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Treatment response to maxillary expansion and protraction

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SUMMARY A prospective clinical trial was conducted to determine the skeletal and dental contributions to the correction of overjet and overbite in Class III patients. Thirty patients (12 males and 18 females with a mean age of 8.4 ± 1.7 years) were treated consecutively with protraction headgear and fixed maxillary expansion appliances. For each patient, a lateral cephalogram was taken 6 months before treatment (T_0); immediately before treatment (T_1); and 6 months after treatment (T_2). The time period ($T_1 - T_0$) represented changes due to 6 months of growth without treatment; ($T_2 - T_1$) represented 6 months of growth and treatment. Each patient served as his/her own control. Cephalometric analysis described by Björk (1947) and Pancherz (1982a,b) was used. Sagittal and vertical measurements were made along the occlusal plane (OLs) and the occlusal plane perpendicular (OLp), and superimposed on the mid-sagittal cranial structure. The results revealed the following: with 6 months of treatment, all subjects were treated to Class I or overcorrected to Class I or Class II dental arch relationships. Overjet and sagittal molar relationships improved by an average of 6.2 and 4.5 mm, respectively. This was a result of 1.8 mm of forward maxillary growth, a 2.5-mm of backward movement of the mandible, a 1.7-mm of labial movement of maxillary incisors, a 0.2-mm of lingual movement of mandibular incisors, and a 0.2-mm of greater mesial movement of maxillary than mandibular molars. The mean overbite reduction was 2.6 mm. Maxillary and mandibular molars were erupted occlusally by 0.9 and 1.4 mm, respectively. The mandibular plane angle was increased by 1.5 degrees and the lower facial height by 2.9 mm. Individual variations in response to maxillary protraction was large for most of the parameters tested. Significant differences in treatment changes between male and female subjects were found only in the vertical eruption of mandibular incisors and maxillary and mandibular molars. These results demonstrate that significant overjet and overbite corrections can be obtained with 6 months of maxillary protraction in combination with a fixed expansion appliance.

Introduction

The prevalence of Class III malocclusion in white Caucasian populations is between 1 and 5 per cent (Walther, 1960; Haynes, 1970; Thilander and Myberg, 1973; Foster and Day, 1974). In Chinese and Japanese populations, however, the incidence of Class III malocclusion can be as high as 14 per cent (Allwright and Burndred, 1964; Irie and Nakamura, 1975).

Attempts to restrict mandibular growth using chin-cup retraction devices have met with limited success. While most of the cephalometric and experimental studies indicate that mandibular growth was altered during orthopaedic treatment (Janzen and Bluher, 1965; Matsui, 1965; Suzuki, 1972; Irie and Nakamura, 1975; Graber, 1977; Sakamoto, 1981; Ohyama and Sakuda, 1982; Wendell *et al.*, 1985; Asano, 1986; Sugawara *et al.*, 1990), others find no modification in growth pattern with chin cup therapy (Thilander, 1963, 1964; Mitani and Sakamoto, 1978; Mitani and Fukazawa, 1986). Graber (1977) treated 30 Class III children, with 450 g of orthopaedic chin-cup force for a 3-year period, and found redirection of horizontal mandibular growth in a vertical direction. Wendell *et al.* (1985), in a study of 10 Japanese patients treated with chin-cup therapy for an average of 3 years, found a reduction in mandibular growth rate, direction, and pattern. In animal studies (Janzen and Bluher, 1965; Matsui, 1965; Asano, 1986), permanent bony changes were found in the mandible with chin-cup appliances. On the other hand, longitudinal clinical studies by Mitani and Sakamoto (1978) found a variable reaction to chin-cap treatment with only a slight effect on mandibular growth velocity. Sugarwara *et al.* (1990) found that the improvement in skeletal profile during the initial stages of chin-cap therapy were not always maintained. Patients who entered treatment at an earlier age showed a catch-up manner of mandibular growth in a forward and downward direction before growth was completed.

Several surveys suggest that a good majority of Class III malocclusions exhibit maxillary retrusion (Sanborn, 1955; Ellis and McNamara, 1984; Guyer *et al.*, 1986). Early treatment of these patients with maxillary protraction appliances showed promising results. Campbell (1983) found an improvement in maxillo-mandibular skeletal relationships with maxillary expansion and protraction. However, much of the information to date is derived from animal (Dellinger, 1973; Kambara, 1977; Nanda, 1978; Jackson *et al.*, 1979) and skull studies (Hata *et al.* 1987; Tanne and Sakuda, 1991). Dellinger (1973) reported that the maxilla can be moved forward by means of rapid palatal expansion and 6 pounds of heavy anterior force delivered during a 7-day period. Kambara (1977), using model casts, cephalometric radiographs, and bone markers, found that the maxillary complex can be displaced anteriorly with significant changes in the circum-maxillary sutures and the maxillary tuberosity. In histological sections, he found opening of the sutures, stretching of sutural connective tissue fibres, new bone deposition along the stretched fibres, and homeostasis which maintained the sutural width.

Nanda (1978) found that the mid-facial bones could be displaced anteriorly by sutural modification and the nature of movement was related to the direction of force application. The author cautioned that with the same line of force, different mid-facial bones displace in different directions depending on the moments of force generated at the sutures. Jackson *et al.* (1979) found that anterior positioning of the maxillary complex was often accompanied by a small amount of counterclockwise rotation during the experimental period. Hata and colleagues (1987), examining the deformation effects on the human skull resulting from maxillary protraction, found that protraction forces at the level of the maxillary arch produced forward, but counterclockwise rotation of the maxilla unless a heavy downward vector of force was applied. Tanne and Sakuda (1991) found similar rotation of the maxilla with force applied on the first molars in the anterior direction parallel to the occlusal.

Relatively few clinical studies are available on maxillary protraction treatment (Oppenheim, 1944; Delaire *et al.*, 1978; Nanda, 1980; Wisth *et al.*, 1987; Mermigos *et al.*, 1990; Ngan *et al.*, 1992; Takada *et al.*, 1993). In particular, long-term prospective studies on craniofacial growth changes after maxillary protraction is lacking. Oppenheim (1944) was first to suggest the possibility of counterbalancing mandibular protrusion by bringing the maxilla forward. Haas (1970) demonstrated that the maxilla may move in a forward and downward direction as a result of palatal expansion. Delaire *et al.* (1978) used a facial mask to protract the maxilla anteriorly. Elastics generating forces of 1000–2000 g were used from the distal of the maxillary molars to the wires of the facial mask. Petit (1983) modified the basic concepts of Delaire by increasing the amount of force generated by the appliance, thus decreasing the overall treatment time. Nanda (1980) reported that the maxilla could be displaced 1–3 mm forward and the maxillary dentition 1–4 mm in 4–8 months. Wisth *et al.* (1987) followed the growth changes of patients after treatment and found that face mask treatment had a normalizing effect not only on overjet correction, but also on general facial morphology. Ngan *et al.* (1992) published a preliminary report on the treatment of Class III patients with maxillary deficiency by protraction headgear and fixed palatal expansion appliance. Significant overjet and molar corrections could be achieved in 6 months.

The objective of this study was to determine the skeletal and dental contributions to overjet and overbite correction in patients treated with protraction headgear and fixed maxillary expansion appliances.

Materials and Methods

The sample consisted of before and after treatment lateral cephalometric radiographs of 30 Southern Chinese patients with Skeletal Class III malocclusion (12 males and 18 females). These patients were treated consecutively with protraction headgear and maxillary expansion appliances in the Department of Children's Dentistry and Orthodontics, University of Hong Kong. All patients had no previous orthodontic treatment. Mean age of the subjects at the start of treatment was 8.4 years ranging from 6 to 11 years (SD = 1.7 years). Mean horizontal and vertical centric occlusion-centric relation deflection before treatment was -1.8 ± 0.9 mm and 2.6 ± 2.1 mm, respectively. A selection of cephalometric records describing the dentofacial morphology of the subjects before and after treatment is shown in Table 1.

Appliances for Class III correction (Figs 1A and 2A)

The Hyrax rapid palatal expansion appliance was constructed by using bands on the posterior teeth. Bands were fitted on the maxillary primary second molars and permanent first molars. In primary dentition cases, bands were fitted on the primary first and second molars. These bands were joined by a heavy wire (0.043-inch) to the palatal plate, which had a jack screw in the midline. The appliance was activated twice daily (0.25 mm per turn) by the patient for 1 week. In patients with a constricted maxilla, activation of the expansion screw was applied for 2 weeks. An 0.045-inch wire was soldered bilaterally to the buccal aspects of the molar bands and extended anteriorly to the canine area. In addition, a lingual wire could be soldered to the premolar band and extended to the cingulum of the maxillary incisors to increase anchorage control if needed.

The face mask was a one-piece construction with an adjustable anterior wire and hooks to accommodate a downward and forward pull of the maxilla with elastics. To avoid an opening of the bite as the maxilla was repositioned, the protraction elastics were attached near the maxillary canines with a downward and forward pull of 30 degrees to the occlusal plane.

Maxillary sutural protraction generally requires 300–600 g per side, depending on the patient. In this study, elastics that delivered 380 g of force per side as measured by a gauge were used. Patients were instructed to wear the headgear 12 hours a day.

Cephalometric analysis

For each patient, the first lateral cephalogram was taken 6 months prior to the initiation of headgear treatment (T_0). A second radiograph was taken at the initiation of protraction headgear treatment (T_1). Therefore, ($T_1 - T_0$) represented 6 months of growth with no treatment.

Table 1 Changes of cephalometric measurements (degrees) and mandibular lengths (mm) in 30 patients treated with protraction headgear before treatment (T_1) and 6 months after treatment (T_2).

