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# Cephalometric and occlusal changes following maxillary expansion and protraction

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SUMMARY A prospective clinical trial was conducted to determine the cephalometric and occlusal changes following maxillary expansion and protraction. Twenty Southern Chinese patients (eight males and 12 females with a mean age of 8.4 ± 1.8 years) with skeletal Class III malocclusions were treated consecutively with maxillary expansion and a protraction facemask. Growth adaptation of these patients was followed for 2 years after removal of the appliances and compared with a control group of subjects with no treatment. Lateral cephalometric radiographs were used to quantify the skeletal and dental changes before treatment ($T_1$), immediately after treatment ($T_2$) and 2 years after removal of appliances ($T_3$). With 8 months of treatment ($T_2 - T_1$), overjet was overcorrected from a –2.0 to 3.5 mm. The maxilla moved forwards by an average of 2.1 mm and the molar relationship was improved to a Class I dental arch relationship. The palatal and occlusal planes were tilted upward 1.0 and 2.0 degrees, respectively. Two years following removal of the appliances ($T_3 - T_2$), a positive overjet was maintained in 18 out of 20 patients. The maxilla continued to move forwards in the treated subjects similar to the controls. The mandible outgrew the maxilla. In most instances, dental compensation with proclination of the maxillary incisors was observed. The palatal plane returned to pre-treatment value. The occlusal plane continued to tilt upward due to eruption of the molars and proclination of the incisors. Analysis of dental casts showed a significant increase in maxillary intercanine (2.2 mm) and intermolar widths (2.3 mm) with 7 days of rapid palatal expansion followed by maxillary protraction. The percentage relapse in maxillary intermolar widths was 30–45 per cent after 1 year, in most cases with minimal retention. In the mandibular arch, the concurrent increase in intermolar width (2.3 mm) was primarily due to buccal uprighting of the posterior molars when the maxilla was protracted into a Class I skeletal relationship and was stable after 1 year.

The results of this study indicate stability of orthopaedic treatment of Class III malocclusions directed at the maxilla. Despite some relapse, a net improvement in maxillomandibular relationship and a positive overjet was maintained in 18 out of 20 patients at the end of the follow-up period.

## Introduction

The developing skeletal Class III malocclusion is one of the most challenging problems confronting the practising orthodontist. The incidence of this type of malocclusion in the Caucasian population in the United Kingdom and Scandinavia is approximately 3–5 per cent (Huber and Reynolds, 1946; Björk, 1947; Humphreys and Leighton, 1950; Massler and Frankel, 1951; Newman, 1956; Ast *et al.*, 1965). It has been estimated that the incidence of Class III malocclusion among the Japanese and Chinese is as high as 14 per cent of the population (Iwagaki, 1938; Allwright and Burndred, 1964; Irie and Nakamura, 1975).

Many clinicians have attempted early intervention with such appliances as the chin cup, protraction headgear, or the functional regulator (Delaire *et al*., 1976; Graber, 1977; Ishii *et al*., 1987); Tindlund, 1989; Ülgen and Firatti, 1994). The utilization of the chin cup has resulted in limited stability. Latent mandibular growth and a return to the pre-treatment condition are common among reported studies on chin cup therapy (Thilander, 1963; Mitani and Fukazawa, 1986; Ritucci and Nanda, 1986; Sugawara *et al*., 1990). Recent studies suggest that a majority of Class III malocclusions have maxillary retrusion as the main or at least part of the cause of skeletal Class III malocclusions. Ellis and McNamara (1984) reported that 60 per cent of the skeletal Class III patients in their study had maxillary skeletal retrusion.

Protraction facemask in conjunction with a maxillary expansion appliance has been used to correct malocclusions associated with maxillary deficiency and/or mandibular prognathism (McNamara, 1987; Turley, 1988; Ngan *et al*., 1992, 1996). The use of a protraction facemask was first described more than 100 years ago (Potpeschnigg, 1875), with other descriptions appearing early in this century. Delaire *et al*. (1976) revived the interest in this technique. Petit (1983) later modified the basic concepts of Delaire by increasing the amount of force generated by the appliance, thus decreasing the overall treatment time.

Several investigators have demonstrated dramatic skeletal changes that can be obtained in animals with continuous protraction forces to the maxilla (Jackson *et al*., 1979; Kambara, 1977; Nanda, 1978). Not only is point A affected through forward incisor movement, but the entire maxilla is displaced anteriorly, with significant effects as far posteriorly as the zygomaticotemporal suture. McNamara (1987) and Turley (1988) reported cases of early orthopaedic intervention of Class III malocclusion using protraction facemask in combination with a rapid palatal expansion appliance. Ngan and colleagues (1996) recently completed a prospective study on 30 Class III patients treated with maxillary expansion and protraction. The results showed significant dental, skeletal and profile changes following 6–8 months of treatment.

Very few studies have reported on craniofacial and occlusal changes following maxillary expansion and protraction. Animal and human studies (Cederquist, 1987; Subtelny, 1980; Jackson *et al*., 1979; Stensland *et al*., 1988, Chong *et al*., 1996) have shown that the treatment effects on the maxilla remain stable 1–2 years after treatment. However, Rune (1982) reported relapse in an 11-year-old boy with maxillonasal dysplasia treated with a facemask. Jackson *et al*. (1979) found that the degree of relapse was negatively correlated to the length of stabilization. Stensland *et al*. (1988) reported on a group of 51 children treated with protractor and chin-cap therapy. They found 43 children responded well to treatment and eight patients responded poorly. The group that responded poorly demonstrated a number of morphological characteristics: a shorter cranial base, a more anteriorly positioned mandible, a more open mandibular angle, and a more acute prominence of the chin. When these patients were followed one-and-a-half years after treatment, the authors found the size of the cranial base angle, mandibular prognathism, size of the jaw angle, the prominence of the chin, and size of the interincisor angle all influenced the success of treatment.

Occlusal changes in response to maxillary expansion and protraction in Class III patients have not been reported in the literature. Previous studies with dental casts have shown increases in both the intercanine and intermolar widths in the maxillary arch with maxillary expansion appliances alone (Wertz, 1970; Gryson, 1977; Berlocher *et al*., 1980; Adkins *et al*., 1990; Spillane and McNamara, 1995). Reports on concomitant expansion in the mandibular arch were not as consistent (Wertz, 1970; Gryson, 1977; Sandstrom *et al*., 1988; Adkins *et al*., 1990). A few studies have reported on the long-term stability of cases treated by rapid maxillary expansion. Stockfisch (1969) showed that in a group of 150 patients, 5–15 years after expansion, the degree of relapse varied with the degrees of initial expansion. When the initial expansion was 14 mm, every case relapsed to 10 mm of final stable expansion. When the initial expansion was 10 mm, 80 per cent of the cases relapsed to 7–8 mm. Timms

(1976) re-examined a group of 26 patients who were more than 5 years out of retention. The residual expansion varied from 81 to 10 per cent of the original expansion, with a mean of 44 per cent. Linder-Aronson and Lindgren (1979) recorded the stability of dental changes in 23 patients 5 years post-retention. The final increase in maxillary intermolar width and intercanine width was 45 and 23 per cent of that achieved initially by rapid maxillary expansion. Spillane and McNamara (1995) showed that in a group of 162 patients who underwent rapid maxillary expansion in the early mixed dentition, 90.5 per cent of the original expansion at the first permanent molars remained after the first year and 80.4 per cent of the expansion at the end of 2.4 years. Maxillary dental arches that were initially narrow or with more lingually inclined molars tended to retain a greater percentage of the achieved expansion.

Rapid palatal expansion appliances can be used to correct posterior crossbites and in conjunction with protraction headgear, to disarticulate maxillary sutures to allow more efficient forward protraction of the maxilla (Turley, 1988). The benefit of this treatment modality has not been substantiated. The purpose of this study was to evaluate quantitatively: (1) on lateral cephalometric radiographs, the skeletal and dental changes with maxillary expansion and protraction during treatment and 2 years after removal of appliances; and (2) on study casts, the occlusal changes during treatment and 1 year after removal of appliances.

