ORIGINAL ARTICLE

Long-term effects of Class III treatment with rapid maxillary expansion and facemask therapy followed by fixed appliances

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In this cephalometric investigation, we compared the long-term effects of an initial phase of rapid maxillary expansion and facemask (RME/FM) therapy followed by comprehensive edgewise therapy with the effects of growth in untreated, matched controls. The treated sample consisted of 34 patients who underwent RME/FM treatment before the pubertal growth spurt (average age, 8 years 3 months at the beginning of treatment). At the final observation period (average age, 14 years 10 months), all patients were in decelerative growth phases as determined by the cervical vertebral maturation (CVM) method. After the first 10 months of active treatment, significant favorable changes in both the maxillary and the mandibular skeletal components were noted. The forward movement of the maxilla was 1.8 mm greater than in the controls, mandibular projection was reduced by almost 3 mm, and the relative sagittal intermaxillary discrepancy improved by 4.3 mm, as measured by the Wits appraisal. During the posttreatment period, the treated and untreated Class III subjects generally grew similarly, although the skeletal relationship of the maxilla to the mandible remained unchanged in the RME/FM group, whereas the controls had an increased skeletal discrepancy of 3.0 mm. Over the long term, there was a slightly greater increase in midfacial length (1.6 mm) in the treatment group than in the controls. Similarly, the distance from Point A to nasion perpendicular decreased by 1.2 mm in the treated group. The overall increase in mandibular length was 2.4 mm less in the RME/FM group than in the controls, and mandibular projection relative to nasion perpendicular was 3.0 mm less in the treated group. The change in the Wits appraisal was substantial between groups (6.1 mm), with an improvement in the intermaxillary relationship in the treated group (3.4 mm); the Wits appraisal worsened (−2.7 mm) in the untreated controls. No clinically significant differences were observed between the groups in the vertical dimension. Overjet increased significantly in the treated group relative to the controls (4.4 mm), whereas the molar relationship decreased significantly (–3.9 mm). It appears that the favorable skeletal change observed over the long term is due almost entirely to the orthopedic correction achieved during the RME/FM protocol. During the posttreatment period that includes the pubertal growth spurt, craniofacial growth in RME/FM patients is similar to that of untreated Class III controls. Aggressive over-correction of the Class III skeletal malocclusion, even toward a Class II occlusal relationship, appears to be advisable, with the establishment of positive overbite and overjet relationships essential to the long-term stability of the treatment outcome. (Am J Orthod Dentofacial Orthop 2003;123:306-20)

Treating a Class III malocclusion in a young patient is one of the most challenging and perplexing orthodontic endeavors, mainly because of the uncertainty of a stable outcome after the active growth period. The clinical success of early Class III treatment in most patients through growth modification, however, has resulted in the development of several strategies to treat Class III disharmony, including the chincup,[1-3] the function regulator of Fränkel,[4,5] and the orthopedic facemask.[6,7]

During the past decade, a number of studies[8-13] have described the general treatment effects of rapid

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maxillary expansion and facemask therapy (RME/FM) during a single phase of treatment, with a combination of skeletal and dentoalveolar modifications in both the maxilla and the mandible noted. This combined therapy produces more favorable outcomes in patients treated in the deciduous or early mixed dentition than in the late mixed dentition with respect to untreated Class III controls.[14-16] To date, however, few studies have evaluated the craniofacial modifications after orthopedic correction.[8,9,16-19]

Most of the few studies investigating posttreatment changes in Class III malocclusion with regard to combined RME/FM protocols have shown that, after active treatment, the pattern of Class III disharmony often is reestablished. For example, Shanker et al[17] reported no significant differences in the changes at Point A in treated Chinese children compared with untreated children with Class III malocclusions during a 12-month posttreatment period. Ngan et al[8] analyzed maxillary and mandibular modifications in a sample of Chinese subjects with Class III malocclusions treated with banded expanders and facemasks and compared them with a matched control group. The maxillae of the treated group moved forward and downward at a slightly greater rate than in the control group during the first 2 years after treatment. Maxillary growth was similar in both groups during the third and fourth years of posttreatment observation. No significant differences between treated and control groups in the sagittal and vertical position of the mandible were identified during the 4 years after therapy.