	T_1				T_2				$T_2 - T_1$	
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Maxillary position (SNA)	80.9	3.7	73.0	91.5	82.3	3.4	77.0	94.0	1.3	1.3***
Mandibular position (SNB)	81.1	2.7	76.5	88.0	79.4	2.5	75.0	88.0	−1.7	1.2***
Sagittal jaw relation (ANB)	−0.2	2.2	−5.0	3.5	2.8	2.0	−0.5	6.5	3.0	1.2***
Palatal plane angle (Ans–Pns/SN)	9.4	3.3	4.5	17.5	8.4	3.2	4.5	17.0	−1.0	1.8*
Mandibular plane angle (Tgo–M/SN)	34.6	4.0	26.5	42.0	36.5	4.0	29.5	44.0	1.9	1.4***
Lower face height (Ans–Me)	59.9	3.1	54.5	66.5	63.0	3.5	58.0	71.5	3.1	1.9***
Occlusal plane angle (OL/SN)	22.6	3.9	14.0	28.5	20.6	3.4	13.5	27.5	−2.0	3.0***
Max incisal angle (Isi–Isa/SN)	104.8	11.0	85.0	120.0	108.2	9.0	84.5	117.0	3.4	7.8 NS
Mand incisal angle (Iii–Iia/Tgo–M)	90.7	9.2	77.0	107.5	85.6	6.6	70.0	105.0	−5.2	5.6***
Interincisal angle (Isi–Isa/Iii–Iia)	129.4	14.5	105.5	169.0	129.0	10.5	114.5	163.0	−0.3	10.6 NS
Maxillary length (Co–A)	77.6	3.7	69.0	84.5	79.9	3.7	73.0	86.0	2.3	1.2***
Mandibular length (Co–Gn)	104.0	5.2	95.5	116.0	105.2	5.3	97.0	117.0	1.2	0.9***
Maxillo-mandibular difference	26.4	3.6	19.5	35.5	25.2	3.7	15.5	33.0	−1.2	1.5***
Wits' analysis	−7.9	4.2	−14.5	6.5	−3.46	2.3	−6.5	1.0	4.5	3.3***

NS, not significant; ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

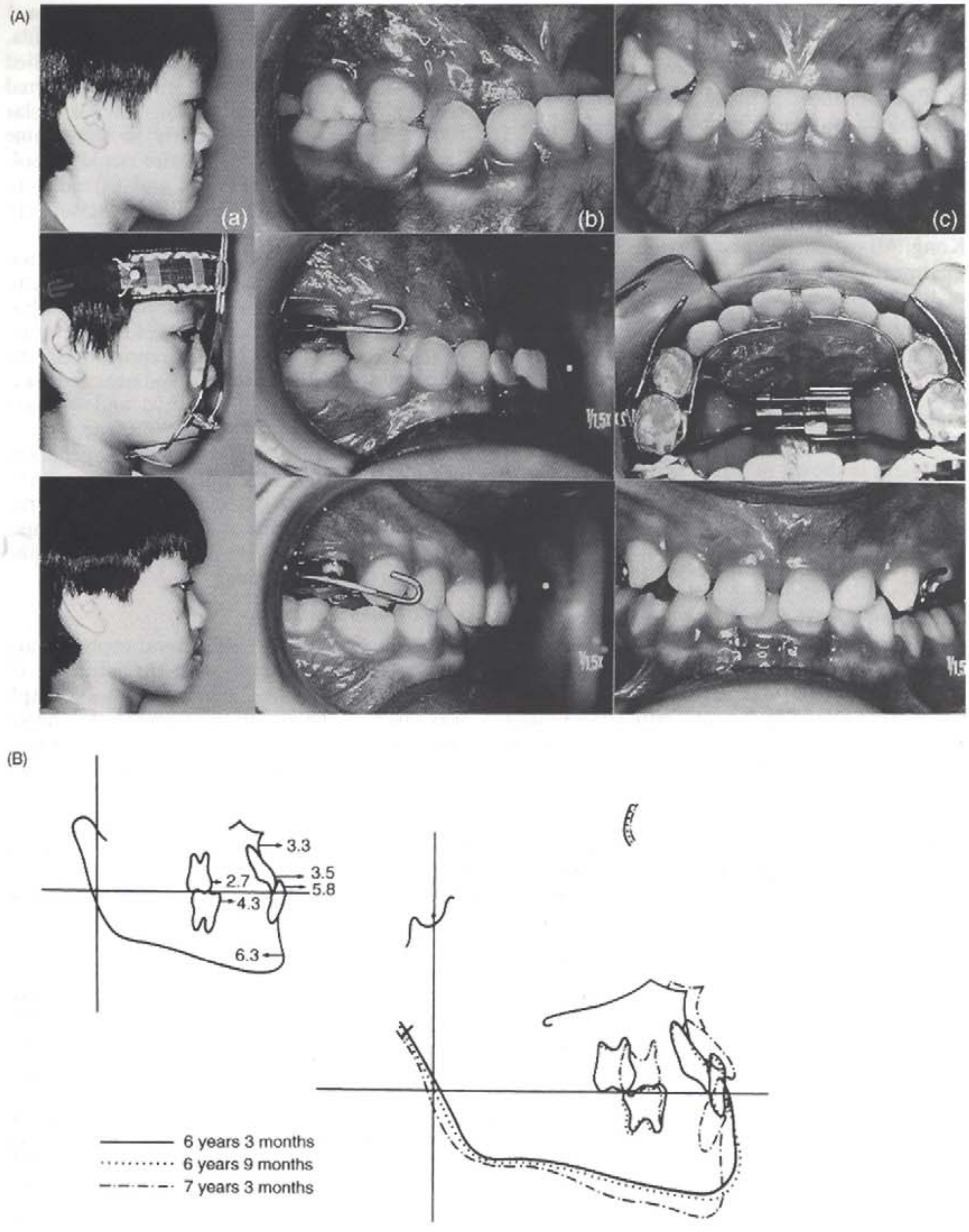
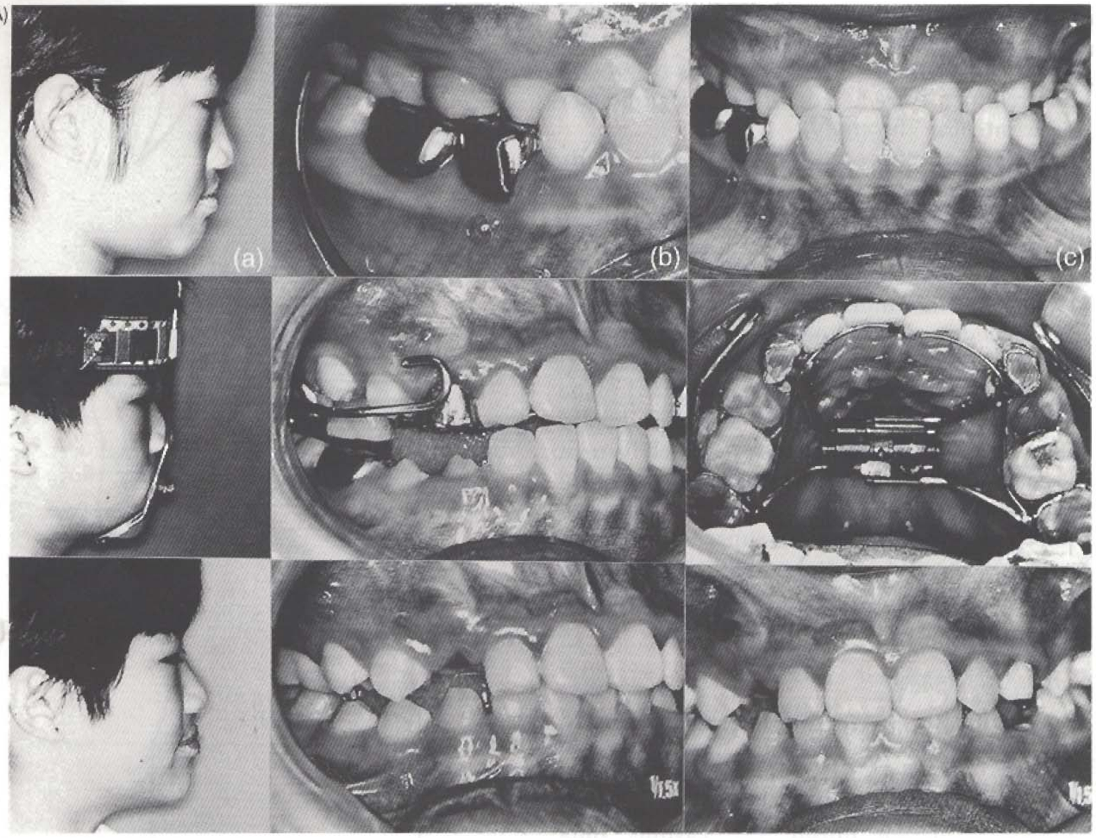


Figure 1 (A) Case no. 16. Extra- and intra-oral photographs. (a) Before treatment. (b) At the start of treatment with maxillary expansion and protraction appliances. (c) After 6 months of treatment. (B) Cephalometric tracings superimposed on the nasion–sella line with sella as registration point. Diagrammatic representation of sagittal, skeletal and dental changes (mm) occurring after 6 months of treatment.

(A)



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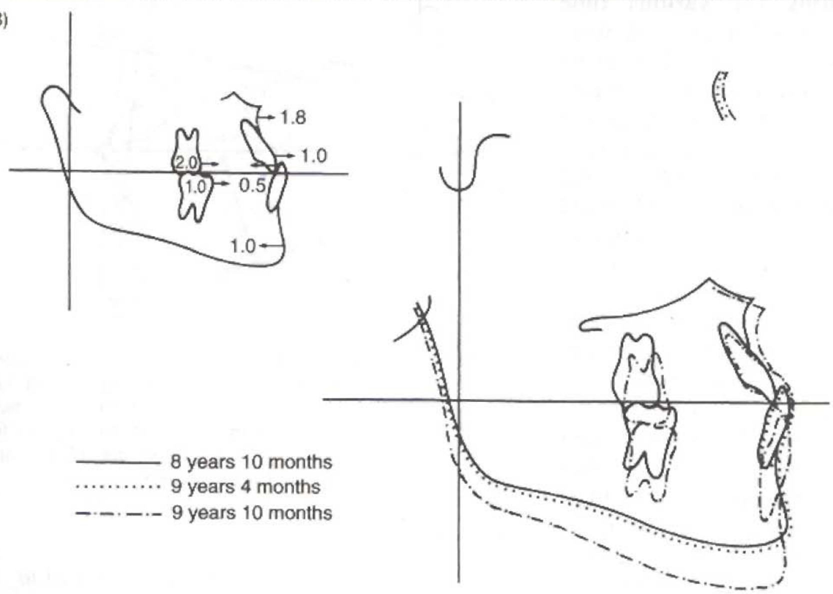

Figure 2 (A) Case no. 3. Extra- and intra-oral photographs. (a) Before treatment. (b) At the start of treatment with maxillary expansion and protraction appliances. (c) After 6 months of treatment. (B) Cephalometric tracings superimposed on the nasion–sella line with sella as registration point. Diagrammatic representation of sagittal, skeletal and dental changes (mm) occurring after 6 months of treatment.

