ORIGINAL ARTICLE

Cephalometric variables to predict future success of early orthopedic Class III treatment

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Background: The objective of this study was to select a model of cephalometric variables to predict future Class III growth patterns based on the results of early orthopedic treatment with a protraction facemask. **Material:** Sixty-four patients with Class III malocclusion were treated with a protraction facemask. Cephalometric radiographs were taken before treatment and a minimum of 3 years after treatment. The sample was divided into 2 groups: successful and unsuccessful according to overjet and molar relationships. Eleven linear and 5 angular measurements were made on the pretreatment radiograph. A logistic regression model was used to identify the dentoskeletal variables most responsible for the prediction of successful and unsuccessful outcomes in subjects receiving treatment. **Results:** Stepwise variable selection generated 4 variables significant in predicting successful treatment outcomes: position of the condyle with reference to the cranial base (Co-GD, $P = .02$), ramal length (Co-Goi, $P = .03$), mandibular length (Co-Pg, $P = .01$), and gonial angle (Ar-Goi-Me, $P < .0001$). The gonial angle was found to be significantly larger in the unsuccessful group. Controlling for other variables, the probability of successful treatment is an increasing function of Co-GD and Co-Goi, and a decreasing function of Co-Pg and Ar-Goi-Me. A logistic equation was established that is accurate in predicting successfully treated Class III patients 95.5% of the time and unsuccessful ones 70% of the time. **Conclusions:** These results suggest that Class III growing patients with forward position of the mandible, small ramal length, large mandibular length, and obtuse gonial angle are highly associated with unsatisfactory treatment outcomes after pubertal growth. (Am J Orthod Dentofacial Orthop 2005;127:301-6)

Class III malocclusion is a major challenge in orthodontic treatment. Patients receiving early orthopedic treatment to correct the skeletal disharmony might have to be retreated later because of differential skeletal growth of the maxilla and mandible during the pubertal growth spurt.[1] Currently, it is difficult to predict growth in young Class III patients awaiting long-term results of early treatment to determine the benefits of such treatment.

A prospective clinical study on the treatment of Class III malocclusion with the protraction facemask showed that a positive overjet can be obtained in all patients after 6 to 9 months of treatment. However, at the end of the 4-year observation period, 5 of the 20 patients (25%) reverted to a reverse incisal relationship. These 5 patients were found to have excess horizontal mandibular growth that was not compensated dentally by the incisors.[2] Sugawara et al[3] studied long-term changes in the skeletal Class III profile after chincap therapy and found that initially favorable changes were often not maintained during puberty. Other studies with chincap treatment also suggest that growth changes of the jaws are variable and that the effects of chincap treatment depend on individual mandibular growth characteristics.[4,5]

Several investigators have attempted to predict the progression of Class III malocclusions. The aim was to determine whether growth prediction can be used to differentiate children with Class III skeletal growth tendency. Johnston[6] proposed a simplified method of generating long-term forecasts by using a printed "forecast grid." This method used mean-change expansion of a few cephalometric landmarks. The author stated that the grid might provide a simple introduction to growth prediction. However, a drawback to the grid system is that it does not fit a random series of patients nearly as well. The objective of this study was to select a model of cephalometric variables to predict future Class III growth patterns based on the results of early orthopedic Class III treatment using a protraction facemask.

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0889-5406/$30.00
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Submitted, December 2003; revised and accepted, February 2004.
0889-5406/$30.00

