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Prediction of post-treatment outcome after combined treatment with maxillary protraction and chincap appliances

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SUMMARY The aims of this study were to identify differences in the initial skeletal morphology between successful and unsuccessful groups and to establish a novel method for predicting the final outcome of treatment with a maxillary protraction appliance (MPA) and chincap. The cephalograms used in this study were taken from 32 Japanese girls (mean age 10.2 years) with a Class III malocclusion at the beginning of treatment with an MPA and chincap (T1), at removal of the appliance (T2), and during the final post-treatment period (T3). The subjects were divided into two groups according to the treatment outcome at T3.

Lower face height (ANS–Me), total face height (N–Me), ratio of face height (ANS–Me/N–ANS), maxillary position, mandibular plane and gonial angle at T1 were all significantly larger in the unsuccessful group, compared with the successful group. Discriminant analysis indicated that lower face height and gonial angle were significant determinants for distinguishing between the two groups at T1. From T1 to T2, while the anterior displacement of the maxilla was almost the same in the two groups, SNB decreased by 1.6 degrees in the successful group and 0.4 degrees in the unsuccessful group. After orthopaedic treatment, a second phase of treatment with a multibracket system was performed (T2 to T3). From T2 to T3, SNA increased by 0.4 degrees in the successful group and decreased by 0.7 degrees in the unsuccessful group. These results indicate that the vertical dimensions of the craniofacial skeleton are important for predicting the prognosis of skeletal Class III patients treated with a MPA and chincap and that the discriminant formula established in this study is effective in predicting the final treatment outcome.

Introduction

The goal of early orthopaedic treatment is to correct existing and developing skeletal, dentoalveolar and functional imbalances, which could help to minimize the possibility of complicated orthodontic treatment involving permanent tooth extraction or orthognathic surgery (McNamara and Bruden, 1993). A chincap and/or maxillary protraction appliance (MPA) are commonly used to correct the intermaxillary discrepancy and anterior crossbite in patients with skeletal Class III malocclusions (Irie and Nakamura, 1975; Graber, 1977; Sakamoto, 1981; Mitani and Sakamoto, 1984; Ishii *et al*., 1987; Mermigos and Full, 1990; Allen *et al*., 1993; Takada *et al*., 1993; Baik, 1995; Chong *et al*., 1996; Deguchi and Kitsugi, 1996; Ngan *et al*., 1996; Baccetti *et al*., 1998; Yoshida *et al*., 1999a,b; Kajiyama *et al*., 2000; Üçüncü *et al*., 2000; Suda *et al*., 2000; Deguchi *et al*., 2002). The effects of treatment with such orthopaedic appliances have been extensively investigated and have been reported to be as follows: acceleration of forward growth of the maxilla with counterclockwise rotation, forward movement of the maxillary dentition, retardation of mandibular growth and backward movement of the mandible with counterclockwise rotation (Irie and Nakamura, 1975; Ishii *et al*., 1987; Mermigos and Full, 1990; Takada *et al*., 1993; Baik, 1995; Chong *et al*., 1996; Ngan *et al*., 1996; Baccetti *et al*., 1998; Üçüncü *et al*., 2000). In previous studies, the combination of MPA and chincap treatment was shown to be effective for correcting skeletal discrepancy, although a moderate mandibular rebound occurred (Yoshida *et al*., 1999a,b).

Clinically, variation in the growth patterns of individual patients and difficulty in maintaining a corrected skeletal profile and anterior overjet have been observed (Mitani and Fukazawa, 1986; Sugawara *et al*., 1990; Battagel and Orton, 1993). Some patients with skeletal Class III malocclusions exhibit unexpected and progressive mandibular growth and relapse of the anterior crossbite during pubertal growth, even though the Class III skeletal profile and occlusion have been previously corrected. This is one of the most perplexing problems in diagnosing and treating Class III malocclusions during the growth stage. However, little information is available concerning the prediction of post-treatment stability and suitable conditions for the application of orthopaedic appliances, except in chincap therapy (Choi *et al*., 1999; Tahmina *et al*., 2000).

The aims of this study were to identify differences in initial skeletal morphology between successful and unsuccessful groups, and to establish a novel method for predicting treatment outcome with a MPA and chincap appliance using discriminant analysis. The aim is to establish a more appropriate long-term treatment plan for skeletal Class III malocclusions.