## Materials and methods

### *Sample description for the cephalometric study*

The treated sample was drawn from a prospective study on 30 Chinese patients with skeletal Class III malocclusions who were treated with a maxillary expansion and protraction facemask in the Department of Children's Dentistry and Orthodontics, University of Hong Kong (Ngan *et al.*, 1996). During the observation period, 10 patients either discontinued treatment or immigrated to other countries. Twenty patients (eight males and 12 females), with lateral cephalometric radiographs before treatment ($T_1$), 6 months after treatment ($T_2$) and 2 years after removal of appliances ($T_3$), were included in this study. The mean age at the start of the study was $8.4 \pm 1.8$ years. The stage of dental development varied from early mixed to early permanent dentition. All subjects had a negative overjet and a skeletal Class III malocclusion at the start of treatment. The mean treatment time was $8 \pm 3$ months. No retentive device was needed in ten patients due to adequate overbite. In ten patients, a reverse activator was placed as a retainer for 1 year after attainment of a positive overjet. No further orthodontic or orthopaedic treatment was rendered after facemask treatment.

The control sample consisted of lateral cephalometric radiographs from a group of untreated Chinese subjects with Class III malocclusions who were closely matched in age, sex, and pretreatment skeletal morphology to the treated group.

### *Sample description for the occlusal study*

Sixteen patients (five males and 11 females) with study casts at centric occlusion 6 months before treatment ($T_0$), immediately before treatment ($T_1$), 6 months after treatment ($T_2$), and 1 year after removal of appliances ($T_3$), were included in this study. The number of subjects was smaller than the cephalometric study because, in a number of patients, there was a transition from the deciduous to the permanent dentition. Due to the different bucco-lingual widths of these teeth and measurements that would alter over time irrespective of any real occlusal changes, patients with transition from deciduous to permanent dentition during the studied time periods were excluded from the study. Bilateral posterior crossbite was present in eight patients. Two patients had unilateral posterior crossbite with a mandibular shift. The mean age at the start of treatment was $8.2 \pm 1.7$ years. The time period ($T_1 - T_0$) represented 6 months of growth without treatment, and ($T_2 - T_1$) represented 6 months of growth and treatment. In this way, the patients served as their own control in the occlusal study.

### Appliances for Class III correction

The Hyrax rapid palatal expansion appliance was constructed by placing 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 facemask (Figure 1Ab) was a one-piece construction with an adjustable anterior wire and hooks to accommodate a downward and forward pull of the maxilla with elastics. The protraction elastics were attached near the maxillary canines with a downward and forward pull of 30 degrees to the occlusal plane. Maxillary protraction generally requires an orthopaedic force of 300–600 g per side, depending on the age of the patient. In the present study, elastics that delivered 380 g per side as measured by a gauge were used. The patients were instructed to wear the facemask for 12 hours a day.

### Cephalometric analysis

Lateral cephalometric radiographs were taken before treatment ($T_1$), immediately after treatment ($T_2$), and 2 years after removal of the appliance ($T_3$). The cephalometric analyses described by Björk (1947) and Pancherz (1982a,b) were used in this study. The landmarks used are defined in Figures 2A, B and C. Registration of the lateral cephalograms was performed on 0.003-inch matte acetate tracing film with a 0.3-mm mechanical number 2 lead pencil. The measurement for each variable was performed twice with digital calipers. Linear and vertical measurements were recorded to the nearest 0.1 mm. Angular measurements were recorded using protractors to the nearest 0.1 degree. Analysis of the sagittal skeletal and dental changes was recorded along the occlusal plane (OLs) and to the occlusal plane perpendicular (OLp) from the first cephalogram, which formed the reference grid. The grid was then transferred to subsequent cephalograms by superimposing the tracings on the mid-sagittal cranial structure.

### Dental cast analysis

Serial maxillary and mandibular dental casts were measured by one investigator (C.Y.). The points from which measurements were to be made were marked with a fine lead pencil to facilitate identification. The points were recorded with a two-dimensional digitizer (Vidas, Videoplan, Zeiss, West Germany). Measurements were recorded to the nearest 0.1 mm. The following measurements were made: arch width, length and perimeter, and palatal depth.

### Arch width determination

This was measured on the maxillary dental casts as the distance between the most lingual point at the free gingival margins on the first permanent molars (6–6), the second primary molars (E–E), the first primary molars (D–D), and the primary canines (C–C). Measurement of width at the gingival margin of teeth minimized the error that could have resulted from buccal crown tipping during the expansion procedures. With the mandibular dental casts, the distances between the buccal gingival margin at the buccal groove of the first permanent molars (6–6) and the second primary molars (E–E), as well as the buccal gingival margin at the most prominent portion of the first primary molars (D–D) and primary canines (C–C) were measured.

### Arch length determination

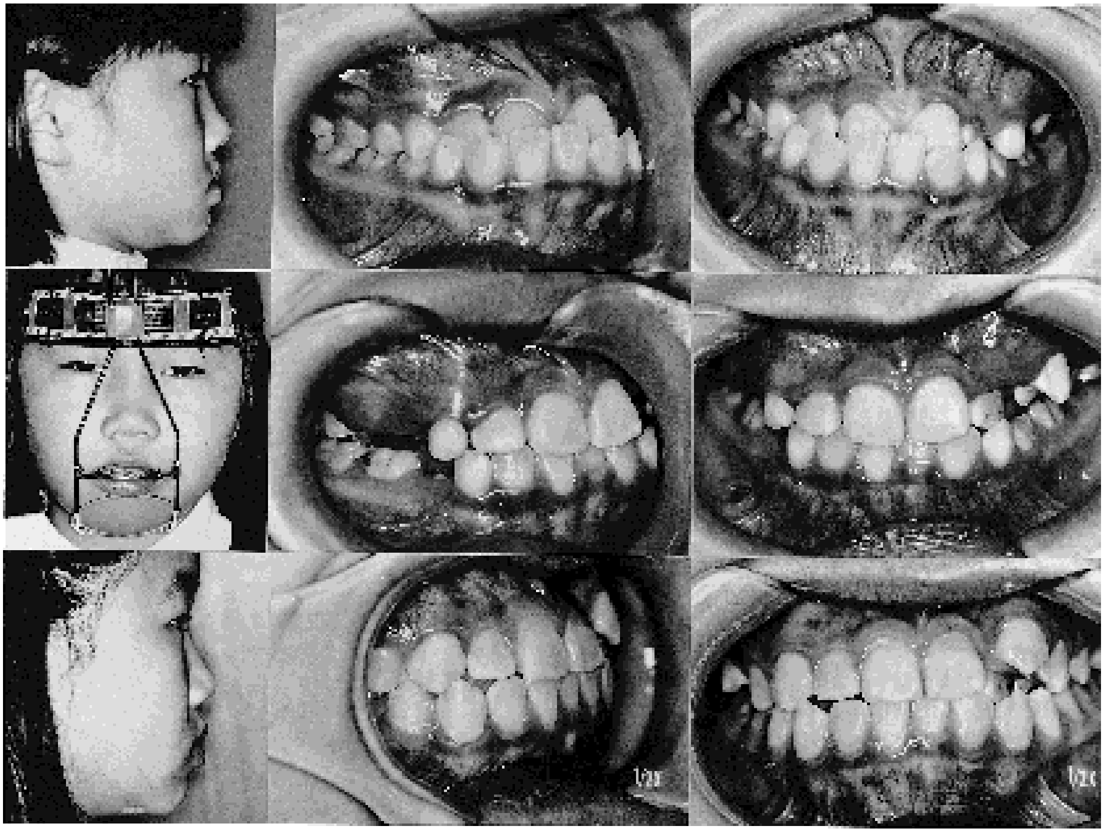
This was measured as the perpendicular distance from the most facial point on the most prominent central incisor to a line constructed between the contact points, mesial of the first permanent molars.