doi:10.1016/j.ajodo.2004.02.014

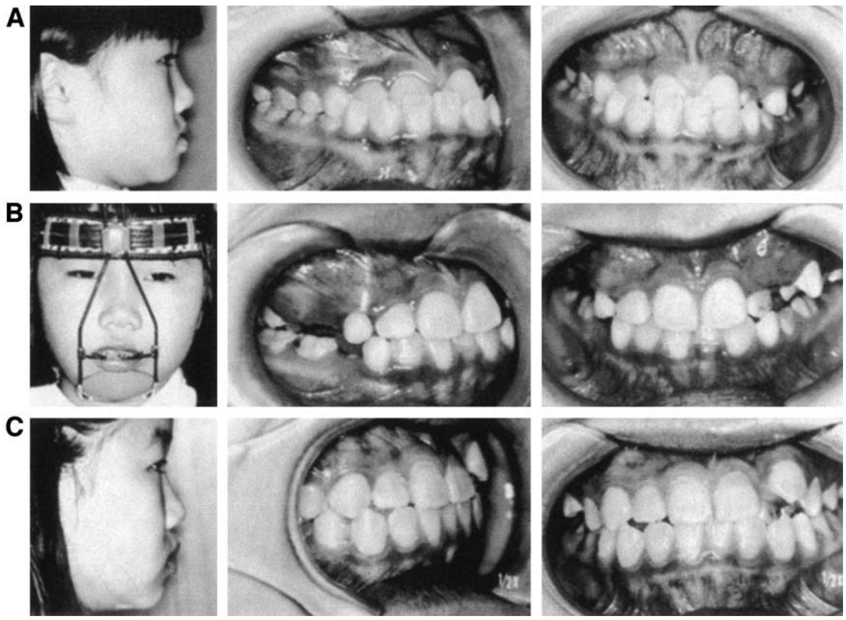

Fig 1. Subject in successful treatment group; **A**, 9-year-old Chinese girl with Class III malocclusion, anterior crossbite, and maxillary deficiency; **B**, treatment included expansion appliance and protraction facemask for 8 months; **C**, 3-year follow-up records show Class I molar relationship and positive overjet.

MATERIAL AND METHODS

A sample of 64 subjects, 35 female and 29 male, with Class III malocclusion in the primary and mixed dentitions was included in this study. These patients were selected from the files of the Department of Children's Dentistry and Orthodontics, University of Hong Kong and from the Department of Orthodontics, West Virginia University School of Dentistry. Selection criteria included patients who (1) were treated with a maxillary expansion and protraction facemask appliance, (2) had no previous orthodontic treatment, and (3) had pretreatment records and follow-up records at least 3 years posttreatment. There were 30 Chinese patients and 34 white patients in the sample. At the first observation, all subjects had Class III malocclusions, anterior crossbites, and maxillary retrusion. Correction of anterior crossbite was accomplished by means of maxillary expansion and protraction (Fig 1, *A* and *B*). The mean age of the subjects at prereatment was 9.2 $\pm$ 1.8 years. Posttreatment records were used to divide the sample into 2 groups, successful and unsuccessful treatment, according to the following criteria: (1) a positive overjet of $>$ 1 mm and (2) a Class I molar relationship (Fig 1, *C*).

Cephalometric analysis was performed on all the pretreatment cephalometric radiographs. A basicranial reference system was used for linear measurements, consisting of 2 lines perpendicular to each other[7]: sella horizontal (SH), a line parallel to Frankfort horizontal passing through sella; and great divide (GD), a vertical line passing through sella, perpendicular to sella horizontal.

The landmarks and measurements used are shown in Figures 2 and 3. Definitions of these landmarks correspond to those given by Björk,[8] Odegaard,[9] and Riolo et al[10]: sella (S), point A (A), point B (B), prosthion (Pr), infradentale (Id), pogonion (Pg), menton (Me), gonial intersection (Goi), articulare (Ar), condylion (Co), center of the condyle (Cs), basion (Ba), anterior nasal spine (ANS), posterior nasal spine (PNS), nasal line (NL), mandibular line (ML), and condylar axis (CondAx), which is the line passing through Co and Cs. Linear measurements for assessment of sagittal relationships were A-GD, B-GD, Pr-GD, Id-GD, Pg-GD, Goi-GD, Co-GD, and ANS-PNS. Linear measurements for assessment of mandibular dimensions were Co-Pg, Co-Goi, and Goi-Pg. Angular measurements for assessment of vertical relationships were NL-SH, ML-SH, NL-ML, and gonial angle (Ar-Goi-Me). The angular measurement for assessment of condylar inclination was CondAx-SH.

A logistic regression model was used to identify the dentoskeletal variables most responsible for the prediction of successful and unsuccessful treatment in sub-

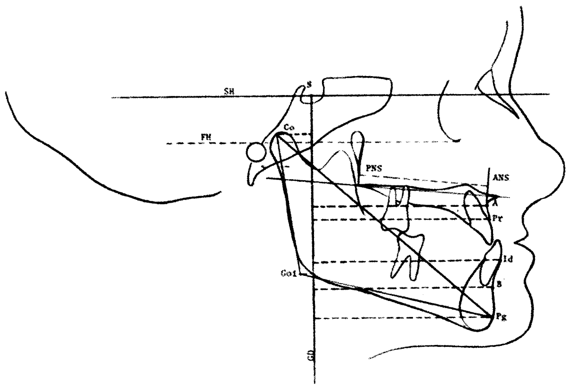

Fig 2. Landmarks and linear cephalometric measurements.