Subjects and methods

Thirty-two female Japanese patients (mean age 10.2 years) who had been diagnosed as skeletal Class III and had received a combined MPA and chincap appliance and subsequent multibracket therapy were used in this study (Table 1). Since there are male–female differences in the amount and timing of growth in Class III patients (Mitani *et al*., 1993), only female patients were considered to simplify the analysis of the data. Cephalograms were taken at the beginning (T1) and at the end of the first phase (T2) of treatment, and post-treatment (T3). The patients were treated with a combined MPA and chincap appliance (Ishii *et al*., 1987; Yoshida *et al*., 1999a,b) during the first phase of treatment (T1 to T2). From T2 to T3, they underwent a second phase of treatment with a multibracket system, if necessary, when pubertal growth was almost complete. This was followed by retention.

The subjects were divided into two groups at T3 according to the status of the anterior bite and molar and canine relationships: successful (mean age 9.9 years, $n = 16$) and unsuccessful (mean age 10.4 years, $n = 16$). The successful group exhibited favourable responses to the orthopaedic appliances during the first phase of treatment, and optimal molar and canine relationships with a normal overjet and overbite were achieved at the end of the second phase of treatment and maintained until T3. In the unsuccessful group, all patients were treated with a multibracket appliance with Class III mechanics in the second phase of treatment, but a Class I molar and canine relationship and normal anterior bite were either not achieved at the end of the second-phase of treatment or not maintained at T3. In this group, orthognathic surgery was recommended to correct unacceptable occlusions with skeletal problems at T3.

Table 1 Ages of the patients at the beginning of maxillary appliance (MPA) treatment (T1), on removal of the MPA (T2) and post-treatment (T3).

	Successful $n = 16$	Unsuccessful $n = 16$	
	Mean SD	Mean SD	*P*
T1	9.9 ± 1.6	10.4 ± 1.5	0.36
T2	11.2 ± 1.4	12.0 ± 1.2	0.10
T3	16.6 ± 2.2	17.4 ± 2.8	0.35

Appliance design

The combined MPA and chincap appliance used in this study has been described previously (Ishii *et al*., 1987; Yoshida *et al*., 1999a). Briefly, the maxillary intraoral appliance consisted of a palatal wire frame, a palatal plate and bands fixed on the molars or on the first premolars and molars (Figure 1). The intraoral appliance was attached to buccal hooks on the first premolars or first molars. A protraction force of 200 to 300 g per side was used with an antero-inferior force vector of approximately 20 degrees to the occlusal plane. The vector of the chincap force was in the direction of the condyle and the total

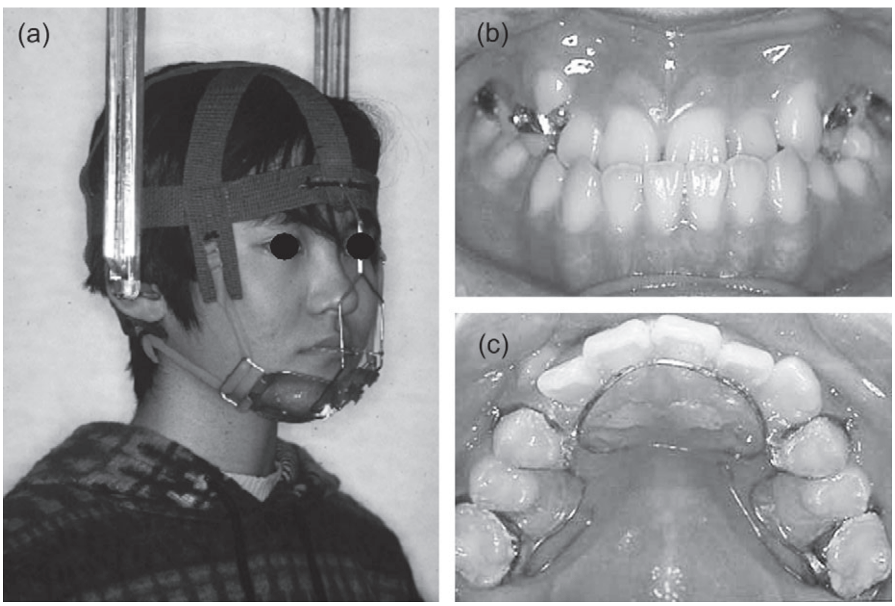

Figure 1 Facial (a) and intraoral (b,c) photographs of maxillary protraction and chincap appliance.

amount of force was approximately 600 g. The patients were instructed to wear the appliance for at least 14 hours per day.