A

(a)

(b)

(c)



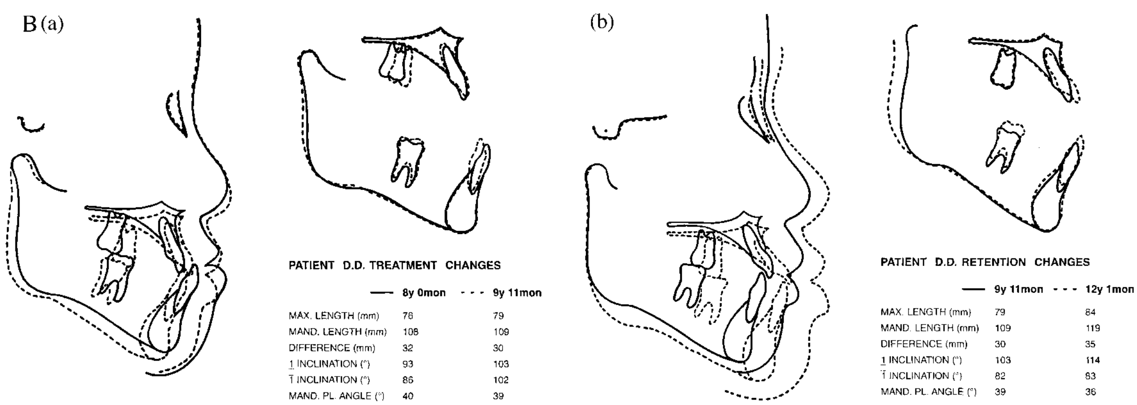



**Figure 1** (A) Extra- and intra-oral photographs. (a) At the start of treatment with maxillary expansion and protraction appliances. (b) After 9 months of treatment. (c) Two years after removal of appliances. (B) Cephalometric tracings superimposed on the nasion-sella line with sella as the registration point. (a) Treatment changes. (b) Retention changes.

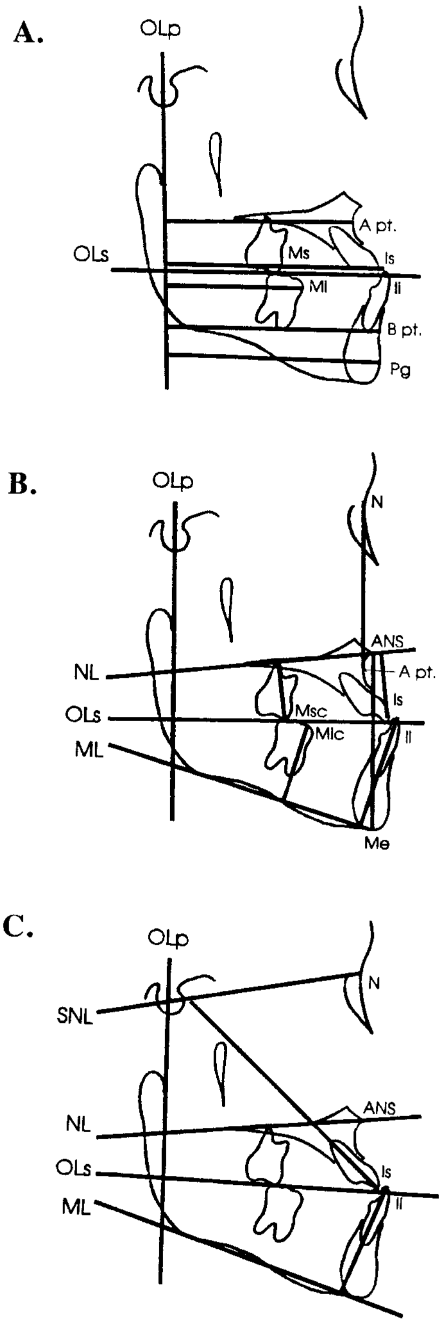



**Figure 2** Points used in the cephalometric analysis for (A) sagittal measurements. The registration line (NSL) and reference grid (OLs) and (OLp) are shown (B) vertical measurements and (C) angular measurements.

*Arch perimeter determination*

This was measured as the sum of the segments between the contact points of the adjacent teeth from the mesial mid-point of the first permanent molar to the corresponding point on the contralateral side of the maxillary or mandibular arch. In the event of the malalignment of individual teeth, the arch perimeter was digitized following the form of the arch rather than the malaligned teeth.

*Palatal depth*

This was recorded as the distance from the functional occlusal plane at the level of the maxillary second primary molars to the palatal raphe.

*Statistical methods*

For the cephalometric analysis, comparison of treatment changes between the treated and control groups was performed using a two-tailed *t*-test. The levels of significance used were $P < 0.05$, $P < 0.01$, and $P < 0.001$.

For the occlusal analysis, a Student's paired *t*-test was performed to determine whether the changes in arch dimensions were significantly different between the time periods $T_0$ and $T_1$, $T_1$ and $T_2$, and $T_1$ and $T_3$.

*Error study*

For the cephalometric analysis, the error in locating, superimposing, and measuring the changes of the different landmarks by one examiner (intra-examiner error) was performed on cephalograms of 10 subjects. All cephalograms were recorded twice independently on two separate occasions with a 2-week interval between. For all the cephalometric variables, differences between the independent repeated measurements of each individual before/after treatment, and two years after removal of appliances were recorded. Intraclass Correlation Coefficient of Reliability ($R$) was used to determine the reliability of cephalometric measurements. The $R$ value ranged from 0 to 1.00, with $R$ value greater than 0.90 indicating high reliability.

$$R = \frac{(\mathrm{MSA} - \mathrm{MSE})}{\mathrm{MSA} + [(\mathrm{k} - 1)\mathrm{MSE}]}$$

**Table 1** Accuracy of sagittal, vertical and angular measurements at pretreatment ($T_1$), immediately after treatment ($T_2$), and 2 years post-treatment ($T_3$). The mean difference of repeated measurements (1 and 2) on cephalograms of 10 subjects.

| Measurements | $T_1$ | | $T_2$ | | $T_3$ | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| *Sagittal (mm)* | | | | | | |
| Overjet | 0.14 | 0.13 | 0.18 | 0.16 | 0.18 | 0.13 |
| OLp–Apt | 0.13 | 0.08 | 0.25 | 0.19 | 0.38 | 0.26 |
| OLp–Pg | 0.20 | 0.15 | 0.48 | 0.37 | 0.70 | 0.31 |
| Is/OLp | 0.17 | 0.12 | 0.42 | 0.23 | 0.49 | 0.28 |
| Ii/OLp | 0.08 | 0.10 | 0.46 | 0.25 | 0.40 | 0.28 |
| Molar rel. | 0.10 | 0.07 | 0.21 | 0.26 | 0.11 | 0.08 |
| Ms/OLp | 0.09 | 0.10 | 0.15 | 0.17 | 0.19 | 0.17 |
| Mi/OLp | 0.10 | 0.08 | 0.29 | 0.29 | 0.20 | 0.12 |
| *Vertical (mm)* | | | | | | |
| Overbite | 0.10 | 0.08 | 0.08 | 0.08 | 0.10 | 0.07 |
| Is–NL | 0.07 | 0.07 | 0.09 | 0.07 | 0.07 | 0.03 |
| Ii–Ml | 0.11 | 0.07 | 0.30 | 0.55 | 0.11 | 0.07 |
| Msc–NL | 0.11 | 0.09 | 0.13 | 0.12 | 0.13 | 0.11 |
| Mic-Ml | 0.10 | 0.05 | 0.11 | 0.06 | 0.12 | 0.06 |
| ANS–Me | 0.11 | 0.08 | 0.30 | 0.28 | 0.15 | 0.16 |
| *Angular (degrees)* | | | | | | |
| SNA | 0.05 | 0.16 | 0.10 | 0.30 | 0.15 | 0.24 |
| SNB | 0.20 | 0.24 | 0.20 | 0.26 | 0.15 | 0.24 |
| ANB | 0.10 | 0.21 | 0.15 | 0.24 | 0.20 | 0.35 |
| SNL–ML | 0.40 | 0.46 | 0.40 | 0.39 | 0.30 | 0.35 |
| SNL–OLs | 0.30 | 0.35 | 0.25 | 0.35 | 0.45 | 0.37 |
| SNL–NL | 0.30 | 0.35 | 0.20 | 0.35 | 0.30 | 0.42 |
| Is/SNL | 1.00 | 0.85 | 1.30 | 0.72 | 1.10 | 0.46 |
| Ii/ML | 0.80 | 0.63 | 0.85 | 0.58 | 0.45 | 0.37 |

where MSA is the mean square between the variables and $k$ is the number of repeated measures.