A third radiograph was taken 6 months after protraction headgear treatment (T_2). In this way, (T_2-T_1) represented 6 months of growth and treatment. Each patient served as his/her own control in the study.

All radiographs used in the present study were taken in the same cephalostat with the teeth in habitual occlusion, the lips in repose. The cephalometric system used in this study has been described by Björk (1947) and Pancherz (1982a,b). The landmarks used are defined in Fig. 3a and b. All radiographs were traced on acetate paper. Analysis of the sagittal and dental changes were recorded along the occlusal plane (OLs) and to the occlusal plane perpendicular (OLp) from the first cephalogram which formed the reference grid for all the sagittal and vertical measurements. The grid was then transferred to the second cephalogram by superimposing the tracing on the mid-sagittal cranial structure. All sagittal measurements were assessed and recorded twice with calipers.

Statistical methods

The arithmetic mean (mean) and standard deviation (SD) were calculated for each cephalometric variable, and paired t-tests were performed to assess the statistical significance of changes occurring during the various time periods. The levels of significance used were $P<0.05$, $P<0.01$, and $P<0.001$. For error measurements, cephalograms of 10 subjects taken 6 months before treatment (T_0), at the start of (T_1), and 6 months post-treatment (T_2) were used in this part of the analysis. All measurements of cephalograms were recorded twice independently on two separate occasions with a 1-week interval between. For all the cephalometric variables, differences between the independent repeated measurements of each individual before/after treatment and treatment changes were calculated. The null hypothesis that there was no difference between the repeated measurements was tested by two tailed t-test. The results are shown in Table 2. The mean differences were all small (less than 0.8 mm or degree) and not statistically significant. However, the standard deviation of certain variables (OL/NSL, ILs/ILi, B/OLp, Msc–L) were quite large, exceeding 1.2 mm or degrees, indicating that for individual measurement, the variation was wide.

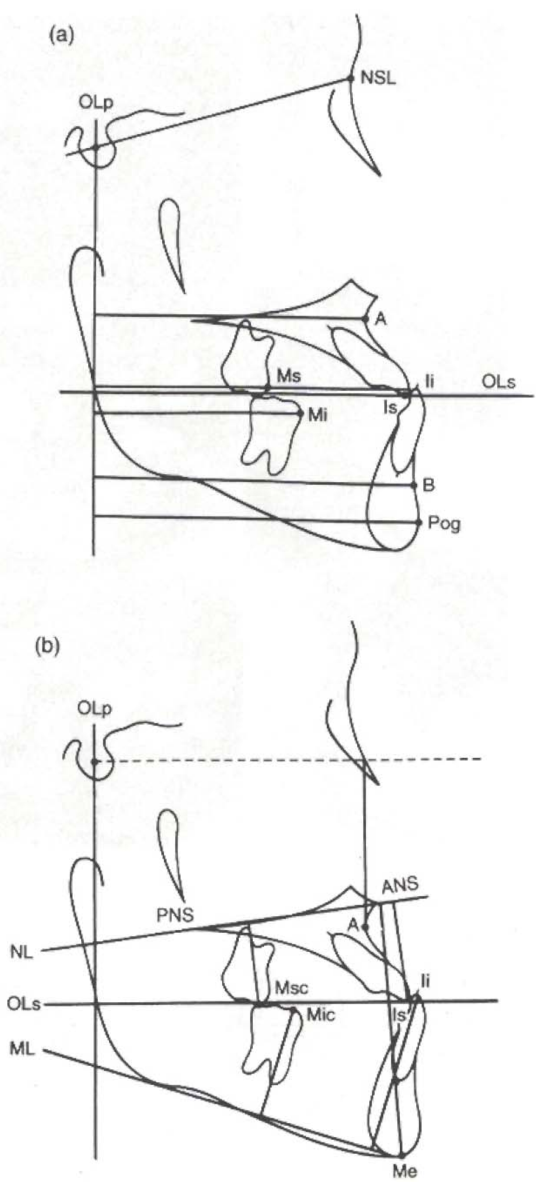

Figure 3 (a) Measuring points used in the cephalometric analysis for sagittal measurements. The registration line (NSL) and reference grid (OLs and OLp) are shown. (b) Measuring points used in the cephalometric analysis for vertical measurements. The registration line (NSL) and reference grid (OLs and OLp) are shown.

Results

Sagittal changes with growth and treatment in pooled subjects

The cephalometric changes due to growth (T_1-T_0), growth and treatment (T_2-T_1), and

Table 2 Accuracy of measuring sagittal and vertical distances (mm) between the first and superimposed radiographs. The differences of repeated measurements (1 and 2) of the cephalograms of 10 subjects.

	T_1-T_0				T_2-T_1			
Variable	Mean	SD	Min	Max	Mean	SD	Min	Max
Sagittal distances								
A–OLp	0.6	1.04	−0.5	3.3	−0.4	0.92	−2.3	0.5
Is–OLp	0.3	0.69	−0.8	1.3	−0.5	0.69	−1.8	0.3
Ii–OLp	0.7	0.57	−0.3	1.8	−0.5	0.64	−1.3	1.0
MS–OLp	0.8	0.87	−0.8	2.3	−0.3	1.06	−1.8	1.5
Mi–OLp	0.4	0.88	−1.0	1.8	−0.2	0.52	−1.3	0.5
Pg–OLp	0.2	0.89	−1.5	1.3	−0.1	1.08	−1.3	2.3
Vertical distances								
A–OL	0.1	1.07	−1.5	2.3	1.0	1.24	−1.0	3.5
Ii–OL	0.1	1.08	−1.3	2.8	0.0	1.24	−2.5	1.5
ANS–Me	−0.2	0.71	−1.0	1.0	0.0	0.72	−1.3	1.0
Is–NL	0.0	0.67	−1.0	1.3	−0.3	0.49	−1.0	0.3
Msc–NL	0.0	1.26	−2.3	1.8	0.4	0.91	−1.0	1.5
Ii–ML	−0.4	0.85	−1.5	1.0	0.4	0.78	−0.8	1.5
Mic–ML	0.3	0.69	−1.0	1.3	0.2	0.93	−2.0	1.3

their differences are shown in Tables 3, 4, and 5, respectively.

Table 3 (bottom row) shows the pooled sagittal changes at 6 months without treatment (T_1-T_0). No significant changes were found in overjet and molar relationship. Small, but significant changes were found in maxillary and mandibular incisors ($P<0.001$), maxillary and mandibular molars ($P<0.001$), and maxillary and mandibular bases ($P<0.05$ and $P<0.001$, respectively).

Table 4 (bottom row) shows changes with growth and treatment (T_2-T_1) and over 6 months (T_2-T_1). Larger and significant changes were observed in all of the variables tested ($P<0.001$) except for changes in mandibular molars.

Table 5 (bottom row) shows changes with treatment only $(T_2-T_1)-(T_1-T_0)$. Significant changes were still found in all maxillary and mandibular variables tested ($P<0.001$).

Figures 4 and 5 summarize the skeletal and dental contributions to the overjet and molar corrections from treatment. With 6 months of treatment, all subjects were corrected to a Class I or overcorrected to a Class I or Class II dental arch relationship. Overjet and sagittal molar relationships improved by an average of 6.2 and 4.5 mm, respectively. This was a result of 1.8 mm of forward maxillary growth, a 2.5-mm of backward movement of the mandible, a 1.7 mm labial movement of the maxillary incisors, a 0.2 mm lingual movement of the mandibular incisors, and a 0.2 mm greater mesial movement of the maxillary than mandibular molars.

Individual sagittal changes with growth and treatment

Tables 3, 4 and 5 (top rows) shows individual changes with growth (T_1-T_0); growth and treatment (T_2-T_1) and treatment alone $(T_2-T_1)-(T_1-T_0)$.

Considering the treatment changes shown in Table 5 only, with 6 months of maxillary protraction, the mean overjet changes were large (6.2 mm) and the variations were wide ranging from 2.0 to 12.8 mm.

In general, the effect of protraction headgear on the maxillary base was small with a mean increase of 1.8 mm ($P<0.001$), but the variation was wide, ranging from −1.5 to 5.8 mm. The sagittal changes in the mandibular base were also small with a mean decrease of 2.5 mm, but the variation was wide, ranging from −7.8 to 1.0 mm.

The maxillary incisors were found to move labially in all subjects as judged by the increase in mean sagittal distances, Is–OLp of 3.5 mm ($P<0.001$). Again, the variation was wide, ran-

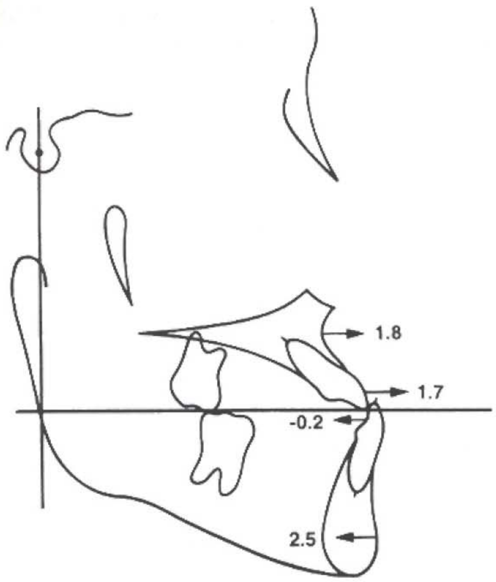

Figure 4 Skeletal and dental changes (mm) contributing to alterations in overjet in 30 Class III malocclusions treated with maxillary expansion and protraction appliances for 6 months.

ging from -1.0 to 8.3 mm. Mandibular incisors were found to move lingually with treatment in all subjects as judged by the decrease in mean sagittal distance, Ii–OLp of -2.7 mm. The variation was wide, ranging from -6.5 to 0.3 mm.