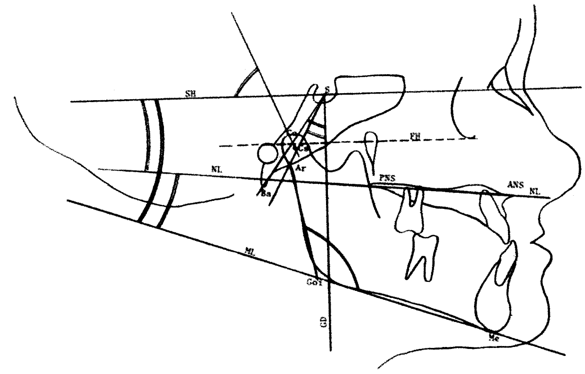

Fig 3. Landmarks and angular cephalometric measurements.

jects receiving early Class III treatment. A stepwise variable selection was used to identify good predictor variables. This multivariate approach was allowed by exploratory comparison between the values for all variables in the successful and unsuccessful groups, with a 1-way analysis of variance at the first observation.[11,12] The significant level was set at $P < .05$.

For error measurements, cephalometric analyses were performed on 10 subjects independently on 2 separate occasions with 1 week between. For all cephalometric variables, the intraclass correlation coefficients of reliability were found to be greater than 0.86.

RESULTS

Linear and angular cephalometric measurements for the total sample, the successful group, and the unsuccessful group at the first observation are shown in Table I. The chi-square test showed no significant difference for either sex ($P = .49$) or race ($P = .39$) for any of the variables tested. Stepwise variable selection generated 4 variables found to be significant in predicting successful and unsuccessful treatment in subjects with early Class III treatment: position of the mandible relative to cranial base (Co-Gd), ramal length (Co-Goi), mandibular length (Co-Pg), and gonial angle (Ar-Goi-Me). An odds ratio was developed with these 4 significant variables (Table II). For example, an increase in Co-GD of 1 unit (millimeter) increases the probability of having successful treatment by a factor of 1.21. A patient with the condyle or mandible positioned more posteriorly is more likely to be successful than a patient with the condyle or mandible positioned more anteriorly, assuming that all other variables for the 2 patients have identical values. Similarly, an increase in the measurement of Co-Pg by 1 unit (millimeter) decreases the probability of being successful by a factor of 0.87. A patient with more mandibular length is less likely to have successful treatment than one with less mandibular length, assuming that all other variables for the 2 patients have identical values. An increase in ramal length (Co-Goi) of 1 unit increases the probability of being successful by a factor of 1.17. An increase in gonial angle (Ar-Goi-Me) of 1 unit decreases the probability of being successful by a factor of 0.81. Table III shows the amount of increase (or decrease) in the unit of a variable (millimeter or degree), which would lead to an increase in the probability of being successful by a factor of 2.

The logistic regression model used in the current study led to the following estimated logic function equation, where P is the probability that early orthopedic treatment will be successful in a patient with Class III malocclusion:

$$P = \frac{1}{1 + \mathrm{Exp}(-L)}$$

where $L = 30.557 + 0.196$ (Co-GD) – 0.129 (Co-Pg) + 0.162 (Co-Goi) – 0.206 (Ar-Goi-Me).

By using the above formula and variables, the percentages of patients that could be predicted to be successful or unsuccessful are shown in Table IV. The fitted model correctly predicted 95.5% (42 of 44) of the successful cases and missed or misclassified as unsuccessful 4.5% (2/44). Similarly, the fitted model correctly predicted 70% (14/20) of the unsuccessful cases and missed or misclassified as successful 30% (6 of 20).

DISCUSSION

Class III malocclusion with mandibular prognathism continues to challenge practicing orthodontists

Table I. Cephalometric measurements of total sample, successful group, and unsuccessful group