McGill and McNamara[19] evaluated posttreatment changes in patients with Class III malocclusions treated with bonded acrylic-splint expanders and facemasks during a 13.7-month postprotraction period. They observed less than average maxillary growth and greater than expected mandibular growth, which resulted in a decreased ANB angle during the posttreatment period. Furthermore, the results of the study by Macdonald et al[11] during a 2-year period after facemask therapy indicated that the maxilla continued to grow anteriorly similarly to the Class III controls, but less than the Class I controls. Postprotraction mandibular growth was equal for both groups.

Because excessive mandibular growth appears to play a major role in determining unfavorable long-term outcomes of orthopedic treatment in Class III malocclusion, more efficient methods for evaluating skeletal maturity in treated patients are necessary than simply relying on chronological age. An adequate appraisal of posttreatment changes after facemask therapy should include evaluating treated patients after the pubertal growth spurt to more effectively determine the long-term effects. In assessing a patient's skeletal maturity, several biological indicators have been advocated.[20-32] Among these, the cervical vertebral maturation (CVM) method[30-32] has proven to be an effective means to assess the adolescent growth peak in both body height and mandibular size. In addition, the required data on vertebrae are available routinely in lateral headfilms; no additional radiation exposure is necessary, as is the case with hand/wrist radiographs.

The aim of this study was to evaluate both the active treatment and the posttreatment outcomes of skeletal and dentoalveolar modifications induced by orthopedic and orthodontic treatment of Class III malocclusions. An initial phase of RME/FM followed by a second phase of preadjusted edgewise therapy was included in this study. Specific outcomes were assessed for all subjects after the pubertal growth spurt as determined by the CVM method. Craniofacial changes in treated Class III subjects were compared with the growth changes in untreated Class III controls during the treatment and post-RME/FM phases.

SUBJECTS AND METHODS

The parent sample consisted of the cephalometric records of 102 Class III subjects treated with RME/FM therapy followed by comprehensive preadjusted edgewise therapy. From the parent sample, the treatment groups were selected according to these inclusionary criteria: (1) European-American ancestry (white); (2) Class III malocclusion at the first observation (T1) characterized by an anterior crossbite or edge-to-edge incisal relationship and a Wits appraisal[33] of −1.5 mm or less; (3) no permanent teeth congenitally missing or extracted before or during treatment; (4) cephalograms of adequate quality available at T1, within 1 month after RME/FM therapy (T2), and at the long-term observation after the 2-phase treatment (T3); and (5) postpubertal skeletal maturation at T3 based on the CVM method of developmental staging (stage 4, 5, or 6).[30]

From the parent sample, 34 subjects (20 girls and 14 boys) were selected for the treated group (TG). Lateral cephalograms for each subject were analyzed at all 3 observation periods. The mean ages of the TG at T1, T2, and T3, and the mean duration of observation intervals are given in Table I.

The TG was compared with control groups (CGs) with untreated Class III malocclusions to evaluate the short-term and long-term effectiveness of RME/FM therapy followed by fixed appliances. The cephalometric comparisons between the groups aimed to evaluate skeletal and dentoalveolar modifications at the following time periods: (1) from T1 to T2, the effects of

Table I. Descriptive statistics for treated group (TG): mean starting ages and duration for each observation period

Observation period/interval	*n*	*Mean*	*SD*	*Minimum*	*Maximum*
T1	34	8 y 3 m	1 y 10 m	5 y 5 m	12 y 0 m
T2	34	9 y 0 m	1 y 10 m	6 y 5 m	13 y 4 m
T3	34	14 y 8 m	1 y 9 m	11 y 4 m	20 y 8 m
T1-T2	34	10 m	4 m	5 m	2 y 0 m
T2-T3	34	5 y 7 m	2 y 3 m	1 y 4 m	12 y 3 m
T1-T3	34	6 y 4 m	2 y 3 m	2 y 1 m	12 y 11 m

Table II. Descriptive statistics for control groups (CG): mean starting ages and duration for each observation period

Observation period/interval	*n*	*Mean*	*SD*	*Minimum*	*Maximum*
CG T1-T2					
T1	12	8 y 1 m	2 y 2 m	5 y 2 m	12 y 4 m
T2	12	9 y 3 m	2 y 3 m	5 y 10 m	13 y 11 m
T1-T2	12	1 y 2 m	4 m	8 m	1 y 11 m
CG T2-T3					
T2	15	8 y 10 m	2 y 4 m	5 y 9 m	14 y 2 m
T3	15	14 y 10 m	2 y 3 m	12 y 0 m	18 y 8 m
T2-T3	15	6 y 0 m	2 y 5 m	1 y 6 m	11 y 4 m
CG T1-T3					
T1	22	8 y 8 m	2 y 5 m	4 y 2 m	14 y 2 m
T3	22	15 y 2 m	1 y 11 m	12 y 0 m	18 y 8 m
T1-T3	22	6 y 5 m	2 y 2 m	3 y 5 m	11 y 3 m