Mesial movement of maxillary molars was found in all except one male subject (no. 4). The average forward movement was 3.4 mm with a range from -0.5 to 8.8 mm. Distal movement of mandibular molars was found in most subjects except two female subjects (nos 2 and 18) and one male subject (no. 8). The average distal movement was -1.1 mm with a range of -4.8 to 1.8 mm.

Comparisons of sagittal changes between male and female subjects (Tables 3, 4, 5)

In general, the gender differences were small. Significant differences were found only in two variables, maxillary incisor changes Is–OLp and mandibular molar changes Mi–OLp for the time period (T_1-T_0).

Vertical changes with growth and treatment in pooled subjects

Table 6 (bottom row) shows the pooled vertical changes over 6 months without treatment (T_1-T_0). Small, but significant changes $(P<0.05)$ were found in overbite, movement of maxillary base, maxillary incisors, and mandibular incisors.

Table 7 (bottom row) shows changes with growth and treatment (T_2-T_1). Larger and more significant changes $(P<0.001)$ were observed in overbite, lower facial height, mandibular incisors, and maxillary and mandibular molar changes.

Table 8 (bottom row) shows changes with treatment after growth was subtracted $(T_2-T_1)-(T_1-T_0)$. Significant changes were still found with regard to overbite, lower facial height, and maxillary and mandibular molars $(P<0.05)$.

Figure 6 summarizes the contributions to overbite correction from treatment. The mean overbite reduction was 2.6 mm, an average of 90 per cent reduction of the before-treatment value (2.9 mm). The lower facial height, on average, increased 2.9 mm. The vertical distances of maxillary and mandibular incisors did not change appreciably with treatment. The maxillary and mandibular molars, however, were occlusally erupted by 0.9 and 1.4 mm, respectively. The changes of the nasal plane were minimal. The mandibular plane angle was increased by 1.5 degrees. The dental changes rotated the occlusal plane in a clockwise direction by 2.3 degrees.

Individual vertical changes with growth and treatment

Tables 6, 7, and 8 (top rows) show the individual changes with growth (T_1-T_0), growth and treatment (T_2-T_1), and treatment alone $(T_2-T_1)-(T_1-T_0)$, respectively. Considering treatment changes, shown in Table 8 only, with 6 months of maxillary protraction, vertical maxillary base change were small, mean = 0.1 mm with a range of -6.5 to 5.0 mm. The overbite reduction in individual subjects ranged from -7.8 to 1.8 mm. In some female subjects (cases nos 2, 9, 12), there was no change in overbite. The lower facial height increased in most sub-

Table 3 Individual sagittal changes (mm) between T_0 and T_1 in 30 subjects (18 female, 12 male). Overjet (Is/OLp minus Ii/OLp), molar relationship (Ms/OLp minus Mi/OLp), maxillary base (A/OLp), mandibular base (pg/OLp), maxillary incisor (Is/OLp), mandibular incisor (Ii/OLp), maxillary molar (Ms/OLp), and mandibular molar (Mi/OLp).

Subjects	Overjet	Maxillary incisor	Mandibular incisor	Molar relationship	Maxillary molar	Mandibular molar	Maxillary base	Mandibular base
Female								
1	0.8	0.0	−0.8	−0.3	0.0	0.3	0.5	0.0
2	0.8	0.5	−0.3	−0.3	0.0	0.3	−0.3	0.0
3	−1.3	−1.0	0.3	−1.5	−0.3	1.3	−0.3	0.0
4	−0.8	0.5	1.3	0.8	1.0	0.3	0.3	1.5
5	0.0	1.5	1.5	0.0	1.8	1.8	0.3	1.8
6	0.8	0.0	−0.8	−0.3	0.8	1.0	−0.3	−0.5
7	−1.3	0.5	1.8	−1.8	0.0	1.8	−0.3	2.3
8	−2.8	−0.3	2.5	0.3	−0.5	−0.8	0.3	3.8
9	1.3	2.5	1.3	0.8	1.0	0.3	−0.3	1.5
10	0.3	0.0	−0.3	1.0	2.0	1.0	0.5	0.8
11	1.5	0.5	−1.0	−0.5	0.5	1.0	0.5	0.0
12	0.0	1.5	1.5	−0.1	0.9	1.0	0.8	1.8
13	1.8	0.5	−1.3	0.3	−0.5	−0.8	0.3	−0.5
14	0.3	1.5	1.3	−0.3	0.5	0.8	0.0	1.0
15	0.0	1.3	1.3	−0.8	0.3	1.0	0.0	1.5
16	0.5	0.8	0.3	−1.0	−1.0	0.0	0.5	0.3
17	0.8	0.8	0.0	−0.5	−0.3	0.3	0.0	0.3
18	0.3	0.5	0.8	−0.3	−0.3	0.0	0.0	0.5
Mean	0.3	0.6*	0.4	−0.1	0.5	0.6	0.1	0.9
SD	1.2	0.8	1.1	0.9	1.1	0.8	0.3	1.1
Min	−2.8	−1.0	−1.3	−1.8	−1.0	−0.8	−0.3	−0.5
Max	1.8	2.5	2.5	1.0	2.0	1.8	0.8	3.8
Male								
1	0.3	0.8	0.5	0.0	0.5	0.5	0.0	1.0
2	0.3	0.0	−0.3	−0.5	0.3	0.8	−0.3	0.5
3	−1.0	0.8	1.8	−0.5	0.3	0.8	1.0	1.5
4	1.0	2.0	1.0	0.5	1.0	0.5	0.0	0.5
5	0.5	1.5	1.0	−0.8	−1.5	1.3	0.3	2.3
6	−0.8	0.5	1.3	−0.3	0.5	0.8	0.8	2.3
7	−3.5	−1.5	2.0	−1.3	0.0	1.3	0.8	1.5
8	2.5	3.0	0.5	−1.0	0.8	1.8	−0.3	1.0
9	1.8	3.0	1.3	−0.3	0.5	0.8	0.3	0.8
10	−0.3	0.3	0.5	0.3	0.5	0.3	0.0	0.3
11	1.0	0.8	−0.3	0.5	0.3	−0.3	−0.5	0.0
12	−2.3	−1.0	1.3	0.0	1.0	1.0	1.0	1.0
Mean	0.0	0.8*	0.9	−0.4	0.3	0.8*	0.2	1.0
SD	1.7	1.4	0.7	0.9	0.7	0.5	0.5	0.7
Min	−3.5	−1.5	−0.3	−1.3	−1.5	−0.3	−0.5	0.0
Max	2.5	3.0	2.0	0.5	1.0	1.8	1.0	2.3
Pooled								
Mean	0.1	0.7***	0.6***	−0.3	0.4***	0.7***	0.2*	0.9***
SD	1.3	1.1	1.0	0.9	0.9	0.7	0.4	1.0
Min	−3.5	−1.5	−1.3	−1.3	−1.5	−0.8	−0.5	−0.5
Max	2.5	3.0	2.5	1.0	2.0	1.8	1.0	3.8

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

jects. In two female subjects (nos 12 and 13) and one male subject (no. 5), the lower facial height was slightly reduced. In most subjects, maxillary and mandibular molars were found to erupt occlusally with treatment. No consistent pattern was found in vertical changes of incisors.

Table 4 Individual sagittal changes (mm) between T_1 and T_2 in 30 subjects (18 female, 12 male). Overjet (Is/OLp minus Ii/OLp), molar relationship (Ms/OLp minus Mi/OLp), maxillary base (A/OLp), mandibular base (pg/OLp), maxillary incisor (Is/OLp), mandibular incisor (Ii/OLp), maxillary molar (Ms/OLp), and mandibular molar (Mi/OLp).

Subjects	Overjet	Maxillary incisor	Mandibular incisor	Molar relationship	Maxillary molar	Mandibular molar	Maxillary base	Mandibular base
Female								
1	9.8	4.3	−5.5	4.0	3.8	−0.3	0.8	−2.3
2	5.5	4.3	−1.3	4.0	5.3	1.3	0.8	0.0
3	5.5	4.0	−1.5	8.0	4.5	−3.5	2.5	0.5
4	7.5	3.8	−3.8	3.8	2.5	−1.3	2.3	−2.5
5	5.5	3.3	−2.3	3.5	2.8	−0.8	1.3	−1.0
6	5.3	3.8	−1.5	5.3	5.0	−0.3	2.3	−1.0
7	6.5	5.0	−1.5	5.8	6.5	0.8	2.8	−0.8
8	10.0	7.3	−2.8	5.0	5.8	0.8	3.3	−1.3
9	3.3	3.3	0.0	1.8	1.8	0.0	1.8	−2.0
10	8.3	8.3	0.0	2.3	3.3	1.0	2.5	1.8
11	4.8	2.5	−2.3	3.8	4.5	0.8	1.0	−0.5
12	2.5	2.5	0.0	2.6	1.3	−1.3	−0.8	0.0
13	6.3	3.8	−2.5	3.5	2.8	−0.8	1.0	−1.5
14	3.3	0.5	−2.8	6.8	5.3	−1.5	2.3	−4.0
15	8.5	4.0	−4.5	3.8	3.0	−0.8	1.8	−2.3
16	4.8	3.5	−1.3	2.8	2.8	0.0	2.3	−0.8
17	7.8	5.5	−2.3	8.8	8.5	−0.3	1.8	−1.0
18	7.0	6.0	−1.0	7.0	7.8	0.8	3.5	−2.3
Mean	6.0	4.1	−1.9	4.5	4.2	−0.3	1.8	−1.2
SD	2.5	1.9	1.7	2.1	2.1	1.2	1.0	1.3
Min	2.5	0.5	−5.5	1.8	1.3	−3.5	−0.8	−4.0
Max	10.0	8.3	0.0	8.8	8.5	1.3	3.5	1.8
Male								
1	3.8	2.0	−1.8	3.0	2.8	−0.3	2.3	−1.8
2	5.3	1.8	−3.5	3.0	3.8	0.8	1.8	−0.8
3	6.3	7.5	1.3	7.5	6.3	−1.3	2.3	−4.8
4	5.0	3.3	−2.8	2.0	0.5	−1.5	0.5	−3.0
5	8.3	4.3	−4.0	4.3	4.3	0.0	1.5	−0.8
6	9.5	5.0	−4.5	5.3	2.0	−3.3	3.8	−5.5
7	7.3	5.8	−1.5	1.8	0.8	1.0	1.3	−1.8
8	8.8	9.3	0.5	5.0	8.5	3.5	5.5	0.3
9	9.8	4.5	−5.3	6.3	3.3	−3.0	2.0	−4.8
10	5.5	1.8	−3.8	2.0	1.5	−0.5	0.8	−2.3
11	3.8	1.8	−2.0	5.0	3.5	−1.5	2.5	−1.3
12	7.0	6.8	−0.3	2.5	2.5	0.0	2.3	−1.0
Mean	6.7	4.4	−2.3	4.0	3.3	−0.7	2.2	−2.3
SD	2.1	2.6	2.0	1.9	2.3	1.8	1.4	1.8
Min	3.8	1.8	−5.3	1.8	0.5	−3.3	0.5	−5.5
Max	9.8	9.3	1.3	7.5	8.5	3.5	5.5	0.3
Pooled								
Mean	6.3***	4.2***	−2.1***	4.3***	3.8***	−0.4	2.0***	−1.6***
SD	2.4	2.1	1.8	2.0	2.2	1.4	1.2	1.6
Min	2.5	0.5	−5.5	1.8	0.5	−3.5	−0.8	−5.5
Max	10.0	9.3	1.3	8.8	8.5	3.5	5.5	1.8