Cephalometric variables	Total sample (n = 64)					Successful group (n = 44)					Unsuccessful group (n = 20)				
	Mean	SD	SE	Max	Min	Mean	SD	SE	Max	Min	Mean	SD	SE	Max	Min
A-GD (mm)	60.98	5.78	0.51	73.0	48.5	60.32	5.47	0.58	73.0	48.5	62.45	6.23	0.99	72.0	52.0
B-GD (mm)	58.70	8.29	0.73	79.0	39.5	58.15	7.51	0.80	79.0	39.5	59.90	9.80	1.55	77.5	39.5
Pr-GD (mm)	62.71	6.78	0.60	78.0	42.0	62.11	6.85	0.73	78.0	42.0	64.04	6.51	1.03	74.0	52.5
Id-GD (mm)	62.34	7.73	0.68	80.5	45.0	61.84	6.78	0.72	80.0	46.0	63.45	9.49	1.50	80.5	45.0
Pg-GD (mm)	57.78	9.68	0.86	82.5	33.0	57.39	8.89	0.95	82.5	33.0	58.63	11.31	1.79	78.0	33.0
Goi-GD (mm)	9.28	7.88	0.70	43.0	−10.0	10.86	7.41	0.79	43.0	−1.0	5.79	7.85	1.24	19.0	−10.0
Co-GD (mm)	10.76	3.17	0.28	19.5	1.5	11.12	3.18	0.34	19.5	5.5	9.99	3.03	0.48	15.5	1.5
Co-Pg (mm)	108.72	13.81	1.22	127.0	96.0	107.06	15.58	1.66	123.0	96.0	112.35	7.71	1.22	127.0	101.0
Co-Goi (mm)	57.07	7.09	0.63	100.5	45.0	57.80	7.87	0.84	100.5	48.0	55.45	4.67	0.74	66.5	45.00
Goi-Pg (mm)	72.67	4.80	0.42	84.0	62.5	72.88	4.80	0.51	84.0	63.0	72.21	4.84	0.76	83.5	62.5
NL-SH (deg)	3.37	4.36	0.39	16.5	−6.0	3.70	4.32	0.46	16.5	−4.0	2.63	4.42	0.70	10.0	−6.0
ML-SH (deg)	30.22	6.02	0.53	54.0	14.0	29.00	5.44	0.58	42.0	14.0	32.89	6.42	1.02	54.0	24.0
NL-ML (deg)	27.43	5.77	0.51	45.5	12.5	25.88	5.04	0.54	37.5	12.5	30.84	5.87	0.93	45.5	18.5
Ba-S-GD (deg)	33.50	4.94	0.44	48.0	13.0	34.12	4.28	0.46	48.0	26.5	32.14	6.00	0.96	40.0	13.0
Ar-S-GD (deg)	27.64	5.34	0.47	39.0	14.5	28.80	5.41	0.58	39.0	14.5	26.64	5.09	0.82	35.5	18.0
Ar-Goi-Me (deg)	127.14	7.79	0.69	146.0	103.0	124.31	6.81	0.73	138.0	103.0	133.36	6.04	0.95	146.0	121.5
CondAx-SH (deg)	96.30	17.11	1.51	125.0	52.0	95.28	17.38	1.85	116.5	52.0	98.55	16.46	2.60	125.0	57.0
ANS-PNS (mm)	43.81	2.96	0.26	50.0	38.0	43.59	3.07	0.33	50.0	38.0	42.83	2.86	0.38	49.5	39.0

Max, Maximum; *Min,* minimum.

Table II. Odds ratios for the significant variables

Significant variable	Odds ratio	P value
Co-GD	1.21	.02
Co-Pg	0.87	.01
Co-Goi	1.17	.03
Ar-Goi-Me	0.81	<.0001

Table III. Increase (or decrease) in unit of variable (millimeter or degree) that will lead to increase in probability of success by factor of 2

Significant variable	Increase	Decrease	K
Co-GD	3.53	—	2
Co-Goi	4.27	—	2
Co-Pg	—	5.37	2
Ar-Goi-Me	—	3.36	2

because it is difficult to predict craniofacial growth for each patient. In a study by Guyer,[13] 57% of the patients with either a normal or a prognathic mandible showed a deficiency in the maxilla. Class III patients with maxillary deficiency can benefit from early treatment with maxillary expansion and protraction. The effect of early orthopedic treatment is well documented in the literature.[2,14-16] However, successful orthodontic or orthopedic treatment to camouflage skeletal discrepancies require growth prediction. Currently, there is no method to accurately predict future mandibular growth. In the present retrospective study, long-term treatment records and discriminate analyses were used to identify cephalometric variables clinicians can use to predict future mandibular growth with a single radiograph. This will help clinicians decide whether to start camouflage treatment during the growth period or wait until completion of growth for orthognathic surgery treatment.