The results are shown in Table 1. The mean differences for all linear measurements were less than 0.8 mm. The greatest mean error for angular measurement was 1.3 degrees for the measurement of maxillary central incisal angle (Is/NSL). The reliability coefficient for all measurements was greater than 0.93, indicating a high level of reliability.

For dental cast analysis, pre-expansion maxillary casts of 16 subjects were digitized independently on two separate occasions with 2-week interval between. The mean differences were 0.4 mm for intercanine width, 0.2 mm for intermolar width, 0.6 mm for arch perimeter, 0.4 mm for arch depth, and 0.1 mm for palatal depth. The reliability coefficient for all measurements was greater than 0.92 with the exception of Arch C–C which was 0.83, indicating a high level of reliability.

## Results

### *Cephalometric changes*

Changes in cephalometric measurements in patients treated with protraction headgear before treatment ($T_1$), 6 months after treatment ($T_2$), and 2 years after removal of appliances ($T_3$) are shown in Table 2. Table 3 and Figure 3A and B summarize the changes during treatment ($T_2 - T_1$) in treated and control subjects. Significant differences were found in most of the variables tested ($P < 0.05$). In the treated group, all subjects were overcorrected to a Class I or

**Table 2** Changes in cephalometric measurements in 20 patients treated with protraction headgear. Before treatment ($T_1$), immediately after treatment ($T_2$), and 2 years post-treatment ($T_3$).

| Measurements | $T_1$ | | $T_2$ | | $T_3$ | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| *Sagittal (mm)* | | | | | | |
| Overjet | –1.9 | 1.1 | 3.6 | 2.2 | 2.6 | 2.1 |
| OLp–Apt | 69.5 | 2.7 | 71.6 | 3.2 | 74.3 | 3.3 |
| OLp–Pg | 79.3 | 5.4 | 78.3 | 4.9 | 84.5 | 5.8 |
| Is/OLp | 76.8 | 3.7 | 80.6 | 3.6 | 85.8 | 3.8 |
| Ii/OLp | 78.8 | 3.5 | 77.1 | 3.7 | 83.2 | 4.1 |
| Molar rel. | –3.2 | 1.9 | 0.8 | 0.8 | –1.2 | 2.1 |
| Ms/OLp | 50.5 | 4.1 | 55.1 | 4.5 | 58.5 | 4.2 |
| Mi/OLp | 53.8 | 5.1 | 54.4 | 4.9 | 59.6 | 4.8 |
| *Vertical (mm)* | | | | | | |
| Overbite | 2.2 | 2.6 | 0.8 | 1.1 | 1.2 | 11.0 |
| Is–NL | 25.2 | 2.7 | 25.6 | 2.2 | 26.2 | 1.9 |
| Ii–Ml | 37.8 | 2.5 | 38.4 | 2.5 | 41.2 | 2.5 |
| Msc–NL | 19.7 | 2.04 | 21.0 | 1.9 | 22.4 | 2.0 |
| Mic-ML | 28.5 | 1.4 | 29.6 | 1.2 | 31.8 | 2.18 |
| ANS–Me | 60.2 | 2.8 | 62.8 | 3.4 | 65.2 | 3.4 |
| *Angular (degrees)* | | | | | | |
| SNA | 79.0 | 3.2 | 80.6 | 3.3 | 80.3 | 3.0 |
| SNB | 79.0 | 2.6 | 77.5 | 2.9 | 79.1 | 2.5 |
| ANB | 0.1 | 2.1 | 3.1 | 2.1 | 1.1 | 2.3 |
| SNL–ML | 36.9 | 3.9 | 38.3 | 4.2 | 37.1 | 4.6 |
| SNL–OLs | 23.6 | 4.3 | 21.6 | 4.3 | 20.4 | 3.3 |
| SNL–NL | 11.4 | 2.3 | 10.3 | 2.3 | 11.3 | 2.7 |
| Is/SN | 100.9 | 10.2 | 102.6 | 11.3 | 110.0 | 6.1 |
| Ii/ML | 91.5 | 9.2 | 87.1 | 8.3 | 90.3 | 6.7 |

Class II dental arch relationship. Overjet and sagittal molar relationships improved by an average of 5.5 and 3.9 mm, respectively. In the control group, a decrease in overjet (–0.1 mm) and molar relationship (–0.3 mm) was observed. Vertical changes included a significant increase in lower face height ($P < 0.05$), and maxillary and mandibular molar eruption ($P < 0.05$). Overbite decreased 1.5 mm in the treated group and increased 0.7 mm in the control group, $P < 0.05$.

Table 4 and Figures 4A and B show the cephalometric changes two years after removal of appliances ($T_3 - T_2$) in the treated and control groups. Significant differences were found in seven of the 24 variables. A positive overjet was maintained in 18 out of 20 patients. Sagittal movement of the maxilla, and maxillary and mandibular incisors was found to be greater in the treatment group as compared with the control group ($P < 0.05$). Over 2 years, the maxilla continued to move forward 2.7 mm in the treated group and 1.8 mm in the control group. The mandible outgrew the maxilla in both groups with twice the amount of growth during the same period. The palatal plane angle showed a 1 degree clockwise rotation in the treated group and a 0.5-degree counterclockwise rotation in the control group ($P < 0.05$). The maxillary and mandibular incisal angle showed a greater increase in the treated as compared with the control group ($P < 0.05$).

Figure 5A and B shows the net changes with 8 months of treatment and 2 years of observation ($T_3 - T_1$). In the treated group, the maxilla moved forwards 4.8 mm and the mandible 5.2 mm. The maxillary incisor was tipped labially 4.1 mm and

**Table 3** Comparison of sagittal, vertical, and angular changes between $T_1$ and $T_2$ in 20 treated and matched control subjects.

| Variables | Treated | | Control | | Significance |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| *Sagittal (mm)* | | | | | |
| Overjet | 5.5 | 2.11 | –0.1 | 1.8 | *** |
| OLp–Apt | 2.1 | 1.1 | 0.5 | 1.0 | *** |
| OLp–Pg | –1.0 | 2.3 | 1.7 | 1.2 | *** |
| Is/OLp | 3.8 | 1.7 | 1.4 | 1.3 | *** |
| Ii/OLp | –1.7 | 2.0 | 1.4 | 1.3 | *** |
| Molar rel. | 3.9 | 2.1 | –0.3 | 1.2 | *** |
| Ms/OLp | 4.4 | 1.8 | 0.9 | 1.3 | *** |
| Mi/OLp | 0.5 | 1.8 | 1.2 | 1.3 | NS |
| *Vertical (mm)* | | | | | |
| Overbite | –1.5 | 2.9 | 0.7 | 1.8 | ** |
| Is–NL | 0.4 | 1.7 | 0.9 | 1.3 | NS |
| Ii–ML | 0.6 | 1.3 | 0.8 | 1.2 | NS |
| Msc–NL | 1.3 | 1.0 | 0.1 | 1.4 | ** |
| Mic-ML | 1.1 | 0.7 | 0.4 | 1.1 | * |
| ANS–ME | 2.6 | 1.7 | 1.0 | 1.4 | ** |
| *Angular (degrees)* | | | | | |
| SNA | 1.6 | 1.2 | –0.1 | 1.0 | *** |
| SNB | –1.5 | 1.4 | 0.2 | 1.0 | *** |
| ANB | 3.0 | 1.5 | –0.2 | 0.8 | * |
| SNL–ML | 1.3 | 1.5 | –0.2 | 1.9 | ** |
| SNL–OLs | –2.0 | 4.1 | 0.4 | 2.4 | * |
| SNL–NL | –1.0 | 1.6 | 0.1 | 1.6 | * |
| Is/SNL | 3.7 | 5.8 | 4.3 | 4.5 | NS |
| Ii/ML | –4.4 | 5.5 | 0.4 | 3.2 | ** |