***$P < 0.001$.

Comparisons of vertical changes between male and female subjects (Tables 6–8)

Significant differences were found in mandibular incisor changes for all three time periods; maxillary molar changes for time period $(T_2-T_1)-(T_1-T_0)$; and mandibular molar changes for time period (T_2-T_1) and $(T_2-T_1)-(T_1-T_0)$.

Table 5 Individual sagittal changes (mm) between $T_2 - T_1$ and $T_1 - T_0$ in 30 subjects (18 female, 12 male). Overjet (Is/OLp minus Ii/OLp), molar relationship (Ms/OLp minus Mi/OLp), maxillary base (A/OLp), mandibular base (pg/OLp), maxillary incisor (Is/OLp), mandibular incisor (Ii/OLp), maxillary molar (Ms/OLp), and mandibular molar (Mi/OLp).

Subjects	Overjet	Maxillary incisor	Mandibular incisor	Molar relationship	Maxillary molar	Mandibular molar	Maxillary base	Mandibular base
Female								
1	9.0	4.3	−4.8	4.3	3.8	−0.5	0.3	−2.3
2	4.8	3.8	−1.0	4.3	5.3	1.0	1.0	0.0
3	6.8	5.0	−1.8	9.5	4.8	−4.8	2.8	0.5
4	8.3	3.3	−5.0	3.0	1.5	−1.5	2.0	−4.0
5	5.5	1.8	−3.8	3.5	1.0	−2.5	1.0	−2.8
6	4.5	3.8	−0.8	5.5	4.3	−1.3	2.5	−0.5
7	7.8	4.5	−3.3	7.5	6.5	−1.0	3.0	−3.0
8	12.8	7.5	−5.3	4.8	6.3	1.5	3.0	−5.0
9	2.0	0.8	−1.3	1.0	0.8	−0.3	2.0	−3.5
10	8.0	8.3	0.3	1.3	1.3	0.0	2.0	1.0
11	3.3	2.0	−1.3	4.3	4.0	−0.3	0.5	−0.5
12	2.5	1.0	−1.5	2.7	0.4	−2.3	−1.5	−1.8
13	4.5	3.3	−1.3	3.3	3.3	0.0	0.8	−1.0
14	3.0	−1.0	−4.0	7.0	4.8	−2.3	2.3	−5.0
15	8.5	2.8	−5.8	4.5	2.8	−1.8	1.8	−3.8
16	4.3	2.8	−1.5	3.8	3.8	0.0	1.8	−1.0
17	7.0	4.8	−2.3	9.3	8.8	−0.5	1.8	−1.3
18	7.3	5.5	−1.8	7.3	8.0	0.8	3.5	−2.8
Mean	5.8	3.5	−2.3	4.6	3.7	−0.9	1.7	−2.0
SD	3.4	2.4	2.2	2.7	2.9	1.5	1.2	1.8
Min	2.0	−1.0	−5.8	1.0	0.4	−4.8	−1.5	−5.0
Max	12.8	8.3	0.3	9.5	8.8	1.5	3.5	1.0
Male								
1	3.5	1.3	−2.3	3.0	2.3	−0.8	2.3	−2.8
2	5.0	1.8	−3.3	3.5	3.5	0.0	2.0	−1.3
3	7.3	6.8	−0.5	8.0	6.0	−2.0	1.3	−6.3
4	4.0	0.3	−3.8	1.5	−0.5	−2.0	0.5	−3.5
5	7.8	2.8	−5.0	7.0	5.8	−1.3	1.3	−3.0
6	10.3	4.5	−5.8	5.5	1.5	−4.0	3.0	−7.8
7	10.8	7.3	−3.5	3.0	0.8	−2.3	0.5	−3.3
8	6.3	6.3	0.0	6.0	7.8	1.8	5.8	−0.8
9	8.0	1.5	−6.5	6.5	2.8	−3.8	1.8	−5.5
10	5.8	1.5	−4.3	1.8	1.0	−0.8	0.8	−2.5
11	2.8	0.0	−1.8	4.5	3.3	−1.3	3.0	−1.3
12	9.3	7.8	−1.5	2.5	1.5	−1.0	1.3	−2.0
Mean	6.7	3.5	−3.2	4.4	3.0	−1.4	1.9	−3.3
SD	2.6	2.8	2.0	2.2	2.5	−1.6	1.5	2.2
Min	2.8	0.3	−6.5	1.5	−0.5	−4.0	0.5	−7.8
Max	10.8	7.8	0.0	8.0	7.8	1.8	5.8	−0.8
Pooled subjects:								
Mean	6.2***	3.5***	−2.7***	4.5***	3.4***	−1.1***	1.8***	−2.5***
SD	3.1	2.5	2.1	2.5	2.7	1.5	1.3	2.0
Min	2.0	−1.0	−6.5	1.0	−0.5	−4.8	−1.5	−7.8
Max	12.8	8.3	0.3	9.5	8.8	1.8	5.8	1.0

***$P < 0.001$.

Case reports

The cases of one boy (male subject case no. 3) and one girl (female subject case no. 16) whose Class III malocclusions were treated with maxillary expansion and protraction are presented.

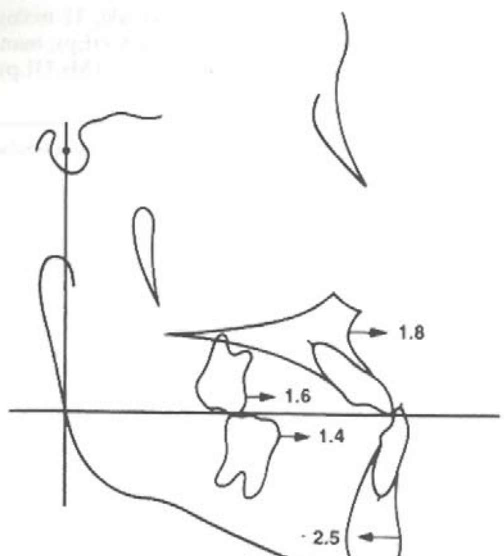

Figure 5 Skeletal and dental changes (mm) contributing to alterations in sagittal molar relationships in 30 Class III malocclusions treated with maxillary expansion and protraction appliances for 6 months.

Case no. 3 (Fig. 1A and B)

The patient was 6 years 3 months of age. Treatment was started 6 months later and patient was treated with protraction headgear for 6 months. Molar bands were fitted on primary first and second molars for construction of a Hyrax rapid palatal expansion appliance. An 0.045-inch wire was soldered bilaterally to the buccal aspects of the molar bands and extended anteriorly to the canine area for maxillary protraction with 380 g of elastic force per side. A lingual wire was soldered to the molar bands and extended to the cingulum of the maxillary incisors to increase anchorage control.

Treatment changes. Overjet changed from negative to positive, a total of 7.3 mm. This was accompanied by 3.3 mm of forward and downward maxillary growth, 6.3 mm of backward and downward mandibular growth, 3.5 mm labial movement of maxillary incisors, and 5.8 mm of labial movement of mandibular incisors. Sagittal molar relationship was corrected from negative Class III molar relationship to positive molar relationship, a total of 8.0 mm. In addition to the difference in mandibular-maxillary growth, this was a result of a 2.8 mm forward movement of maxillary molars, and 4.3 mm of mesial movement of the mandibular molars.

Case no. 16 (Fig. 2A and B)

The patient was aged 9 years and 4 months at the start of active treatment. The mechanotherapy was the same as for case no. 3, except that the molar bands were fitted on the permanent first molars and primary canines.

Treatment changes. Overjet changed from negative to positive, a total of 4.3 mm. This was accompanied by 1.8 mm of forward and downward maxillary growth, 1.0 mm of backward and downward mandibular growth, 1.0 mm labial movement of maxillary incisors, and 0.5 mm of lingual movement of mandibular incisors. Sagittal molar relationship was corrected from negative Class III molar relationship to positive molar relationship, a total of 3.8 mm. In addition to the difference in mandibular-maxillary growth, there was a 2.0 mm forward movement of maxillary molars, and 1.0 mm of mesial movement of the mandibular molars.

Discussions

In the present study, 30 patients were treated consecutively utilizing identical appliance and force systems. No adjunctive orthodontic therapy such as fixed labial wires or removable bite planes were used that would confound the interpretation of the data.

The extra effort in taking an additional lateral cephalogram 6 months prior to the initiation of treatment provides a means of assessing individual growth changes at the time of treatment (T_1-T_0). Six months of growth changes (T_1-T_0) can be compared to 6 months of growth and treatment (T_2-T_1) or subtracted from (T_2-T_1) to obtain the treatment effect alone. In this way, each patient serves as his/her own control. In addition, changes due to growth can be differentiated from those of appliance treatment. This is under the assumption that there is no significant growth differences

Table 6 Individual vertical changes (degrees) or (mm) between T_0 and T_1 in 30 subjects (18 female, 12 male).