In this study, 4 measurements were found to be useful for prediction: Co-GD, Co-Pg, Co-Goi, and Ar-Goi-Me. Decreases in mandibular length (Co-Pg) and gonial angle (Ar-Goi-Me) are associated with successful treatment, and increases in the position of the mandible relative to the cranial base (Co-GD) and ramal length (Co-Goi) are also associated with successful treatment. These results agree with those reported by others.[17-19] In a study by Schulhof et al,[17] the molar relationship, cranial deflection, porion location and ramus positions on cephalometric radiographs were found to be useful in predicting normal and abnormal growth. Using longitudinal data of patients treated with chincap therapy, Franchi et al[18] showed that the inclination of the condylar axis relative to the basicranial line and the inclination of the nasal line to the mandibular line can be used to predict success or failure of early chincap treatment using the discriminant analysis. In a study of Japanese patients, the gonial angle and the

Table IV. Percentage of patients that could be predicted to be successful or unsuccessful with the fitted model and equation

Actual group	*Patients (n)*	*Correct predictions (n)*	*Correct predictions (%)*	*Incorrect predictions (n)*	*Incorrect predictions (%)*
Successful	44	42	95.5	2	4.5
Unsuccessful	20	14	70	6	30

position of the mandible relative to cranial base (N-A-Pog and the ramus plane to SN angles were found to be the variables for discriminating between successful and unsuccessful groups.[19]

Surprisingly, none of the variables relating to the size or position of the maxilla is a good predictor of treatment outcome. In several studies, the maxilla was found to be located more posteriorly relative to the cranial base in the unsuccessful group.[1,7,20,21] However, Lu et al[22] found that the anteroposterior position of the maxilla in patients with mandibular prognathism tended to approach that of the controls after correction of anterior crossbite either by chincap or protraction facemask. It is also possible that correction of the anterior crossbite in this study released the mechanical restraint that prevented forward growth of the maxilla.

The shape of the mandible, on the other hand, is determined by a greater component of genetic variability and various environmental factors such as development of the masticatory muscle and occlusal systems.[23] Björk[24] suggested that the condyle is a primary growth site and is responsible for increases in mandibular length. Condylar growth direction also determines the direction of growth and position of the chin. Therefore, it is not surprising that the shape (length and gonial angle) and the position of the mandible, as well as chin position, are good predictors of future mandibular growth.

When we used the logistic regression model and equation for predicting early Class III treatment, 95.5% of the patients were found to correspond to their original successful group, and 70% were found to correspond to their original unsuccessful group. These results suggest that the current model is better in predicting successful cases than unsuccessful ones. The accuracy of computer software in predicting abnormal mandibular growth to warn orthodontists of possible difficulty in treatment is currently around 70% to 80%.[25]

There are several shortcomings in our retrospective study. First, the results might have been affected by sex or racial differences (because of the mix of Asian and white subjects) even though analysis of pretreatment cephalometric measurements showed no significant sex or racial differences. Second, some patients had been followed for only 3 years, so a certain amount of residual craniofacial growth remained. It would be ideal if successful and unsuccessful judgments were made after maximum pubertal growth, as determined by hand-wrist radiographs. Third, this prediction scheme has not been tested for efficiency on a separate sample. Fourth, other elements (such as soft tissue features) that might have improved the accuracy of the model were not included in this analysis. This predictive model can identify Class III patients as good or bad responders to early treatment with protraction facemask It can help clinicians decide whether to camouflage the skeletal malocclusion or wait until growth is completed. It does not automatically recognize surgical versus nonsurgical patients.

CONCLUSIONS

A retrospective study was conducted to select a model of cephalometric variables that could predict future Class III growth patterns, based on the results of early orthopedic treatment of 64 patients using a protraction facemask. According to the outcome at least 3 years posttreatment, all subjects were divided into 2 groups: a successful group having acceptable treatment outcome and an unsuccessful group having relapse in anterior overjet. Cephalometric measurements were subjected to discriminant analysis to identify key determinants for differentiating between the 2 groups. The following results were obtained:

1. Stepwise variable selection generated 4 variables that were significant in predicting successful treatment outcomes: position of the condyle relative to cranial base (Co-GD, $P = .02$), ramal length (Co-Goi, $P = .03$), mandibular length (Co-Pg, $P = .01$), and gonial angle (Ar-Goi-Me, $P < .0001$). The probability of successful treatment is an increasing function of Co-GD and Co-Goi, and a decreasing function of Co-Pg and Ar-Goi-Me.
2. A logistic equation was established that accurately predicted successfully treated Class III patients 95.5% of the time and unsuccessfully treated patients 70% of the time.

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