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

the mandibular incisor tipped lingually 0.9 mm, resulting in a net overjet correction of 4.6 mm. In the control group, a similar amount of mandibular growth was observed, but maxillary forward movement was half that of the treated group. Lingual inclination of the mandibular incisors was observed but not enough to compensate for the 5.5 mm of mandibular growth, thus resulting in a negative overjet of 0.4 mm. In the treated group, the Class III molar relationship improved to a Class I relationship of 2.0 mm mainly due to a 2.4 mm greater mesial movement of the maxillary than mandibular molars. No improvement in molar relationship was observed in the control group.

For vertical change, an increase of 5.0 mm in lower anterior face height and decrease of 1.1 mm in overbite was observed in the treated group. These changes were due to maxillary and mandibular molar eruption. The palatal and mandibular plane angles returned to pretreatment values. The occlusal plane angle rotated upward 3.2 degrees. This was due to a greater vertical eruption of the maxillary molar (2.7 mm) than incisal eruption (1.0 mm). In the majority of the cases, the maxillary incisors adapted to the continued forward growth of the mandible by incisal proclination. The treated group showed a greater amount of proclination of 9.3 degrees compared with the control of 5.6 degrees. In the control group, a smaller increase of lower face height was observed and the overbite increased to 1.6 mm. The maxillary and mandibular molars erupted less compared with the treated group.

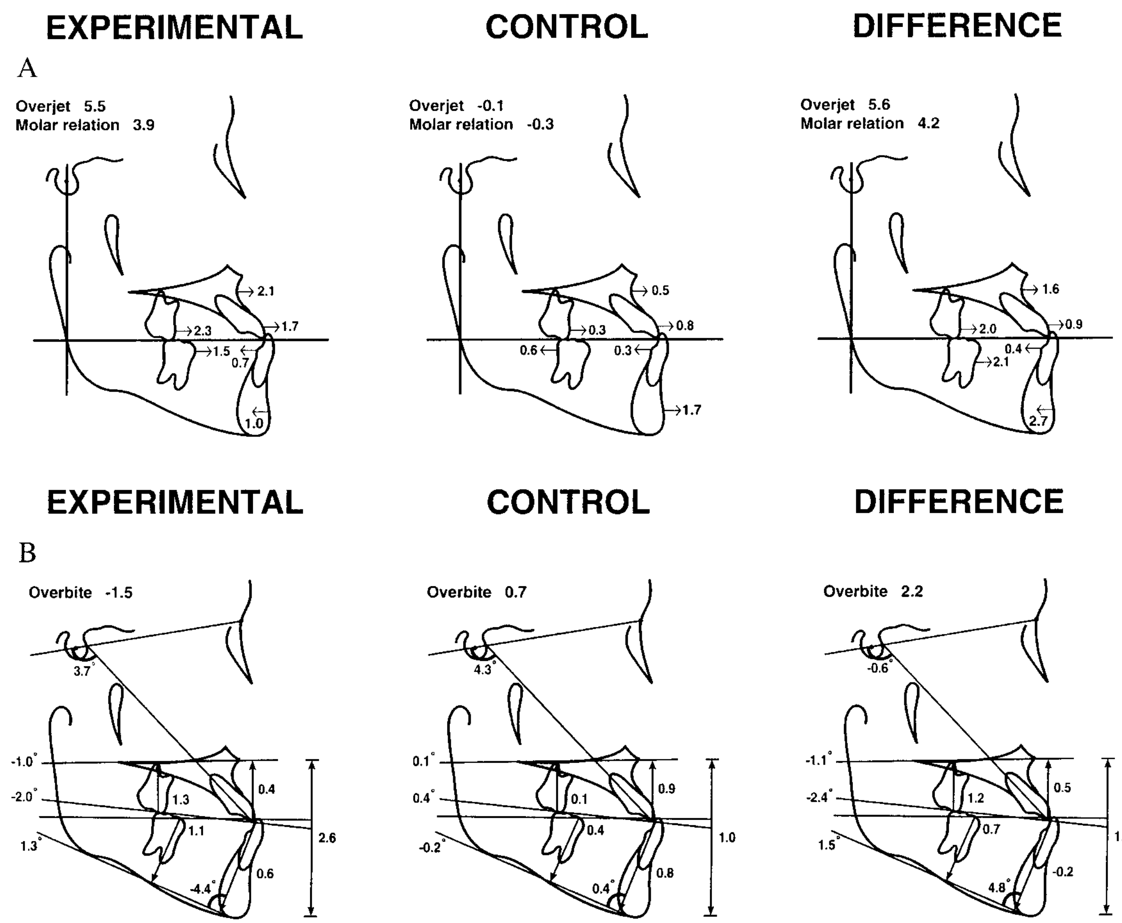



**Figure 3** (A) Skeletal and dental changes (mm) contributing to alterations in overjet and molar relationship in 20 subjects with a Class III malocclusion treated with maxillary expansion and protraction appliances for 8 months. (B) Skeletal and dental contributions to vertical (mm) and angular (degrees) changes with 8 months of treatment.

The occlusal plane angle rotated downward due to greater vertical eruption of the maxillary incisor at 2.1 mm compared with the molar at 0.8 mm.

*Occlusal changes*

Tables 5 and 6 show the measurements of arch dimension at time intervals $T_0$, $T_1$, $T_2$ and $T_3$ in the maxillary and mandibular arches, respectively. Tables 7 and 8 show the mean changes during the pretreatment period ($T_1 - T_0$), 6 months after treatment ($T_2 - T_1$), 1 year after removal of appliances ($T_3 - T_2$), and the net change ($T_3 - T_1$) throughout the observation period in the maxillary and mandibular arches, respectively.