Subjects	Max. base	Overbite	LFH	Max. incisor	Mand. incisor	Max. molar	Mand. molar	ML/NSL	NL/NSL	OL/NSL
Female										
1	1.4	0.0	0.8	−0.8	0.3	−0.3	0.0	0.8	−1.0	1.0
2	−0.5	−0.5	0.8	0.8	−0.3	−0.5	−0.3	0.3	−1.3	−0.8
3	1.8	1.0	1.5	1.3	1.0	0.3	0.3	−0.3	1.8	1.3
4	0.5	1.5	−0.8	0.3	0.0	0.8	−0.5	−0.5	1.3	−1.3
5	−0.3	1.8	0.3	0.8	4.5	2.5	−0.5	−0.3	0.0	−2.0
6	−1.3	0.0	1.3	0.3	0.0	0.0	0.3	2.0	−0.5	1.0
7	−2.0	0.8	1.3	1.5	0.3	1.8	0.3	−0.8	−1.8	−1.3
8	−0.8	2.8	3.0	3.0	2.0	2.5	−1.5	−1.8	−2.0	−2.3
9	0.0	0.0	−0.3	0.5	0.8	0.5	0.0	−2.3	−0.5	−2.0
10	1.3	2.5	−0.3	0.0	1.0	0.5	0.5	−0.5	0.3	2.8
11	0.3	−0.3	−0.3	0.8	−1.3	−0.8	−0.3	0.5	−0.8	0.0
12	−0.3	0.0	0.8	0.0	0.5	0.0	−0.5	−0.8	−1.3	−1.5
13	0.8	0.0	0.5	0.0	−0.5	0.0	−0.5	−0.3	1.3	1.3
14	1.0	1.8	−0.3	2.3	0.3	−1.0	−1.0	0.0	−1.3	0.8
15	1.5	0.0	0.3	0.5	0.3	0.3	0.5	−0.3	−0.3	0.0
16	2.3	1.0	1.0	1.0	0.8	0.3	0.3	0.3	−0.5	1.3
17	1.8	1.3	1.5	1.8	1.5	0.0	0.8	1.3	0.5	1.0
18	0.8	0.3	0.0	−0.5	1.0	−1.5	1.0	−1.0	0.5	−0.8
Mean	0.5	0.8	0.6	0.7	0.7*	0.3	−0.1	−0.2	−0.3	−0.1
SD	1.1	1.0	0.9	1.0	1.2	1.1	0.6	1.0	1.0	1.4
Min	−2.0	−0.5	−0.8	−0.8	−1.3	−1.5	−1.5	−2.3	−2.0	−2.3
Max	2.3	2.8	3.0	3.0	4.5	2.5	1.0	2.0	1.8	2.8
Male										
1	−0.5	0.0	−1.3	−0.5	−0.8	0.0	−1.3	0.3	0.5	0.8
2	1.3	0.3	0.3	1.0	0.0	−0.5	0.0	−0.3	−1.3	−0.3
3	−0.3	−2.8	1.5	−0.3	−0.5	−0.5	0.0	−0.8	−0.3	0.3
4	3.0	−0.3	1.0	1.5	0.5	0.8	1.0	0.5	0.0	2.3
5	−0.5	−0.3	1.5	−0.5	0.8	−0.8	1.0	−0.8	−1.5	0.5
6	−0.2	1.5	−0.3	0.8	1.0	0.8	−0.5	−1.0	−1.0	−0.8
7	0.8	1.0	0.5	1.3	1.0	−0.3	−0.3	−0.5	−1.0	1.5
8	3.0	−0.8	0.0	−1.5	0.5	0.5	0.3	0.0	0.8	−4.3
9	1.0	0.0	0.3	0.5	0.5	2.5	−0.5	1.3	1.8	1.0
10	−0.3	0.5	0.5	0.0	0.0	0.3	−0.3	0.5	−0.5	−0.3
11	−1.3	−0.3	0.0	−0.3	0.5	0.5	−0.3	0.3	0.5	−0.3
12	2.0	2.0	−0.3	2.8	−0.5	0.0	−1.0	−0.8	0.0	3.0
Mean	0.7	0.1	0.0	0.4	0.3*	0.3	−0.1	−0.1	−0.2	0.3
SD	1.4	1.2	1.5	1.1	0.6	0.9	0.7	0.7	0.9	1.8
Min	−1.3	−2.8	−1.3	−1.5	−0.8	−0.8	−1.3	−1.0	−1.5	−4.3
Max	3.0	2.0	1.5	2.8	1.0	2.5	1.0	1.3	1.8	3.0
Pooled subjects:										
Mean	0.5*	0.5*	0.4	0.6**	0.5*	0.3	−0.1	−0.2	−0.3	0.1
SD	1.2	1.1	1.2	1.0	1.0	1.0	0.6	0.9	1.0	1.6
Min	−2.0	−2.8	−1.3	−1.5	−1.3	−1.5	−1.5	−2.3	−2.0	−4.3
Max	3.0	2.8	3.0	3.0	4.5	2.5	1.0	2.0	1.8	3.0

*$P<0.05$; **$P<0.01$.
Max., maxillary; Mand., mandibular.

between the two consecutive 6 monthly growth periods. Previous growth studies have indicated that pre-pubertal growth does not differ significantly within a 6-month period of time (Broadbent *et al.*, 1975; Moyers and Wainright, 1977).

Registration of the cephalograms were undertaken by the same examiner in order to reduce method error. The reference grid used in the evaluation of the sagittal changes made it possible to evaluate the skeletal and dental changes that occurred in the maxilla and mandible along the occlusal plane (OLs). Since all before and after treatment sagittal measurements were made with reference to the same reference plane (before treatment occlusal plane perpendicular

Table 7 Individual vertical changes (degrees) or (mm) between T_1 and T_2 in 30 subjects (18 female, 12 male).

Subjects	Max. base	Overbite	LFH	Max. incisor	Mand. incisor	Max. molar	Mand. molar	ML/NSL	NL/NSL	OL/NSL
Female										
1	0.2	0.3	3.3	3.0	2.0	1.5	0.5	1.5	−2.8	−4.0
2	−2.5	−0.5	3.0	1.5	1.8	2.5	1.5	0.5	−1.0	−1.5
3	0.8	−2.3	4.0	−0.3	0.3	1.8	1.3	0.8	−0.3	−1.5
4	−1.0	−3.3	2.5	−0.8	0.0	−0.5	2.0	0.5	−2.5	−1.0
5	−1.5	−2.8	2.8	−1.3	−1.3	0.8	1.5	1.5	−1.3	−4.5
6	−0.3	−3.8	2.0	−1.5	0.3	2.3	1.0	0.8	−0.5	−6.0
7	0.8	−4.8	3.0	−1.5	−1.8	0.8	1.3	0.3	−2.8	−9.3
8	0.5	−3.3	4.5	1.8	0.5	1.0	2.3	4.5	−0.3	1.8
9	5.0	0.0	4.0	1.0	3.0	1.8	1.8	5.8	1.5	2.0
10	0.8	−1.3	3.5	1.3	2.0	1.0	0.8	0.8	−2.8	−1.0
11	0.3	−1.8	1.5	−2.3	2.0	−0.5	2.0	1.8	−1.5	−1.0
12	4.0	0.0	0.3	−1.5	2.0	−0.5	1.8	0.8	1.8	−0.5
13	1.3	−1.3	0.3	0.3	0.0	0.3	0.8	1.5	−2.3	−2.0
14	0.5	−6.0	6.5	−1.8	0.0	3.8	1.8	3.3	0.3	−2.5
15	0.8	−3.0	6.5	1.0	1.0	3.0	1.0	−6.5	−2.0	−4.5
16	0.5	−4.8	7.0	0.5	0.8	2.8	2.0	3.3	−1.0	−3.5
17	−0.5	−4.5	2.8	−2.8	1.8	1.0	1.8	2.0	−3.8	−6.8
18	−1.0	−1.3	2.5	1.3	1.3	2.5	1.5	2.0	−0.8	−3.5
Mean	0.5	−2.4	3.3	−0.1	0.9*	1.4	1.5*	1.4*	−1.2**	−2.7***
SD	1.8	1.9	1.9	1.6	1.2	1.3	0.5	2.5	1.5	2.9
Min	−2.5	−6.0	0.2	−2.8	−1.8	−0.5	0.5	−6.5	−3.8	−9.3
Max	5.0	0.3	7.0	3.0	3.0	3.8	2.3	5.8	1.8	2.0
Male										
1	0.8	1.5	2.3	1.5	1.5	0.0	1.5	2.3	0.5	3.3
2	1.0	0.5	2.8	1.3	0.5	1.0	0.0	0.5	−2.0	−0.3
3	−1.5	−6.3	4.5	−1.3	0.8	1.5	3.0	2.0	−2.3	−6.8
4	−0.5	−4.0	3.8	0.3	0.0	1.8	0.8	3.0	−0.8	−3.8
5	0.5	1.3	0.0	1.0	0.5	1.3	0.5	1.0	0.0	0.0
6	3.0	−5.8	6.3	−1.8	0.0	2.0	1.5	4.0	0.0	−5.8
7	2.0	−1.0	1.0	0.0	1.3	−0.5	0.5	−0.3	−1.3	−1.0
8	−3.5	−2.3	4.0	1.5	1.3	1.3	2.0	−1.3	−0.8	0.8
9	1.3	0.3	3.5	3.0	0.5	1.8	0.5	−0.8	−2.8	−1.8
10	0.5	−1.5	1.5	2.0	0.5	−0.8	2.5	0.5	−2.8	−1.0
11	0.5	1.5	2.8	2.0	1.0	1.5	0.8	1.8	−0.8	0.3
12	1.0	−3.0	4.5	−1.5	1.5	1.0	3.0	3.0	2.5	0.5
Mean	0.4	−1.6	3.1	0.7	0.8*	1.0	1.0*	1.3*	−1.0*	−1.4
SD	1.7	2.8	1.7	1.5	0.5	0.9	2.1	1.6	1.2	2.8
Min	−3.5	−6.3	0.0	−1.8	0.0	−0.8	−5.0	−1.3	−2.8	−6.8
Max	3.0	1.5	6.3	3.0	1.5	2.0	3.0	4.0	0.5	3.3
Pooled										
Mean	0.4	−2.1***	3.2***	0.2	0.8***	1.2***	1.3***	1.3***	−1.1***	−2.2***
SD	1.7	2.3	1.8	1.6	1.0	1.1	1.4	2.1	1.4	2.9
Min	−3.5	−6.3	0.0	−2.8	−1.8	−0.8	−5.0	−6.5	−3.8	−9.3
Max	5.0	1.5	7.0	3.0	3.0	3.8	3.0	5.8	1.8	3.3

*$P<0.05$; **$P<0.01$; ***$P<0.001$.
Max., maxillary; Mand., mandibular.