Cephalometric analysis

All cephalograms used in this study were traced on acetate paper by one author (IY). The cephalometric measurements were made according to the Cartesian co-ordinate system used by the Department of Orthodontics, Health Sciences University of Hokkaido (Figures 2 and 3). The Frankfort horizontal (FH) plane of the initial tracing at T1 represented the x-axis. The y-axis was constructed by drawing a line perpendicular to the FH line through sella (S). Successive three-stage tracings were superimposed on anatomical structures of the anterior cranial base as reference structures (Björk and Skieller, 1983). The positions of all cephalometric landmarks were calculated using the X-Y co-ordinate system. A mean facial profilogram was constructed for each group. All values were stored on a computer, and 20 cephalometric measurements were analysed. Differences among these data were examined by a t-test.

Discriminant analysis

Discriminant analysis was performed to identify significant variables which distinguished between the successful and unsuccessful groups at T1. The analysis was performed with a multivariate analysis program included in Excel (Statistics Survey System Development Co., Tokyo, Japan). First, six independent variables, including lower face height (ANS–Me), total face height (N–Me), ratio of face height (ANS–Me/N–ANS), SNA, gonial angle and mandibular plane to SN, which showed significant differences between the two groups at T1, were selected from among 20 variables. Second, variables suitable for distinguishing between the two groups were extracted from these six variables using a discriminant analysis with stepwise and trial-and-error approaches. The accuracy of the discriminant function was calculated on the basis of a 2 × 2 cross table.

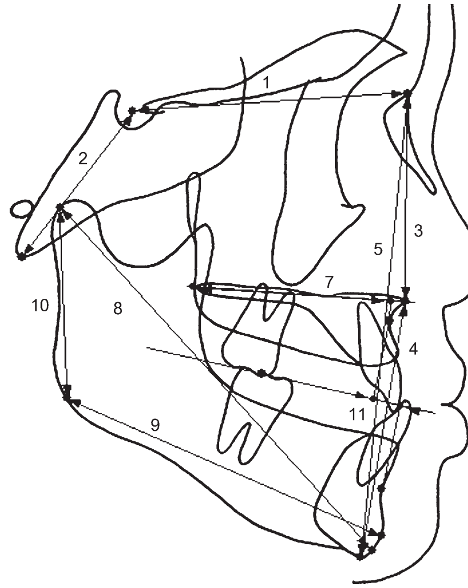

Figure 3 Linear measurements used in this study. 1, anterior cranial base length (N–S); 2, posterior cranial base length (S–Ba); 3, upper face height (N–ANS); 4, lower face height (ANS–Me); (5, total facial height (N–Me); (6) ratio of face height (ANS–Me/N–ANS); 7, maxillary size (A'–Ptm'); 8, total mandibular length (Gn–Cd); 9, mandibular body length (Pog–Go); 10, mandibular ramus length (Cd–Go); 11, intermaxillary position to occlusal plane (Wits appraisal).

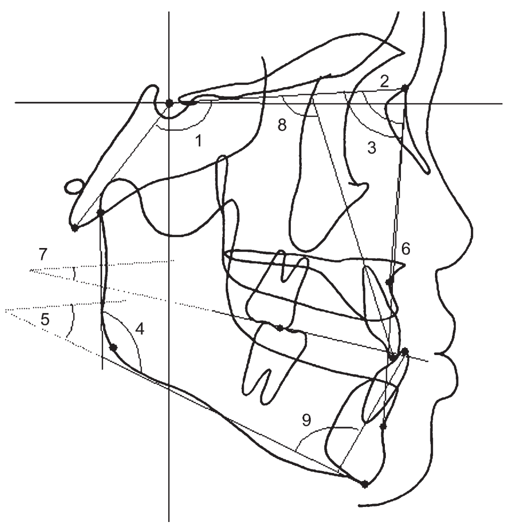

Figure 2 Angular measurements used in this study. 1, cranial base form (S–N–Ba angle); 2, maxillary position (SNA angle); 3, mandibular position (SNB angle); 4, gonial angle (Ar–Go'–Me); 5, mandibular plane angle (Me–Go' to SN); 6, intermaxillary position (ANB angle); 7, inclination of occlusal plane (occlusal plane to SN); 8, inclination of upper incisor (U1 to SN); 9, inclination of lower incisor (L1 to Me–Go').

Error of the method

To evaluate the errors of tracing, superimposition and locating and measuring landmarks, 10 randomly selected cephalograms were retraced and reanalysed by one author (IY) after an interval of approximately one month. The method error (ME) in locating and measuring was calculated by the formula: $ME = \sqrt{\Sigma d^2/2n}$, where $n = 10$ and d = the difference between repeated measurements of cephalometric values. ME did not exceed 0.53 for any of the angular measurements or 0.73 for any of the linear measurements. This result indicates that the present analysis is reliable, compared with other estimations of error (Yoshida *et al.*, 1999a).