There were no significant dental changes observed in either the maxillary or mandibular arches during 6 months of growth without treatment ($T_1 - T_0$). Maxillary expansion and protraction ($T_2 - T_1$) resulted in a mean expansion of 2.3 mm between the maxillary first permanent molars, 2.1 mm between the maxillary second primary molars, 2.6 mm between the maxillary first primary molars, and 2.2 mm between the maxillary canines. The corresponding intercanine

**Table 4** Comparison of sagittal, vertical, and angular changes between $T_2$ and $T_3$ in 20 treated and matched control subjects.

| Variables | Treated | | Control | | Significance |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| *Sagittal (mm)* | | | | | |
| Overjet | –0.9 | 2.1 | –0.3 | 1.9 | NS |
| OLp–Apt | 2.7 | 1.6 | 1.8 | 1.2 | * |
| OLp–Pg | 6.2 | 3.0 | 4.8 | 3.4 | NS |
| Is/OLp | 5.1 | 2.5 | 3.5 | 2.4 | * |
| Ii/OLp | 6.1 | 2.3 | 3.8 | 2.0 | ** |
| Molar rel. | –1.9 | 2.5 | –0.8 | 1.8 | NS |
| Ms/OLp | 3.4 | 2.6 | 3.2 | 2.6 | NS |
| Mi/OLp | 5.3 | 2.8 | 4.1 | 2.9 | NS |
| *Vertical (mm)* | | | | | |
| Overbite | 0.4 | 1.1 | 0.9 | 2.1 | NS |
| Is–NL | 0.6 | 1.6 | 1.2 | 2.1 | NS |
| Ii–ML | 2.8 | 1.4 | 2.0 | 1.8 | NS |
| Msc–NL | 1.4 | 1.0 | 0.8 | 2.2 | NS |
| Mic-ML | 2.2 | 1.6 | 1.4 | 1.8 | NS |
| ANS–ME | 2.4 | 2.2 | 2.1 | 2.3 | NS |
| *Angular (degrees)* | | | | | |
| SNA | –0.3 | 1.4 | 0.5 | 1.7 | NS |
| SNB | 1.6 | 1.8 | 1.5 | 2.1 | NS |
| ANB | –2.0 | 1.3 | –1.1 | 1.7 | NS |
| SNL–ML | –1.2 | 1.9 | –0.5 | 2.2 | NS |
| SNL–OLs | –1.2 | 2.6 | 0.4 | 3.7 | NS |
| SNL–NL | 1.0 | 1.8 | –0.5 | 2.5 | * |
| Is/SNL | 5.6 | 6.0 | 1.3 | 8.5 | * |
| Ii/ML | 3.3 | 5.5 | –1.2 | 4.5 | ** |

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

width increase was 2.2 mm. The arch perimeter increased by 1.7 mm while the arch length and palatal depth showed no significant change.

One year after removal of appliances ($T_3 - T_2$), the width of maxillary first molars, maxillary second and first primary molars relapsed on average 0.7, 1.0, and 1.0 mm, respectively. The arch perimeter relapsed, on average, 1.6 mm while the intercanine width and palatal depth remained relatively unchanged. For the entire observation period ($T_3 - T_1$), only the distances between the upper first permanent molar and upper second primary molar showed a mean net increase of 1.6 mm ($P < 0.01$) and 1.1 mm ($P < 0.05$), respectively. No significant change in arch widths (C–C), (D–D), arch length, or arch perimeter was observed. An increase in palatal depth was found during the entire observation period.

In the mandibular arch, from $T_1$ to $T_2$, there was a concomitant increase of 2.3 mm between the mandibular first permanent molars, 1.9 mm between the second primary molars and 1.5 mm between the first primary molars with maxillary expansion. No significant relapse in arch width was found after removal of the appliances. From $T_1$ to $T_3$, the mean net increase in the width between the first permanent molars, second primary molars, and first primary molars was 1.9 mm ($P < 0.001$), 2.4 mm ($P < 0.001$), and 1.9 mm

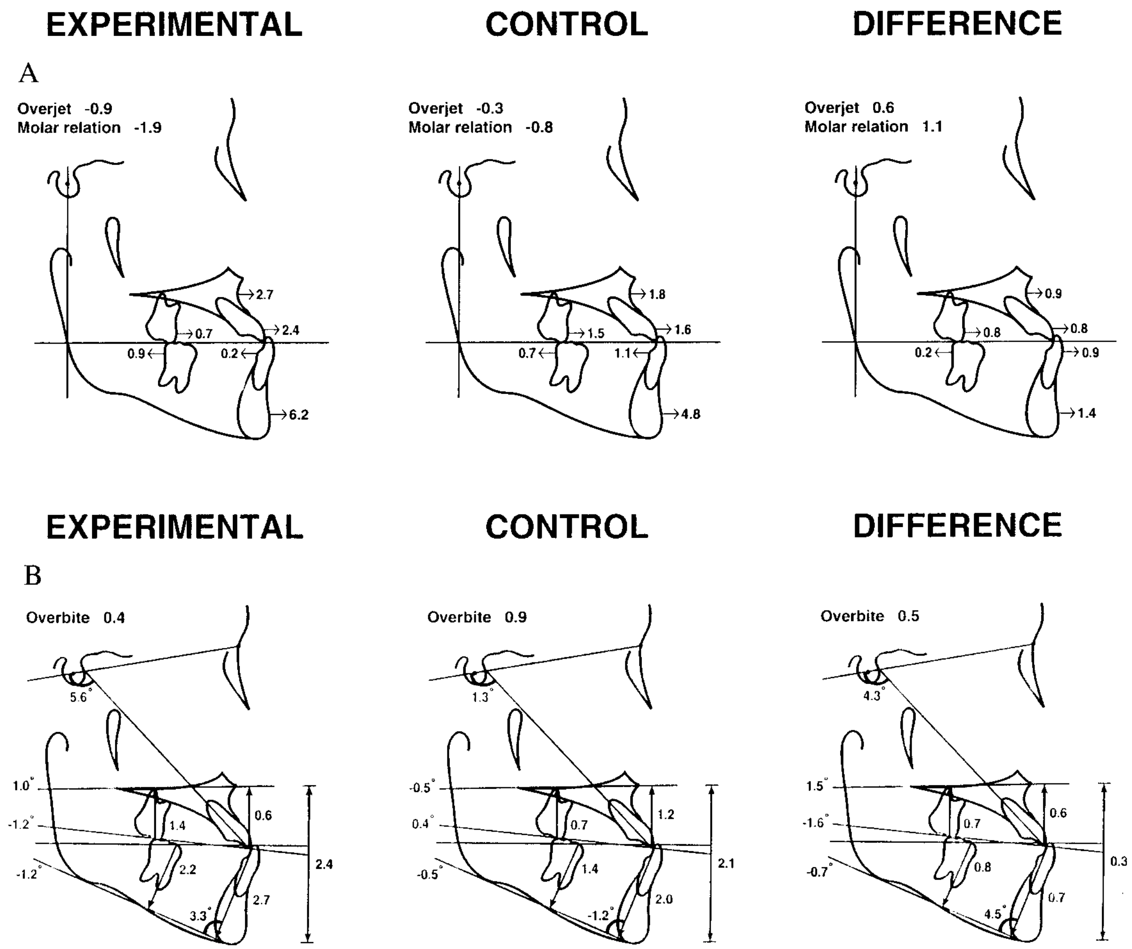



**Figure 4** (A) Skeletal and dental changes (mm) contributing to alterations in overjet and molar relationship in 20 subjects with a Class III malocclusion 2 years after removal of appliances. (B) Skeletal and dental contributions to vertical (mm) and angular (degrees) changes 2 years after removal of appliances.

($P < 0.001$), respectively. A mean net decrease of 1.4 mm of arch perimeter was observed from $T_1$ to $T_3$.