OLp), downward and backward rotation of the occlusal plane (OLs) which occurred during treatment would not affect the reference grid and bias the results.

With regard to the evaluation of the vertical skeletal and dental changes with maxillary protraction, the vertical growth of the maxilla and the remodelling at the lower border of the mandible (Björk and Skieller, 1972) would not significantly influence the results as the treatments were carried out over a period of only 6 months.

In general, the method of cephalometric analysis (Pancherz, 1982a,b) used in the present study was reliable. The error of most variables was within an acceptable limit for the treatment

Table 8 Individual vertical changes (degrees) or (mm) between $T_2 - T_1$ and $T_1 - T_0$ in 30 subjects (18 female, 12 male).

Subjects	Max. base	Overbite	LFH	Max. incisor	Mand. incisor	Max. molar	Mand. molar	ML/NSL	NL/NSL	OL/NSL
Female										
1	−1.2	0.3	2.5	3.8	1.8	1.8	0.5	0.8	−1.8	−5.0
2	−2.0	0.0	2.3	0.8	2.0	3.0	1.8	0.3	0.3	−0.8
3	−1.0	−3.3	2.5	−1.5	−0.8	1.5	1.0	1.0	−2.0	−2.8
4	−1.5	−4.8	3.3	−1.0	0.0	−1.3	2.5	1.0	−3.8	0.3
5	−1.3	−4.5	2.5	−2.0	−5.8	−1.8	2.0	1.8	−1.3	−2.5
6	1.0	−3.8	0.8	−1.8	0.3	2.3	0.8	−1.3	0.0	−7.0
7	2.8	−5.5	1.8	−3.0	−2.0	−1.0	1.0	1.0	−1.0	−8.0
8	1.3	−6.0	1.5	−1.3	−1.5	−1.5	3.8	6.3	1.8	4.0
9	5.0	0.0	4.3	0.5	2.3	1.3	1.8	8.0	2.0	4.0
10	−0.5	−3.8	3.8	1.3	1.0	0.5	0.3	1.3	−3.0	−3.8
11	0.0	−1.5	1.8	−3.1	3.3	0.3	2.3	1.3	−0.8	−1.0
12	4.3	0.0	−0.5	−1.5	1.5	−0.5	2.3	1.5	3.0	1.0
13	0.5	−1.3	−0.3	0.3	0.5	0.3	1.3	1.8	−3.5	−3.3
14	−0.5	−7.8	6.8	−4.0	−0.3	4.8	2.8	3.3	1.5	−3.3
15	−0.8	−3.0	6.3	0.5	0.8	2.8	0.5	−6.3	−1.8	−4.5
16	−1.8	−5.8	6.0	−0.5	0.0	2.5	1.8	3.0	−0.5	−4.8
17	−2.3	−5.8	1.3	−4.5	0.3	1.0	1.0	0.8	−4.3	−7.8
18	−1.8	−1.5	2.5	1.8	0.3	4.0	0.5	3.0	−1.3	−2.8
Mean	0.0	−3.2	2.7	−0.9	0.2*	1.1*	1.5*	1.6*	−0.9**	−2.7***
SD	2.1	2.5	2.1	2.1	2.0	1.9	0.9	2.9	2.1	3.5
Min	−2.3	−7.8	−0.5	−4.5	−5.8	−1.8	0.3	−6.3	−4.3	−8.0
Max	5.0	0.3	6.8	3.8	3.3	4.8	3.8	8.0	3.0	4.0
Male										
1	2.3	1.5	3.5	2.0	2.3	0.0	2.8	2.0	0.0	2.5
2	−0.3	0.3	2.5	0.3	0.5	1.5	0.0	0.8	−0.8	0.0
3	−1.3	−3.5	3.0	−1.0	1.3	2.0	3.0	2.8	−2.0	−7.0
4	−3.5	−3.8	2.8	−1.3	−0.5	1.0	−0.3	2.5	−0.8	−6.0
5	1.0	1.5	−1.5	1.5	−0.3	2.0	−0.5	1.8	1.5	0.5
6	3.2	−7.3	6.5	−2.5	−1.0	1.3	2.0	5.0	1.0	−5.0
7	1.3	−2.0	0.5	−1.3	0.3	−0.3	0.8	0.3	−0.3	−2.5
8	−6.5	−1.5	8.0	3.0	0.8	0.8	1.8	−1.3	−1.5	5.0
9	0.3	0.3	3.3	2.5	0.0	−0.8	1.0	−2.0	−4.5	−2.8
10	0.8	−2.0	1.0	2.0	0.5	−1.0	2.8	0.0	−2.3	−0.8
11	1.8	1.8	2.8	2.3	0.5	1.0	1.0	1.5	−1.3	0.5
12	−1.0	−5.0	4.8	−4.3	2.0	1.0	4.0	3.3	0.5	−3.8
Mean	−0.3	−1.6	3.1	0.3	0.5*	0.7*	1.1*	1.4*	−0.9*	−1.7*
SD	2.6	2.9	2.5	2.3	1.0	1.0	2.3	2.0	1.6	3.5
Min	−6.5	−7.3	−1.5	−4.3	−1.0	−1.0	−5.0	−2.0	−4.5	−7.0
Max	3.2	1.8	8.0	3.0	2.3	2.0	4.0	5.0	1.5	5.0
Pooled										
Mean	−0.1	−2.6*	2.9*	−0.4	0.3	0.9*	1.4*	1.5***	−0.9***	−2.2***
SD	2.3	2.7	2.2	2.2	1.6	1.6	1.6	2.5	1.9	3.5
Min	−6.5	−7.8	−1.5	−4.5	−5.8	−1.8	−0.5	−6.3	−4.5	−8.0
Max	5.0	1.8	8.0	3.8	3.3	4.8	4.0	8.0	3.0	5.0

$^*P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$.
Max., maxillary; Mand., mandibular.

changes in this study (Table 2). However, the interpretation of any treatment changes involving the molars and incisors including the occlusal plane angle should be done with caution due to the overlapping incisors and molars of the opposing arch. For measurements where the measured changes were small as compared to the size of the method errors, results must be interpreted with care.

It had been shown that identification error for different cephalometric landmarks varies widely (Tng *et al.*, 1994). The accuracy of cephalometric landmarks used in the present study has been investigated on skulls of

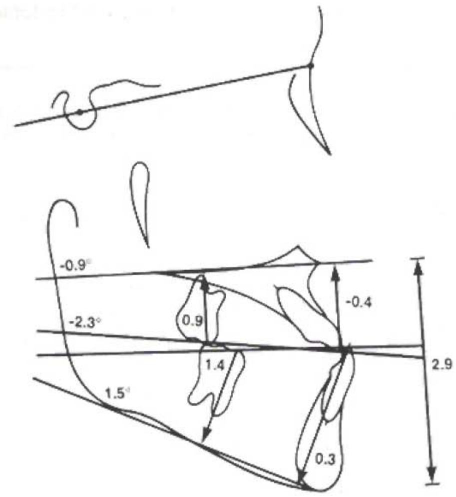

Figure 6 Skeletal and dental changes contributing to vertical changes in 30 Class III malocclusions treated with maxillary expansion and protraction appliances for 6 months.

Southern Chinese origin (Tng *et al.*, 1994). In general, the accuracy was acceptable. The methods of sagittal and vertical analysis by Pancherz (1982a,b) used in the present study were, in general, accurate.

The dramatic change in overjet (6.2 mm) was partially contributed by the presence of horizontal CO–CR displacements prior to treatment. In a study by Wisth *et al.* (1987), 3.4 mm of overjet change was found only in subjects when non-forced anterior cross-bites were included. In the present study, an average of 1.8 mm of forward maxillary movement was obtained in 6 months as compared to 9–16 months as reported by other investigators (Tindlund, 1989; Ishii *et al.*, 1987; Takada *et al.*, 1993). This may be related to the use of a palatal expansion appliance prior to protraction. It has been shown that transversal expansion of the maxilla may result in an anterior movement of point A and the whole maxillary complex may be movable up to 7–8 years of age (Haas, 1961, 1965; Delaire *et al.*, 1976). Since the maxilla articulates with nine other bones of the craniofacial complex, palatal expansion can disarticulate the maxilla and initiate cellular response in the sutures, allowing a more positive reaction to protraction forces. Experiments in monkeys with anterior forces of 500 g showed that the zygomaticomaxillary suture displayed the greatest activity during forward displacement of the maxilla (Jackson *et al.*, 1979; Nanda, 1978). In the present study, maxillary protraction also produced a posterior rotation of the mandible which automatically reduced its prognathism. This finding is supported by other studies (Campbell, 1983; Delaire *et al.*, 1976, 1978). The combination of forward maxillary and backward mandibular movement contribute to 70 per cent of the overjet changes. Forward movement of maxillary incisors and lingual tipping of mandibular incisors help in correcting the overjet and contribute to 30 per cent of the overjet changes.

In 6 months, the molar relationship was improved a total of 4.5 mm. However, the maxillary molar came forward by an average of 1.6 mm indicating a loss in anchorage despite the use of a fixed maxillary appliance. Kokich and colleagues (1985) attempted to use ankylosed primary canines to protract the maxilla with some success. The use of ankylosed primary teeth, however, limited the use of maxillary protraction to the period before exfoliation of the primary teeth. A more promising approach is presently under investigation with the use of on-plants or hydroxyapatite discs for orthopaedic maxillary protraction (Block and Hoffman, 1995).