treatment were compared with changes in a CG of 12 subjects (6 girls, 6 boys); (2) from T2 to T3, the effects of treatment and fixed appliance therapy were compared with changes in an untreated CG of 15 subjects (7 girls, 8 boys); (3) from T1 to T3, the effects of treatment and posttreatment were compared with changes in a CG of 22 subjects (13 girls, 9 boys) with untreated Class III malocclusions (Table II).

The records of the untreated Class III subjects were obtained from the Department of Orthodontics at the University of Florence, the University of Michigan Elementary and Secondary School Growth Study,[34] and 3 private orthodontic practices in Michigan. Magnification was corrected to an 8% enlargement for all radiographs in both the treated and the control samples. Matched control samples allowed for direct comparison of treatment effects on the differences between the values at different time periods without the need for annualizing the data.

Treatment protocol

The 3 components of the orthopedic facemask therapy used in this study were a maxillary expansion appliance, a facemask, and heavy elastics.[35,36] Treatment began with the placement of a bonded or banded maxillary expander to which were attached vestibular hooks extending in a superior and anterior direction. Patients were instructed to activate the expander once or twice a day until the desired transverse width was achieved.

Patients were given facemasks with pads fitted to the chin and forehead for support either during or immediately after expansion. Elastics were attached from the soldered hooks on the expander to the support bar of the facemask in a downward and forward vector, producing orthopedic forces of 300 to 500 g per side. The patients were instructed to wear the facemasks for at least 14 hours per day. All patients were treated at least to a positive dental overjet before discontinuing treatment; most patients were overcorrected toward a Class II occlusal relationship. As occurs in studies involving any removable device, compliance with the instructions of the orthodontist and staff varied among the patients.

All subjects underwent a second phase of preadjusted edgewise therapy after an interim period, during which a removable maxillary stabilization plate typically was worn or, in a few instances, immediately after the RME/FM treatment. On average, fixed appliance therapy lasted 27 months. Class III elastics (and in a

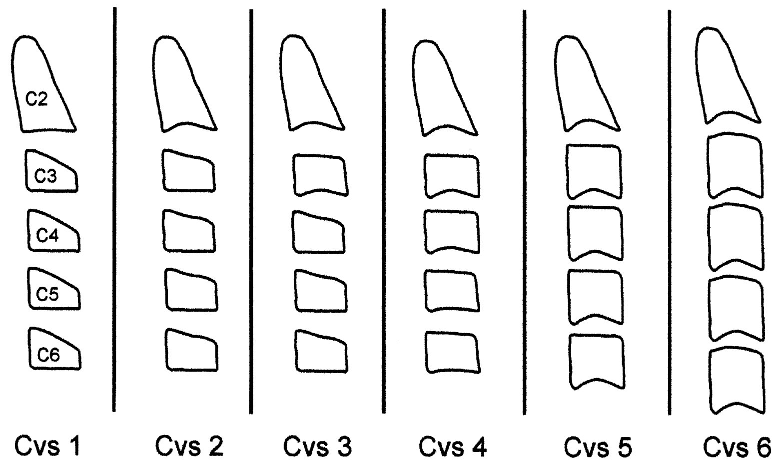

Fig 1. Developmental stages of cervical vertebrae: 1, inferior borders of bodies of all cervical vertebrae are flat, and superior borders are tapered from posterior to anterior; 2, concavity develops in inferior border of second vertebra, and anterior vertical height of bodies increases; 3, concavity develops in inferior border of third vertebra; 4, concavity develops in inferior border of fourth vertebra, with concavities in lower borders of fifth and sixth vertebrae beginning to form (bodies of all cervical vertebrae are rectangular); 5, concavities are well defined in lower borders of bodies of all 6 cervical vertebrae, with bodies nearly square and spaces between them reduced; 6, all concavities have deepened, and bodies are now higher than they are wide.

few instances Class II elastics) were used when appropriate to eliminate minor occlusal discrepancies.

Developmental staging of the cervical vertebrae is a biological indicator of skeletal maturity for both sexes independent of chronological age.[27,29-32] Therefore, we tried to evaluate the long-term effects of RME/FM followed by fixed appliance therapy for subjects identified by postpubertal skeletal maturity rather than by arbitrary chronological age.