*Case report (Figure 1A and B)*

The subject was 8 years of age. Treatment was started 6 months later and the patient was treated with a protraction facemask for 9 months. A positive overjet was obtained with forward and downward movement of the maxilla and downward and backward rotation of the mandible. The maxillary molars were moved forwards. The maxillary incisors were proclined and the mandibular incisors retroclined. Two years after removal of the appliance, a positive overjet was maintained. The maxilla continued to move forward and downward. The mandible outgrew the maxilla with a difference in maxillary and mandibular length of 35 mm. The maxillary

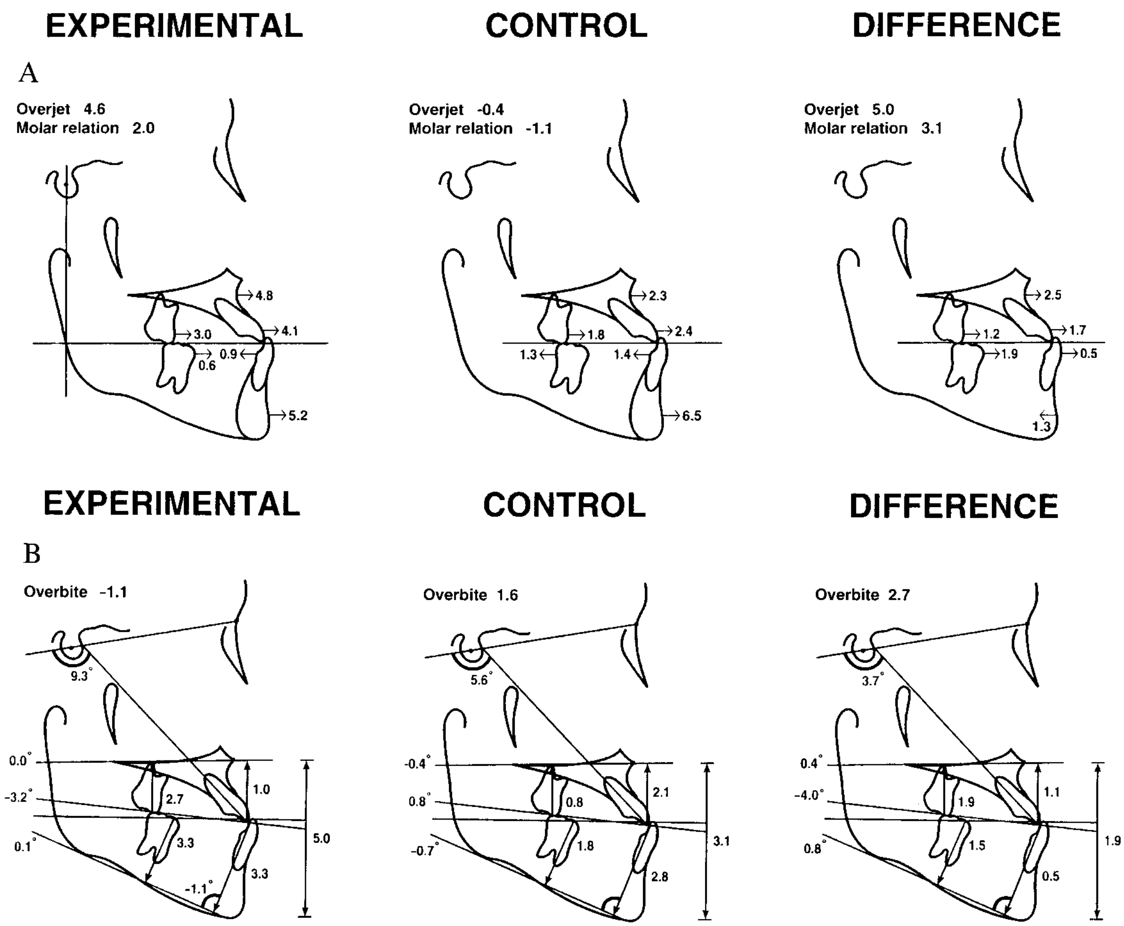



**Figure 5** (A) Skeletal and dental changes (mm) contributing to alterations in overjet and molar relationship in 20 subjects with a Class III malocclusion with 8 months of treatment and 2 years of observation. (B) Skeletal and dental changes contributing to vertical (mm) and angular (degrees) changes with 8 months of treatment and 2 years of observation.

**Table 5** Measurements of the maxillary arch width, arch perimeter, arch length, and palatal depth (mm) in 16 subjects for the time periods $T_0$, $T_1$, $T_2$, and $T_3$.

| Variable | 6 months pretreatment $T_0$ | | Immediately before treatment $T_1$ | | 6 months after treatment $T_2$ | | 1 year after appliance removal $T_3$ | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Arch width C–D | 26.6 | 0.7 | 26.8 | 1.0 | 29.0 | 1.5 | 28.5 | 2.2 |
| Arch width D–D | 29.8 | 1.9 | 30.0 | 1.9 | 32.5 | 2.6 | 31.6 | 3.0 |
| Arch width E–E | 31.1 | 1.3 | 31.5 | 1.4 | 33.5 | 1.8 | 32.6 | 1.5 |
| Arch width 6–6 | 34.7 | 3.1 | 35.1 | 3.6 | 37.4 | 3.5 | 36.7 | 3.4 |
| Arch perimeter | 75.6 | 3.3 | 76.0 | 3.7 | 77.7 | 3.4 | 76.2 | 3.2 |
| Arch length | 24.7 | 1.8 | 25.0 | 1.8 | 24.3 | 1.8 | 24.5 | 1.6 |
| Palatal depth | 16.6 | 2.3 | 16.7 | 2.3 | 17.0 | 2.43 | 17.5 | 1.9 |

**Table 6** Measurements of mandibular arch width and arch perimeter (mm) in 16 subjects for the time periods $T_0$, $T_1$, $T_2$, and $T_3$.

| Variable | 6 months pretreatment $T_0$ | | Immediately before treatment $T_1$ | | 6 months after treatment $T_2$ | | 1 year after appliance removal $T_3$ | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Arch width C–C | 29.5 | 0.8 | 30.1 | 0.8 | 30.7 | 1.5 | 30.8 | 1.7 |
| Arch width D–D | 38.0 | 1.9 | 38.3 | 2.4 | 39.8 | 2.4 | 40.2 | 2.6 |
| Arch width E–E | 45.6 | 2.0 | 45.9 | 2.0 | 47.8 | 2.3 | 48.3 | 2.2 |
| Arch width 6–6 | 55.1 | 3.4 | 55.3 | 3.4 | 57.6 | 3.1 | 57.2 | 3.5 |
| Arch perimeter | 72.7 | 2.6 | 72.5 | 2.7 | 71.9 | 3.1 | 71.0 | 3.2 |

**Table 7** Changes in maxillary arch width, arch length, arch perimeter, and palatal depth (mm) in 16 subjects at the various time periods.

| Variable | 6 months pretreatment $(T_1 - T_0)$ | | 6 months of treatment $(T_2 - T_1)$ | | 1 year after appliance removal $(T_3 - T_2)$ | | Net change $(T_3 - T_1)$ | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Arch width C–C | 0.2 | 0.6 | 2.2* | 1.5 | –0.5 | 1.0 | 1.7 | 2.0 |
| Arch width D–D | 0.2 | 0.4 | 2.6** | 1.2 | –0.9* | 0.7 | 1.6 | 1.8 |
| Arch width E–E | 0.3 | 0.5 | 2.1** | 1.2 | –0.9* | 1.1 | 1.5* | 1.2 |
| Arch width 6–6 | 0.4 | 0.7 | 2.3*** | 0.7 | –0.7* | 0.8 | 1.6** | 0.2 |
| Arch length | 0.3 | 0.7 | –0.7 | 1.3 | 0.2 | 2.0 | –0.5 | 1.8 |
| Arch perimeter | 0.5 | 1.0 | 1.7* | 3.0 | –1.1* | 2.8 | 0.1 | 3.4 |
| Palatal depth | 0.2 | 0.5 | 0.4 | 0.8 | 0.4 | 1.1 | 0.8* | 1.3 |

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

incisors proclined to compensate for the skeletal differences. Note the vertical eruption of the mandibular molars.