Results

Although the mean age of the successful group was six months less than that of the unsuccessful group at the beginning of MPA and chincap treatment (T1), this difference was not significant (Table 1). There was also no significant difference in the timing of removal of the appliance (T2). As a result, the unsuccessful group was treated for longer (0.3 years) than the successful group, which indicated that the unsuccessful group required longer orthopaedic treatment in an attempt to achieve optimal occlusion.

The superimposed profilograms of the successful and unsuccessful groups at T1 are shown in Figure 4. Cephalometric measurements for the two groups at T1 are shown in Table 2. There were several significant differences between the two groups, including lower face height (ANS–Me), total face height (N–Me), ratio of face height (ANS–Me/N–ANS), maxillary position (SNA), gonial angle (Ar–Go'–Me) and mandibular plane angle (Me–Go' to SN). The unsuccessful group showed larger lower and total face heights (ANS–Me, N–Me) and gonial and mandibular plane angles, which are related to vertical parameters of facial morphology. In contrast, there were no significant differences in mandibular position (SNB) or intermaxillary relationship (ANB). At T2 and T3, significant differences were found for almost the same measurements as at T1. The morphological characteristics did not change compared with T1, except for differences in SNA and the inclination of the lower incisor (L1 to Me–Go') (Table 2).

The superimposed facial profilograms of the successful and unsuccessful groups at T1, T2 and T3 are shown in Figure 5. Changes in the cephalometric measurements of the two groups at all stages are shown in Table 3. In both groups, the maxilla moved forward and downward with a counterclockwise rotation of the palatal plane during MPA and chincap treatment (T1 to T2), while the mandible moved downward and backward. The anterior displacement of the maxilla was almost the same in the two groups. SNA increased by 2.1 degrees in the successful group and 1.9 degrees in the unsuccessful group. In contrast, SNB decreased by 1.6 degrees in the successful group and 0.4 degrees in the unsuccessful group, which indicated that the successful group showed more posterior displacement of the mandible. After the orthopaedic appliance was removed (T2 to T3), significant differences were found in ramus height (Cd-Go), SNA and SNB. The maxilla moved antero-inferiorly in the successful group, but mostly inferiorly in the unsuccessful group. SNA increased by 0.4 degrees in the successful group and decreased by 0.7 degrees in the unsuccessful group. On the other hand, the mandible moved forward and downward by 1.6 degrees in the successful group, which was four times the displacement in the unsuccessful group.

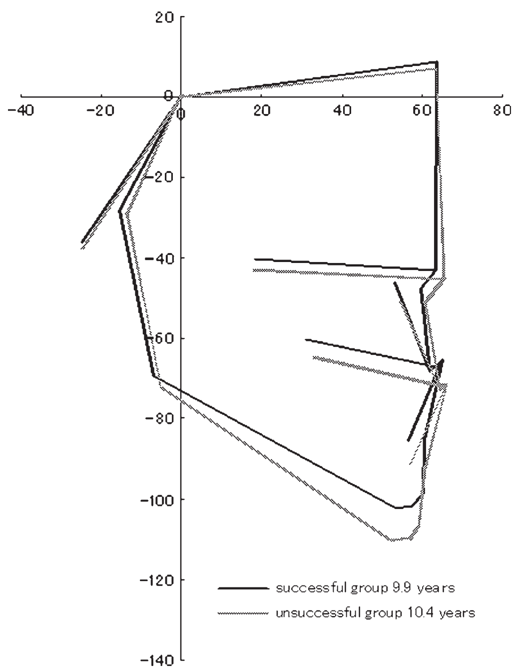

Figure 4 Comparison of mean facial profilograms of the successful and unsuccessful groups at T1. Profilograms were superimposed on the S–N line and registered at S.

For the discriminant analysis, the following six independent variables were selected to distinguish between the two groups: lower face height (ANS–Me), total face height (N–Me), ratio of face height (ANS–Me/N–ANS), SNA, gonial angle and mandibular plane to SN, all of which showed significant differences between the two groups at T1 (Table 2). The accuracy was 71.9 per cent for the selected six-variable model, 65.6 per cent for a one-variable model (ANS–Me) with a stepwise method, and 84.4 per cent for a two-variable model (ANS–Me and gonial angle) with a trial-and-error approach. The discriminant analysis with two variables showed the highest accuracy, and ANS–Me and gonial angle were finally selected as significant parameters for distinguishing between the two groups. The discriminant formula was:

$$z = -0.197\,x_1 - 0.125\,x_2 + 28.5$$

where x_1 = ANS–Me and x_2 = gonial angle. The accuracy of this formula was 84.4 per cent.