The cervical vertebrae were visible on all lateral cephalograms. The stage of CVM was assessed for each film in a patient's series by using the method described by Franchi et al[30] (Fig 1). Staging of cervical vertebrae for each cephalogram was performed by the senior author (P.V.W.) and verified by 2 independent investigators (T.B. and L.F.) experienced in this method.

The pubertal peak in skeletal growth rate occurs between CVM stages 3 (Cvs3) and 4 (Cvs4).[30] During this interval, the greatest increments of mandibular growth rate are observed. After Cvs4, a significant deceleration in craniofacial growth occurs through stage 6 (Cvs6). With this information in mind, the long-term effects of 2-phase Class III correction were assessed only when subjects had attained a skeletal maturity staging of Cvs4, Cvs5, or Cvs6, which correlate to stages beyond the pubertal growth spurt.

Cephalometric analysis

A customized digitization regimen and analysis from Dentofacial Planner (Dentofacial Software, Toronto, Ontario, Canada) was used for all cephalograms examined in this study. The cephalometric analysis required the digitization of 77 landmarks and 4 fiducial markers. The customized cephalometric analysis containing measurements from the analyses of Jacobson,[33] McNamara,[37] Ricketts,[38] and Steiner[39] generated 36 variables and 13 angular and 23 linear measurements for each tracing.

Fiducial markers were placed in the maxilla and the mandible on the T2 tracing and then transferred to T1 and T3 tracings in each subject's cephalometric series, based on superimposition of internal maxillary or mandibular structures. The maxillae were superimposed along the palatal plane by registering on the bony internal details of the maxilla superior to the incisors and the superior and inferior surfaces of the hard palate. Fiducial markers were placed in the anterior and posterior part of the maxilla along the palatal plane. This superimposition describes the movement of the maxillary dentition relative to the maxilla.

The mandibles were superimposed posteriorly on the outline of the mandibular canal. Anteriorly, they were superimposed on the anterior contour of the chin and the bony structures of the symphysis.[37,40] A fiducial marker was placed in the center of the symphysis and another in the body of the mandible near the gonial angle. This superimposition facilitated measuring the movement of the mandibular dentition relative to the mandible.

Cranial-base superimpositions assessed the movements of the maxilla and the mandible relative to the basion-nasion line registered at the posterosuperior aspect of the pterygomaxillary fissure.[37,40] These movements were depicted by the direction and magnitude of displacement of the fiducial markers in the maxilla and the mandible relative to cranial-base structures.

Statistical analysis

To determine the effects of RME/FM therapy (T1 to T2), we assessed significant differences between craniofacial starting forms at T1 by comparing the TG and the CGs. To evaluate the effects of RME/FM therapy in Class III malocclusion, we compared the craniofacial changes from T1 to T2 in the TG with those in CG T1-T2.

The changes from T2 to T3 in both the TG and CG T2-T3 were tested to determine postprotraction effects, including a phase of fixed appliances.

A comparison of starting forms between the TG and CG T1-T3 to evaluate overall treatment and posttreatment effects was carried out at T1. To assess overall treatment effects in Class III correction, the craniofacial changes from T1 to T3 in the TG were compared with those in CG T1-T3.

Significant between-group differences were tested with the Hotelling T^2 as an initial exploratory test (MANOVA). When significance was detected, a 1-way analysis of variance (ANOVA) was applied to identify significant between-group differences for each cephalometric variable. The homogeneity between the TG and the CGs (type of malocclusion, mean ages at each observation time, sex distribution, and mean duration of observation intervals) allowed for comparisons without annualizing the data. All computations were performed with software (Statistical Package for the Social Sciences, Version 10.0, SPSS, Chicago, Ill).

Method error

McNamara et al[41] have reported the error of the method previously. Accuracy of linear measurements ranged from 0.1 to 0.3 mm, with a SD of approximately 0.8 mm. Angular measurements varied by 0.1°, with a SD of 0.4° to 0.6°.

RESULTS

Descriptive statistics for the 28 cephalometric measures at T1 for the groups in the short-term (T1 to T2) and long-term (T1 to T3) evaluations of treatment effects are shown in Tables III and IV, respectively. Multivariate analysis did not show a significant between-group difference in starting forms for the TG when compared with the CG at T1.