## Discussion

### *Cephalometric changes*

The maxilla articulates with nine other bones of the craniofacial complex: frontal, nasal, lacrimal, ethmoid, palatine, vomer, zygoma, inferior nasal concha, opposite maxilla, and, occasionally, sphenoid. Palatal expansion may 'disarticulate' the maxilla and initiate cellular response in the sutures, allowing a more positive reaction to protraction forces (Haas, 1970; Bell, 1982). Baik (1995), divided 60 patients treated with protraction facemask into two groups: 47 patients were treated with rapid palatal expansion appliances and 13 patients with labiolingual appliances. The author found significantly greater forward movement of point A in the expansion group (2 mm) as compared with the labiolingual group (0.9 mm). In the present study, the overjet was over-corrected from a mean of –2.0 to 3.5 mm with an average treatment time of 8 months. This was in anticipation of the continued disproportional growth between the maxilla and mandible in Class III patients (Wisth *et al.*, 1987; Tindlund, 1989). The maxilla moved forwards by an average of 2.1 mm, which is similar to that reported

**Table 8** Changes in mandibular arch width and arch perimeter (mm) in 16 subjects at the various time periods.

| Variable | 6 months pretreatment ($T_1 - T_0$) | | 6 months of treatment ($T_2 - T_1$) | | 1 year after appliance removal ($T_3 - T_2$) | | Net change ($T_3 - T_1$) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Arch width C–C | 0.6 | 0.81 | 0.62 | 1.33 | 0.04 | 1.0 | 0.66 | 1.55 |
| Arch width D–D | 0.3 | 0.69 | 1.48 | 0.77 | 0.43 | 1.15 | 1.92*** | 0.77 |
| Arch width E–E | 0.3 | 0.50 | 1.86*** | 0.70 | 0.53 | 0.80 | 2.39*** | 1.09 |
| Arch width 6–6 | 0.3 | 0.67 | 2.28*** | 0.59 | –0.40 | 1.10 | 1.88*** | 1.13 |
| Arch perimeter | –0.2 | 0.83 | –0.57 | 1.66 | –0.86 | 2.68 | –1.43* | 1.82 |

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

by Nanda (1980) and Ishii *et al*. (1987). Two years after removal of appliances, continuous forward movement of the maxilla was observed. Animal and human studies by Cederquist (1987) and Subtelney (1980), respectively, showed that treatment effects on the maxilla remain stable one to two years after treatment. Jackson *et al*. (1979), on the other hand, found substantial reorientation of the maxillary complex following the termination of active force and recommended a period of stabilization following the application of a force to the maxillofacial complex in order to reduce the amount of post-treatment relapse. In the present study, continuous forward movement of the maxilla was found in 17 of the 20 cases with minimal retention. This may be related to increased sutural activity at the posterior part of the maxilla or the presence of an overbite after treatment that stabilizes in its forward position.

During the observation period, the mandible outgrew the maxilla and the molar relationship became more Class III in both the treated and control groups. However, the dental compensation to skeletal changes differed in the two groups. In the experimental subjects, the maxillary incisors proclined to compensate for the difference in maxillary and mandibular growth. It is cautioned that excess dental compensation with very proclined maxillary incisors could place unfavourable loads on the occlusion. In the control subjects, the mandibular incisors continued to retrocline due to a negative overjet. The lack of treatment in these patients with excess retroclination of mandibular incisors may lead to labial gingival recession.

Studies have shown that protraction along the occlusal plane produces an upward tilting of the palatal (Hata *et al*., 1987; Itoh *et al*., 1985). In the present study, this tilting of the palatal plane was found to be transient. Two years after removal of appliances, the palatal plane returned to pretreatment values. The occlusal plane, however, continued to rotate upward due to extrusion of the posterior molars and proclination of the maxillary incisors.

### *Occlusal changes*

This is the first investigation to report on dental arch dimension changes in Chinese patients. In order to demonstrate that the changes between $T_1$ and $T_2$ were due to treatment rather than growth, the patients were observed for 6 months prior to treatment.

Treatment with maxillary expansion and protraction resulted in significant increases in intercanine and intermolar widths, and arch perimeter. The magnitude of expansion is smaller than that reported by others (Spillane and McNamara, 1995; Adkins *et al*., 1990; Berlocher *et al*., 1980; Gryson, 1977; Wertz, 1970) due to the amount of expansion. In the present study, the rapid palatal expansion screw was activated for 7 days rather than the usual 10–14 days. Expansion was used primarily for 'disarticulating' the maxillary sutures rather than correction of posterior crossbites. In many instances, the correction of the maxillo-mandibular relationship into a more Class I skeletal relationship may be sufficient to eliminate the posterior crossbite.

Maxillary arch length was reduced by 0.7 mm during the treatment period. This may be related to the transition from primary to permanent teeth as reported by Moorrees (1959). Wertz (1970) reported palatal movement of maxillary incisors during expansion which may contribute to the reduction in arch length.

In the mandibular arch, a significant increase in mandibular intermolar width was found which was greater in the posterior permanent molars. This is in agreement with Sandstrom *et al*. (1988) who showed a comparable increase of 2.8 mm of arch width in the permanent molar after rapid maxillary expansion. In the present study, the increase in molar width may be related, in part, to the anteroposterior change from a Class III to a more Class I skeletal relationship. In a Class III malocclusion, the anterior portion of the maxillary arch occludes on the wider portion of the mandibular arch, producing sometimes, a posterior crossbite and/or compensating lingual inclination of the posterior maxillary and mandibular molars. Forward protraction of the maxilla produces a Class I skeletal relationship and buccal uprighting of the posterior molar, leading to an increase in posterior molar width (Wertz, 1970).

One year after removal of the appliances, the percentage relapse in maxillary intermolar width was 36 per cent in the primary first molar area (D–D), 45 per cent in the primary second molar area (E–E), and 31 per cent in the permanent first molar area (6–6). Maxillary arch perimeter was reduced by 93 per cent during this period. With a longer period of observation, a slightly higher relapse rate was reported of 40–55 per cent after 5 years out of retention by Timms (1976), and Linder-Aronson and Lindgren (1979). When arch width was retained after expansion, Spillane and McNamara (1995) reported a 90.5 per cent retention of the original expansion at the first permanent molars after the first year and 80.4 per cent after 2.4 years. The authors suggested that pretreatment arch width as well as molar inclination will affect the degree of relapse in maxillary expansion. Maxillary dental arches that were initially narrow tended to retain a greater percentage of the achieved expansion. Maxillary arches with lingually inclined molars tended to retain more expansion than those with buccally-inclined molars. In the present study, the maxilla was not over expanded since rapid palatal expansion was used primarily for 'disarticulating' the maxillary sutures to facilitate forward movement of the maxilla. Since a retention device was not used in most cases, the stability of the maxillary and mandibular arch widths was primarily the result of a new arch form, new occlusal interdigitation, and the muscular environment.

In the mandibular arch, no significant relapse in intermolar width was found during the observation period after removal of the maxillary expansion appliance. Sandstrom *et al*. (1988) suggested that the stability of mandibular arch width after maxillary expansion may be the result of an altered muscular response exerted on the dentition by the buccinator muscles, which have been carried laterally by maxillary expansion. It may also be attributed to the altered forces of occlusion. In the present study, the mandibular width may have been retained by the Class I skeletal relationship after maxillary protraction and the new muscular and occlusal environment.

As for the net change with treatment and observation, a significant maxillary intermolar width increase was observed in the second primary molar and permanent first molar areas. No net significant increase was found in maxillary intercanine arch width and arch perimeter, suggesting that if crowding is present, one cannot expect this treatment modality to gain space and alleviate maxillary crowding. In the mandibular arch, a significant decrease in lower arch perimeter was observed throughout the study period. Moorrees (1959) found that the arch perimeter decreased in both male and female children, with the greatest decrease between ages nine and 14. Sinclair and Little (1983) also showed a decrease in arch perimeter from the mixed dentition into early adulthood. The palatal depth was 0.75 mm greater at the end of the total observation period when compared with pre-treatment values ($P < 0.05$). The increase has been related to growth rather than treatment (Spillane and McNamara, 1995).

## Conclusions

The results of this study support early treatment of Class III patients with maxillary retrusion. In some ethnic groups of patients, treatment directed at the maxilla was found to be stable 2 years following removal of the appliances. Whilst a positive overjet was maintained in the majority of the treated subjects, the majority of the patients had not reached their pubertal growth spurt. The degree of relapse and ultimate success of this treatment modality require further study. The need for orthognathic intervention after the pubertal growth period remains to be determined.

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