Logistic regression analysis was also performed, and the highest accuracy (81.3 per cent) was again found with a two-variable model.

Discussion

A recent comparative study of the effects of treatment with a chincap and MPA showed that a MPA was more effective for correcting intermaxillary and interarch relationships (Üçüncü *et al*., 2000). Treatment with a MPA produces acceleration of forward growth of the maxilla with counterclockwise rotation, forward movement of the maxillary dentition, and chincap effects on the mandible, such as growth inhibition, alteration of growth direction and backward positioning (Irie and Nakamura, 1975; Ishii *et al*., 1987; Mermigos and Full, 1990; Takada *et al*.,1993; Baik, 1995; Chong *et al*., 1996; Ngan *et al*., 1996; Baccetti *et al*., 1998; Yoshida *et al*., 1999a,b;

Table 2 Cephalometric measurements at the beginning of MPA treatment, on removal of the maxillary protraction appliance (T2), and post-treatment (T3) in the successful and unsuccessful groups.

	T1			T2			T3		
	Successful	Unsuccessful		Successful	Unsuccessful		Successful	Unsuccessful	
	Mean SD	Mean SD	*P*	Mean SD	Mean SD	*P*	Mean SD	Mean SD	*P*
Linear measurements (mm)									
N–S	64.6 ± 3.0	64.2 ± 3.3		65.2 ± 2.9	64.8 ± 3.1		66.8 ± 3.3	65.9 ± 2.9	
S–Ba	43.9 ± 1.7	45.3 ± 3.1		45.5 ± 1.7	46.5 ± 3.0		47.0 ± 2.0	47.8 ± 2.1	
N–ANS	51.7 ± 2.4	52.7 ± 2.7		52.5 ± 2.1	53.9 ± 2.3		55.8 ± 2.7	56.3 ± 2.2	
ANS–Me	60.6 ± 4.0	66.6 ± 6.4	**	63.3 ± 3.2	70.6 ± 4.7	***	67.2 ± 4.1	74.2 ± 5.3	***
N–Me	111.8 ± 5.3	118.3 ± 8.0	*	114.7 ± 4.4	123.0 ± 6.0	***	122.1 ± 4.9	129.5 ± 6.0	**
ANS–Me/N–ANS	1.2 ± 0.1	1.3 ± 0.1	**	1.2 ± 0.1	1.3 ± 0.1	***	1.2 ± 0.1	1.3 ± 0.1	**
A'–Ptm'	43.7 ± 2.7	44.5 ± 2.8		45.4 ± 2.5	46.0 ± 2.5		47.5 ± 3.0	47.4 ± 2.4	
Gn–Cd	110.8 ± 4.6	114.3 ± 7.1		112.5 ± 4.1	118.3 ± 6.4	**	121.5 ± 5.2	124.9 ± 5.7	
Pog–Go	73.5 ± 4.2	73.6 ± 5.2		74.6 ± 4.0	75.6 ± 4.7		79.3 ± 4.2	79.2 ± 4.0	
Cd–Go	52.0 ± 4.3	53.1 ± 3.7		53.3 ± 4.3	55.8 ± 3.9		60.1 ± 4.8	60.2 ± 4.2	
Wits appraisal	–8.9 ± 3.0	–9.9 ± 2.8		–2.3 ± 3.1	–4.7 ± 3.0	*	–4.9 ± 3.7	–6.7 ± 2.3	
Angular measurements (°)									
S–N–Ba	132.1 ± 5.6	129.8 ± 5.8		132.6 ± 5.7	130.2 ± 5.9		132.1 ± 5.9	130.6 ± 5.7	
SNA	77.9 ± 2.8	80.7 ± 3.1	*	80.0 ± 3.3	82.6 ± 2.6	*	80.4 ± 3.6	81.9 ± 2.6	
SNB	80.5 ± 3.2	82.0 ± 3.4		78.9 ± 3.3	81.3 ± 3.2	*	80.5 ± 3.7	81.7 ± 2.6	
ANB	–2.6 ± 2.4	–1.3 ± 2.5		1.1 ± 2.0	1.3 ± 2.4		–0.1 ± 2.3	0.2 ± 1.7	
Gonial angle	126.0 ± 6.6	131.1 ± 5.5	*	124.2 ± 6.3	130.1 ± 5.7	**	122.3 ± 6.4	129.1 ± 5.1	**
Mand. plane angle	34.8 ± 4.8	38.8 ± 5.7	*	35.4 ± 4.7	39.7 ± 5.3	*	33.6 ± 5.8	39.2 ± 5.0	**
Occlusal plane to SN	19.0 ± 3.2	19.4 ± 3.5		15.5 ± 3.9	15.9 ± 4.0		15.5 ± 4.2	16.4 ± 2.8	
U1 to SN	104.9 ± 4.8	107.5 ± 7.1		112.5 ± 8.6	114.5 ± 8.4		112.6 ± 9.0	109.8 ± 5.0	
L1 to Me–Go'	86.5 ± 7.6	82.4 ± 5.2		84.0 ± 6.3	80.2 ± 5.1		90.9 ± 9.2	83.3 ± 8.8	*