Descriptive statistics for the changes in the TG and the CG during the 10-month interval of RME/FM therapy (T1 to T2) are summarized in Table V. The Hotelling T^2 test indicated a significant difference ($P <$ .01) between the means for the TG when compared with the untreated Class III subjects (Fig 2).

The significant short-term outcomes of RME/FM therapy involved most of the craniofacial skeletal measures. Treatment induced a significantly greater increase in midfacial length (Co-PtA) and the sagittal position of the maxilla (SNA and PtA-NaPerp, $P <$ .001). For example, Point A moved anteriorly 1.5 mm relative to the nasion perpendicular in the RME/FM group, whereas the same landmark moved 0.3 mm posteriorly in the Class III controls.

With regard to mandibular skeletal measures, mandibular length (Co-Gn) increased 4.0 mm in the untreated Class III controls and only 1.5 mm in the patient group ($P <$ .001). There also was a significant decrease in mandibular projection (SNB and Pog-NaPerp, $P <$ .001). The skeletal changes in both the maxilla and the mandible led to a significant improvement in the intermaxillary sagittal relationship (Wits appraisal, maxillary-mandibular differential, and ANB, $P <$ .001).

In the vertical plane, the treated group exhibited significantly larger increments in the inclination of the palatal plane relative to Frankfort horizontal and in the mandibular plane angle. The occlusal plane angulation, lower anterior facial height, and the linear measurement for upper facial height did not have any changes of clinical significance during the treatment period.

Overbite and overjet increased significantly during RME/FM therapy. There also was a significant improvement in molar relationship in the TG (3.2 mm) when compared with the CG (-0.6 mm; Table V). This change in molar relationship was due mainly to a significant forward movement of the maxillary molars. The anteroposterior position of the mandibular incisors in relation to the Point A-pogonion line and the mandibular plane showed a significant decrease in the TG.

The position of the lower lip to the esthetic or E-plane indicated a significant decrease in the TG,

Table III. Comparison of starting forms for treated group (TG) and Class III control group (CG T1-T2) at T1†

	TG n = 34		*CG T1-T2 n = 12*		*TG vs CG T1-T2*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*Net difference*	P *value*
Cranial base						
Cranial flexure (°)	127.3	4.7	129.9	5.1	−2.6	.117
Maxillary skeletal						
Co-Pt A (mm)	82.8	4.2	78.5	4.5	4.3	.005**
SNA (°)	80.7	3.8	78.9	4.4	1.8	.117
Pt A to nasion perp (mm)	−1.2	2.6	−1.8	2.7	0.6	.446
Mandibular skeletal						
Co-Gn (mm)	109.1	6.6	106.1	7.0	3.0	.196
SNB (°)	80.6	3.5	79.8	4.4	0.8	.527
Pg to nasion perp (mm)	−2.0	4.8	−2.0	6.6	0.0	.973
Gonial angle (°)	129.4	5.4	132.0	4.6	−2.6	.143
Maxillary/mandibular						
Wits appraisal (mm)	−5.3	1.9	−7.4	3.9	2.1	.017*
Max/mand differential (mm)	26.3	3.9	27.6	6.2	−1.3	.402
ANB (°)	0.1	1.7	−0.9	2.1	1.0	.111
Vertical skeletal						
FH to occlusal plane (°)	9.8	3.9	10.6	2.8	−0.8	.527
FH to palatal plane (°)	0.8	3.5	0.0	2.1	0.8	.472
MPA (°)	26.1	4.1	29.3	4.5	−3.2	.028*
Nasion to ANS (mm)	47.5	3.8	47.2	4.0	0.3	.835
ANS to Me (mm)	60.3	4.1	60.4	5.4	−0.1	.931
Interdental						
Overbite (mm)	0.2	1.3	1.0	1.6	−0.8	.069
Overjet (mm)	−1.6	1.5	−1.9	2.3	0.3	.651
Interincisal angle (°)	132.2	10.1	136.5	9.0	−4.3	.198
Molar relationship (mm)	4.0	1.9	5.5	2.4	−1.5	.026*
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	1.8	2.1	1.8	1.5	0.0	.999
U1 to Frankfort (°)	111.5	6.6	109.6	4.9	1.9	.367
Mandibular dentoalveolar						
L1 to Pt A Pg (mm)	3.1	1.7	3.3	1.9	−0.2	.687
L1 to MPA (°)	90.2	7.7	84.6	6.5	5.6	.028*
Soft tissue						
UL to E-plane (mm)	−3.0	1.8	−4.7	4.1	1.7	.054
LL to E-plane (mm)	0.5	2.2	−0.2	3.6	0.7	.444
Nasolabial angle (°)	105.4	12.8	108.8	7.2	−3.4	.382
Cant of upper lip (°)	12.1	8.6	7.7	9.4	4.4	.147

*$P < .05$; **$P < .01$.
†Hotelling's $T = 2.236$, $F = 1.357$, $P = .258$; not significant.

whereas the nasolabial angle showed a significant increase in the TG when compared with the CGs.

