandibular growth, when almost all active growth was completed. The maturational status of these patients was assessed with a reliable biologic indicator, the cervical vertebral maturation method.[27]

In this study, which analyzed Class III patients treated with combined RME/FM therapy, the examined treatment protocol was effective in the long term: only 12 of 42 patients (28.6%) had final unsuccessful results. Once the factors of difficulty regarding orthopedic Class III treatment are considered (need for patient collaboration and parental support, tendency of Class III malocclusion to aggravate with growth, relapse tendency after treatment), the treatment protocol described here seems to be fairly efficient in correcting Class III skeletal disharmony. These data fully coincide with those of a recent, larger-scale study that reported a success rate of 75% for RME/FM therapy in Class III malocclusion.[5]

As to statistical methodology, discriminant analysis was chosen as an efficient multivariate technique for identifying predictive variables at the first observation (T1). Possibly other factors for the final result of treatment (tooth size, size of the apical bases, heredity, soft tissue features) have not been included in this analysis that might improve the model.[18-21,24,25]

Three predictive measurements for the outcomes of orthopedic treatment of Class III malocclusion were identified (Fig 3): (1) the length of the mandibular ramus or posterior facial height (Co-Goi), (2) the angulation of the cranial base, measured as the posterior angle between the Ba-T line and the SBL, and (3) the inclination of the mandibular plane to the cranial base (ML-SBL). Orthopedic treatment of Class III malocclusion can lead to more favorable craniofacial adaptations when a patient's pretreatment cephalometric records exhibit a short mandibular ramus (ie, decreased posterior facial height), with an obtuse cranial base angle and a low mandibular plane angle. Conversely, excessive length of the mandibular ramus (ie, increased posterior facial height), with an acute cranial base angle and a steep mandibular plane angle must be considered as unfavorable signs in the prognosis of Class III malocclusion.

The important role of vertical skeletal relationships in determining the destiny of early treatment in Class III malocclusion has been emphasized by Franchi et al,[23] who found that Class III patients with a large angle between the mandibular and palatal planes in the deciduous dentition ended up with poorer treatment outcomes in the long term. In the investigations by Tahmina et al[24] and Zentner et al,[25] patients who, before treatment, had larger values for the inclination of the mandibular ramus to the mandibular body (gonial angle) had a higher probability of relapse at the end of the observation period.

The other 2 predictive cephalometric parameters that were selected by multivariate analysis were the angulation of the cranial base and the dimension of the mandibular ramus (ie, posterior facial height). Zentner et al[25] also identified mandibular ramus and body dimensions as discriminating factors between good and poor responders to early Class III treatment. As for cranial base flexure, several contributions[32-34] have implicated a decrease in the angle between the anterior and posterior cranial base segments in the development of prognathic profiles with the consequence of a more anterior location of the glenoid fossa.[35,36] A decreased degree of cranial base angulation seems to be not only a diagnostic feature of patients with Class III malocclusion but also an unfavorable feature in the long-term prognosis of Class III orthopedic therapy.

The predictive model that was developed in the present study can identify good or bad responders to early orthopedic treatment of Class III malocclusion with maxillary expansion and protraction. This observation does not necessarily mean that the model can recognize "surgical vs nonsurgical" patients automatically. In bad responders, the possibilities of alternative orthodontic therapies could be considered in comprehensive treatment planning.

CONCLUSIONS

The assessment of long-term outcomes of orthopedic treatment of Class III malocclusion was performed by means of discriminant analysis, to identify a significant model of predictive variables for the effectiveness and stability of results of RME/FM therapy. Three predictive measurements were selected: (1) length of the mandibular ramus (Co-Goi), (2) angulation of the cranial base (Ba-T-SBL), and (3) inclination of the mandibular plane to the cranial base (ML-SBL). The classificative power of the model for predicting success or failure of orthopedic treatment of Class III treatment is 83% for each new patient. The important role of vertical skeletal relationships and the degree of cranial base flexure in the diagnostic and prognostic evaluation of Class III patients deserves to be emphasized. Orthopedic treatment of Class III malocclusion might be unfavorable over the long term when a patient's cephalometric records show an increased posterior facial height, an acute cranial base angle, and a steep mandibular plane angle at the start of treatment.

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