$^*P < 0.05$, $^{**} P < 0.01$, $^{***}P < 0.001$.

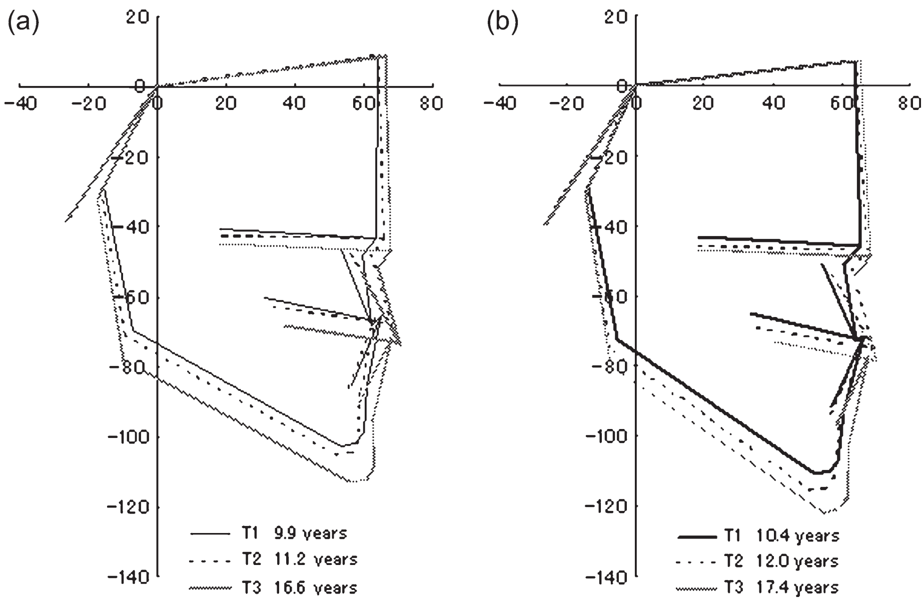

Figure 5 Superimposition of the mean facial profilograms of (a) the successful group at T1 (age 9.9 years), T2 (11.2 years) and T3 (16.6 years) and (b) of the unsuccessful group at T1 (age 10.4 years), T2 (12.0 years) and T3 (17.4 years). Profilograms were superimposed on the S–N line and registered at S.

Kajiyama *et al*., 2000; Suda *et al*., 2000; Üçüncü *et al*., 2000). Previous long-term studies have demonstrated that a combined MPA and chincap was effective for correcting the intermaxillary relationship in subjects with skeletal Class III malocclusions. The results were maintained until growth was complete, although a small rebound of mandibular growth occurred after the appliance was removed (Yoshida *et al*., 1999a,b). Both the successful

Table 3 Differences in the cephalometric between the two groups.