The upward tilting of the nasal plane in response to anterior traction has been reported in cleft palate patients (Rygh and Tindlund, 1982). The direction of force delivery system also affects the maxillary sutural response (Nanda, 1980). Experiments in animal and skull studies have shown that anterior forces along the occlusal plane have a tendency to rotate the skull counterclockwise unless accompanied by a heavy downward pull (Hata *et al.*, 1987; Tanne and Sakuda, 1991). The present study showed that the maxilla only tilted upward by 1 degree with the elastics pulling at 30 degrees forward and downward from the occlusal plane.

Overbite was found to decrease with treatment. This was accompanied by an increase in mandibular plane angle and lower facial height. Some of these vertical changes can be attributed to eruption of posterior molars with maxillary expansion (Bishara and Staley, 1987). Long-term data will show if these vertical changes remain after removal of the appliances and the concern of using vertical protraction devices on growing patients.

Individual variations in treatment response were noted in this study. Individual case reports are presented rather than composite drawings showing mean changes. Several studies have reported on the variation in response to maxillary protraction (Irie and Nakamura, 1975; Tindlund, 1989). In addition, Irie and Nakamura (1975) have classified treatment results into three groups according to the changes in the sella/nasion–mandibular plane angle. Clinicians are recommended to evaluate each case individually. Finally, the present investigation was concerned with the short term, follow-up result of maxillary protraction. The long-term implications of this treatment method need further consideration.

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References

Allwright W C, Burndred W H 1964 A survey of handicapping dentofacial anomalies among Chinese in Hong Kong. International Dental Journal 14: 505–519

Asano T 1986 The effects of mandibular retractive force on the growing rat mandible. American Journal of Orthodontics and Dentofacial Orthopedics 90: 464–474

Bishara S E, Staley R N 1987 Maxillary expansion: Clinical implications. American Journal of Orthodontics and Dentofacial Orthopedics 91: 3–14

Björk A 1947 The face in profile. An investigation into facial prognathism. Dissertation, University of Lund, Sweden

Björk A, Skieller V 1972 Facial development and tooth eruption. An implant study at the age of puberty. American Journal of Orthodontics 62: 339–383

Block M S, Hoffman D 1995 A new device for absolute anchorage for orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics 107: 251–258

Broadbent B H Sr, Broadbent G H Jr, Golden W H 1975 Bolton standards of dentofacial developmental growth. CV Mosby, St. Louis

Campbell P M 1983 The dilemma of Class III treatment, early of late? Angle Orthodontist 53: 175–191

Delaire V J, Verdon P, Floor J 1976 Ziele und ergebnisse extraoraler Zuge in postero-anteriorer Richtung in anwendung einer orthopadischen Maske bei der Behandlung von Fallen der Klasse III. Fortschritte der Kieferorthopädie 37: 246–262

Delaire V J, Verdon P, Floor J 1978 Moglichkeiten und grenzen extraoraler Kratie in postero-anterior Richtung unter verwandung der orthopadischen Maske. Fortschritte der Kieferorthopädie 39: 27–45

Dellinger E L 1973 A preliminary study of anterior maxillary displacement. American Journal of Orthodontics 63: 509–516

Ellis E, McNamara J A 1984 Components of adult Class III malocclusion. Journal of Oral and Maxillofacial Surgery 42: 295–305

Foster T D, Day A J W 1974 A survey of malocclusion and the need for treatment in a Shropshire school population. British Journal of Orthodontics 1: 73–78

Graber L W 1977 Chin cup therapy for mandibular prognathism. American Journal of Orthodontics 72: 23–41

Guyer E C, Ellis E E, McNamara J A, Behrents R G 1986 Components of Class III malocclusion in juveniles and adolescents. Angle Orthodontist 56: 7–30

Haas A J 1961 Rapid expansion of the maxillary dental arch and nasal caity by opening the midpalatal suture. Angle Orthodontist 31: 73–90

Haas A J 1965 The treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthodontist 35: 200–217

Haas A J 1970 Palatal expansion: just the beginning of dentofacial orthopedics. American Journal of Orthodontics 57: 219–255

Hata S, Itoh T, Nakagawa M, Kamogashira K, Ichikawa K, Matsumoto M, Chaconas S J 1987 Biomechanical effects of maxillary protraction on the craniofacial complex. American Journal of Orthodontics and Dentofacial Orthopedics 91: 305–311

Haynes S 1970 The prevalence of malocclusion in English school children aged 11–12 years. Transactions of the European Orthodontic Society, pp. 89–98

Irie M, Nakamura S 1975 Orthopedic approach to severe skeletal Class III malocclusion. American Journal of Orthodontics 67: 377–392

Ishii H, Morita S, Takeuchi Y, Nakamura S 1987 Treatment effect of combined maxillary protraction and chincap appliance in severe skeletal Class III cases. American Journal of Orthodontics and Dentofacial Orthopedics 92: 304–312

Jackson G W, Kokich V G, Shapiro P A 1979 Experimental and postexperimental response to anteriorly directed extraoral force in young *Macaca nemestrina*. American Journal of Orthodontics 75: 318–333

Janzen E K, Bluher J A 1965 The cephalometric, anatomic, and histologic changes in *Macaca mulatta* after application of a continuous-acting retraction force on the mandible. American Journal of Orthodontics 51: 823–855

Kambara T 1977 Dentofacial changes produced by extraoral forward force in *Macaca irus*. American Journal of Orthodontics 71: 249–277

Kokich V G, Shapiro P A, Oswald R, Koskinen-Moffett L, Clarren S K 1985 Ankylosed teeth as abutments for maxillary protraction: a case report. American Journal of Orthodontics 88: 303–307

Matsui Y 1965 Effect of chin cap on the growing mandible. Journal of Japanese Orthodontic Society 24: 165–181

Mermigos J, Full C A, Andreasen G 1990 Protraction of the maxillofacial complex. American Journal of Orthodontics and Dentofacial Orthopedics 98: 47–55

Mitani H, Fukazawa H 1986 Effects of chincap force on the timing and amount of mandibular growth associated with anterior reversed occlusion (Class III malocclusion) during puberty. American Journal of Orthodontics and Dentofacial Orthopedics 90: 454–463

Mitani H, Sakamoto T 1978 Chin cap force to a growing mandible. Long-term clinical reports. Angle Orthodontist 54: 93–112

Moyers R E, Wainright R L 1977 Skeletal contributions to occlusal development. In: McNamara J A (ed.) The biology of occlusal development, Monograph No.7, Craniofacial Growth Series. Center for Human Growth and Development, University of Michigan, Ann Arbor, pp. 9–111

Nanda R 1978 Protraction of maxilla in rhesus monkeys by controlled extraoral forces. American Journal of Orthodontics 74: 121–141

Nanda R 1980 Biomechanical and clinical considerations of a modified protraction headgear. American Journal of Orthodontics 78: 125–139

Ngan P, Wei S H Y, Hägg U, Yiu C K Y, Merwin D, Stickel B 1992 Effect of protraction headgear on Class III malocclusion. Quintessence International 23: 197–207

Ohyama Y, Sakuda M 1982 A longitudinal cephalometric study on craniofacial growth of the orthodontically treated patients with mandibular prognathism. Journal of Osaka University Dental School 22: 175–191

Oppenheim A 1944 A possibility for physiologic orthodontic movement. American Journal of Orthodontics and Oral Surgery 30: 345–368

Pancherz H 1982a The mechanism of Class II correction in Herbst appliance treatment, a cephalometric investigation. American Journal of Orthodontics 82: 107–113

Pancherz H 1982b Vertical dentofacial changes during Herbst appliance treatment. A cephalometric investigation. Swedish Dental Journal 15: 189–196

Petit H 1983 Adaptations following accelerated facial mask therapy. In: McNamara J A Jr, Ribbens K A, Howe R P (eds) Clinical alteration of the growing face, Monograph No. 14, Craniofacial Growth Series. Center for Human Growth and Development, University of Michigan, Ann Arbor, pp. 253–289

Rygh P, Tindlund R 1982 Orthopedic expansion and protraction of the maxilla in cleft palate patients. A new treatment rationale. Cleft Palate Journal 19: 104–112

Sakamoto T 1981 Effective timing for the application of orthopedic force in the skeletal Class III malocclusion. American Journal of Orthodontics 80: 411–416

Sanborn R T 1955 Differences between the facial skeletal pattern of Class III malocclusion and normal occlusion. Angle Orthodontist 25: 208–222

Sugawara J, Asano T, Endo N, Mitani H 1990 Long-term effects of chincap therapy on skeletal profile in mandibular prognathism. American Journal of Orthodontics and Dentofacial Orthopedics 98: 127–133

Suzuki N 1972 A cephalometric observation on the effect of the chin cap. Journal of Japanese Orthodontic Society 31: 64–72

Takada K, Petdachai S, Sakuda M 1993 Changes in dentofacial morphology in skeletal Class III children treated by a modified maxillary protraction headgear and a chin cup: a longitudinal cephalometric appraisal. European Journal of Orthodontics 15: 211–221

Tanne K, Sakuda M 1991 Biomechanical and clinical changes of the craniofacial complex from orthopedic maxillary protraction. Angle Orthodontist 61: 145–152

Thilander B 1963 Treatment of Angle Class III malocclusion with chin-cap. Transactions of the European Orthodontic Society, pp. 384–397

Thilander B 1964 Chin-cap treatment for Angle Class III malocclusion. Transactions of the European Orthodontic Society, pp. 311–327

Thilander B, Myberg N 1973 The prevalence of malocclusion in Swedish school children. Scandinavian Journal of Dental Research 81: 12–20

Tindlund R S 1989 Orthopaedic protraction of the midface in the deciduous dentition. Results covering 3 years out of treatment. Journal of Cranio-Maxillofacial Surgery 17: 17–19

Tng T T H, Chan T C K, Hägg U, Cooke M S 1994 Validity of cephalometric landmarks: an experimental study on human skulls. European Journal of Orthodontics 16: 110–120

Walther D P 1960 Some of the causes and effects of malocclusion. Transactions of the British Society for the Study of Orthodontics, pp. 1–16

Wendell P, Nanda R, Sakamoto T, Nakamura S 1985 The effects of chin cup therapy on the mandible: a longitudinal study. American Journal of Orthodontics 87: 265–274

Wisth P J, Tritrapunt A, Rygh P, Bøe O E, Norderval K 1987 The effect of maxillary protraction on front occlusion and facial morphology. Acta Odontologica Scandinavica 45: 227–237