	T1–T2			T2–T3			T1–T3		
	Successful	Unsuccessful		Successful	Unsuccessful		Successful	Unsuccessful	
	Mean SD	Mean SD	*P*	Mean SD	Mean SD	*P*	Mean SD	Mean SD	*P*
Linear measurements (mm)									
N–S	0.6 ± 0.7	0.7 ± 1.1		1.6 ± 1.2	1.1 ± 1.2		2.2 ± 1.3	1.7 ± 1.1	
S–Ba	1.6 ± 1.2	1.2 ± 1.0		1.5 ± 1.8	1.3 ± 1.8		3.1 ± 2.1	2.5 ± 2.3	
N–ANS	0.8 ± 1.2	1.2 ± 1.4		3.3 ± 1.9	2.4 ± 2.5		4.1 ± 2.3	3.6 ± 3.1	
ANS–Me	2.6 ± 1.8	4.1 ± 2.7		3.9 ± 3.0	3.6 ± 2.5		6.6 ± 4.0	7.7 ± 3.6	
N–Me	2.9 ± 2.6	4.7 ± 3.8		7.4 ± 4.2	6.5 ± 4.6		10.3 ± 5.5	11.2 ± 6.3	
A’–Ptm’	1.7 ± 1.1	1.5 ± 1.1		2.1 ± 2.2	1.4 ± 1.4		3.8 ± 2.4	2.9 ± 1.9	
Gn–Cd	1.7 ± 2.2	4.0 ± 3.4		9.1 ± 4.1	6.6 ± 4.4		10.7 ± 5.3	10.6 ± 5.3	
Pog–Go	1.2 ± 1.3	2.0 ± 2.3		4.7 ± 2.4	3.6 ± 2.5		5.9 ± 3.1	5.6 ± 3.4	
Cd–Go	1.3 ± 1.9	2.6 ± 2.4		6.7 ± 2.9	4.5 ± 3.3	*	8.0 ± 3.1	7.1 ± 3.3	
Wits appraisal	6.6 ± 2.7	5.2 ± 2.7		–2.7 ± 1.9	–2.1 ± 2.9		4.0 ± 3.0	3.2 ± 3.0	
Angular measurements (°)									
S–N–Ba	0.5 ± 1.5	0.4 ± 1.4		–0.5 ± 2.3	0.4 ± 1.6		0.0 ± 2.4	0.8 ± 1.4	
SNA	2.1 ± 1.5	1.9 ± 1.2		0.4 ± 1.1	–0.7 ± 0.8	**	2.5 ± 1.9	1.2 ± 1.0	
SNB	–1.6 ± 1.2	–0.7 ± 1.0	*	1.6 ± 1.4	0.4 ± 1.4	*	0.0 ± 1.7	–0.3 ± 1.6	
ANB	3.7 ± 1.8	2.6 ± 1.6		–1.2 ± 1.3	–1.1 ± 1.3		2.5 ± 1.9	1.5 ± 2.0	
Gonial angle	–1.8 ± 1.3	–1.0 ± 2.4		–1.9 ± 2.6	–1.0 ± 2.0		–3.7 ± 3.2	–1.9 ± 2.6	
Mandibular plane angle	0.6 ± 1.1	0.9 ± 2.3		–1.8 ± 2.3	–0.5 ± 1.5		–1.2 ± 2.3	0.4 ± 2.7	
Occlusal plane to SN	–3.6 ± 2.0	–3.5 ± 2.2		0.0 ± 3.2	0.5 ± 2.2		–3.6 ± 3.3	–3.0 ± 2.0	
U1 to SN	7.6 ± 6.3	7.0 ± 5.4		0.1 ± 7.6	–4.8 ± 7.7		7.7 ± 8.3	2.3 ± 6.9	
L1 to Me–Go’	–2.5 ± 3.9	–2.2 ± 4.8		6.9 ± 6.5	3.1 ± 8.0		4.4 ± 7.0	1.0 ± 8.2	

$^*P < 0.05$, $^{**}P < 0.01$.
T1 beginning of maxillary protraction treatment; T2 removal of the maxillary protraction appliance; T3 post-treatment.

and unsuccessful groups in this study generally showed the above treatment effects from T1 to T2. However, it is conceivable that the response to orthopaedic force varies among Class III patients, since individual patients have different morphologies and inherited potential for growth of the craniofacial skeleton (Mitani and Fukazawa, 1986).

There were several morphological differences between the successful and unsuccessful groups at the initial stage (T1). Cephalometric measurements related to the vertical dimension, such as ANS–Me, N–Me, ANS–Me/N–ANS, gonial angle and mandibular plane angle, were significantly greater in the unsuccessful group. A previous study concerning chincap therapy showed that measurements related to mandibular shape, such as gonial angle and ramus to SN angles, could significantly predict stable and unstable treatment outcomes (Tahmina *et al*., 2000). Since patients in the unsuccessful group could be considered long face types based on vertical parameters (Schendel *et al*., 1976), the results of this study suggest that there may be limitations in the orthopaedic treatment of long face skeletal Class III patients. In fact, several studies have suggested that long face type Class III patients tend to exhibit relapse of the anterior bite after orthopaedic treatment and eventually require orthognathic surgery (Proffit and White, 1990; Choi *et al*., 1999; Tahmina *et al*., 2000).

The morphological differences in skeletal measurements between the two groups at T1 were also observed at T2 and T3, while there were a few late-emerging significant differences in other measurements. Longitudinal studies indicate that the skeletal framework in Class III malocclusion subjects is established before pubertal growth (Battagel, 1993). Therefore, it is conceivable that the differences in skeletal characteristics between the successful and unsuccessful groups already existed and could have been detected at T1.

Discriminant analysis is a multivariable analysis that is used to determine a borderline, i.e. a discriminant formula for clearly separating two groups. In this study, this analysis made it possible to prospectively estimate treatment outcomes. Only a few studies have used discriminant analysis to examine Class III treatment (Tahmina *et al*., 2000; Schuster *et al*., 2003). Tahmina *et al.* (2000) established a discriminant formula to distinguish between stable and unstable groups in chincap treatment. According to their results, the discriminant variables were the gonial, N–A–Pog and ramus plane to SN angles, and the discriminant efficiency was 85.7 per cent. Schuster *et al*. (2003) investigated Class III children before puberty to determine those who can be effectively treated by orthopaedic/orthodontic therapy alone and those who require orthognathic surgery. They reported that their discriminant analysis models correctly classified 93.2 per cent using three cephalometric variables: Wits appraisal, inclination of the palatal plane, and individualized inclination of the lower incisors. Although the gonial angle was also a significant variable in the discriminant formula of Tahmina *et al*. (2000), the other four variables were not found to have a predictive value based on the discriminant formula used in this study. These discrepancies could be associated with differences in skeletal morphology, treatment timing and the orthopaedic appliance used.

Interestingly, the maxilla showed almost the same response to orthopaedic force in the two groups during MPA and chincap treatment (T1 to T2). It moved antero-inferiorly in the successful group but mostly inferiorly in the unsuccessful group after orthopaedic treatment (T2 to T3). Therefore, continued forward growth of the maxilla after MPA and chincap treatment may also contribute to establishing a stable occlusion. With respect to the effects of treatment with a chincap appliance, several studies have indicated that the outcome of the treatment of skeletal Class III malocclusions is associated with antero-inferior growth of the mandible (Choi *et al*., 1999; Tahmina *et al*., 2000), and postero-inferior displacement of point Ar accompanied by growth of the posterior cranial base (Ritucci and Nanda, 1986; Choi *et al*., 1999). In this study, the successful group showed slightly greater displacement of point Ar than the unsuccessful group, which would compensate, at least in part, for excessive growth of the mandible in the successful group. Both groups showed almost the same incremental changes in mandibular size.

Sugawara *et al*. (1990) stated that the principal skeletal framework of patients with mandibular prognathism is established before pubertal growth. Moreover, Battagel and Orton (1993) and Sakamoto *et al*. (1996) showed that the inclination of the occlusal plane was flatter in the control group than in the Class III group. This change in the occlusal plane in the control group could compensate for the dentoalveolar disproportion during growth.

Concerning the total changes in the measured parameters from T1 to T3, significant differences were not observed between the two groups. However, the results also showed that the occlusal plane tended to compensate for the intermaxillary relationship. The successful group showed a large increase in SNA, a small increase in SNB, and flattening of the occlusal plane. Together, these changes influenced Wits appraisal.

The successful group also showed more labially inclined lower incisors at T3, which would be associated with the percentages of extraction and non-extraction cases in each group. There were 14 non-extraction cases (87.5 per cent) in the successful group, but only four (25 per cent) in the unsuccessful group. It is likely that the difference in the percentages of extraction and non-extraction treatment could influence skeletal changes. During T2 to T3, when extraction of the permanent teeth was performed, significant differences were found between the two groups in Cd–Go, SNA and SNB. The unsuccessful group, which included more extraction cases, showed larger increases in Cd–Go and SNB, and a decrease in SNA. Although it is difficult to distinguish between the effects of extraction on the facial skeleton and growth potential, several studies have indicated that extraction influences the position of the dentition, soft tissue profile and clockwise rotation, but not growth of the maxilla and mandible, except for the alveolar region (Ringenberg, 1966; Battagel and Orton, 1991; Paquette *et al.*, 1992). In this study, a greater increase in ramus height was observed in the unsuccessful group. Therefore, the difference in the change in the position of the mandible (SNB) between the two groups may be associated with mandibular growth.

Although the determination regarding extraction or non-extraction depends on various factors, such as the arch length discrepancy, inclination of the incisors, extent of overjet and overbite, and the degree of skeletal discrepancy, it is conceivable that management of not only skeletal discrepancies, but also dental factors, including arch length discrepancy, might be important in treating skeletal Class III patients. The MPA and chincap used in this study was a modified type, where intraoral anchorage was reinforced by a palatal resin plate. This enabled the application of a strong force without a loss of anchorage for the posterior teeth, and was effective in maintaining the available arch length.

Conclusions

The results of the present research indicate that the vertical dimensions of the craniofacial skeleton are important factors in the prognosis of skeletal Class III patients treated by a combined MPA and chincap and that the discriminant formula established in this study was effective for predicting treatment outcome.

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