The statistical comparisons between the TG and the CG on the changes during the postprotraction period of 5 years 7 months including a phase of fixed appliance therapy are shown in Table VI. Although significant differences for several cephalometric variables existed independently, the TG did not differ significantly from the CG as a whole (ie, the Hotelling T^2 was not significant). In other words, the overall craniofacial modifications for the TG during the postprotraction interval (T2 to T3) were similar to those in the CG for the corresponding observation interval (Fig 3).

The exploratory evaluation of the overall craniofacial modifications in the long term (6 years 4 months) showed significant changes in the TG when compared with the CG (Hotelling T^2 test was significant, $P < .001$). Descriptive statistics for changes in both groups are shown in Table VII, along with significant differences between the mean changes of

Table IV. Comparison of starting forms for treated group (TG) and Class III control group (CG T1-T3) at T1†

	TG n = 34		*CG T1-T3 n = 22*		*TG vs CG T1-T3*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*Net difference*	P *value*
Cranial base						
Cranial flexure (°)	127.3	4.7	128.4	5.8	−1.1	.445
Maxillary skeletal						
Co-Pt A (mm)	82.8	4.2	79.4	6.1	3.4	.017*
SNA (°)	80.7	3.8	78.4	4.8	2.3	.052
Pt A to nasion perp (mm)	−1.2	2.6	−2.3	3.2	1.1	.177
Mandibular skeletal						
Co-Gn (mm)	109.1	6.6	107.2	9.1	1.9	.358
SNB (°)	80.6	3.5	78.7	5.0	1.9	.091
Pg to nasion perp (mm)	−2.0	4.8	−4.3	7.8	2.3	.182
Gonial angle (°)	129.4	5.4	131.7	5.2	−2.3	.113
Maxillary/mandibular						
WITS (mm)	−5.3	1.9	−6.6	2.9	1.3	.052
Max/mand differential (mm)	26.3	3.9	27.7	4.8	−1.4	.232
ANB (°)	0.1	1.7	−0.2	2.2	0.3	.531
Vertical skeletal						
FH to occlusal plane (°)	9.8	3.9	11.4	3.9	−1.6	.133
FH to palatal plane (°)	0.9	3.5	−1.9	3.5	2.8	.005**
MPA (°)	26.1	4.1	30.3	5.6	−4.2	.002**
Nasion to ANS (mm)	47.5	3.8	49.1	3.9	−1.6	.138
ANS to Me (mm)	60.3	4.1	62.1	4.8	−1.8	.131
Interdental						
Overbite (mm)	0.2	1.3	0.2	1.8	0.0	.967
Overjet (mm)	−1.6	1.5	−1.0	2.2	−0.6	.238
Interincisal angle (°)	132.2	10.1	137.4	12.8	−5.2	.096
Molar relationship (mm)	4.0	1.9	5.5	1.6	−1.5	.003**
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	1.8	2.1	1.9	2.3	−0.1	.922
U1 to Frankfort (°)	111.5	6.6	109.4	6.3	2.1	.230
Mandibular dentoalveolar						
L1 to Pt A Pg (mm)	3.1	1.7	3.4	2.2	−0.3	.553
L1 to MPA (°)	90.2	7.7	83.0	7.1	7.2	.001***
Soft tissue						
UL to E-plane (mm)	−3.0	1.8	−4.4	2.6	1.4	.021*
LL to E-plane (mm)	0.5	2.2	0.1	3.3	0.4	.624
Nasolabial angle (°)	105.4	12.8	106.7	11.2	−1.3	.691
Cant of upper lip (°)	12.1	8.6	8.0	7.0	4.1	.066

*$P < .05$; **$P < .01$; ***$P < .001$.
†Hotelling's $T^2 = 4.118$, F = 3.971, $P = .004$; significant.

each cephalometric variable as identified by ANOVA (Fig 4).

In the long term, the skeletal changes in the TG included a slight (1.2 mm) increase in the sagittal position of the maxilla at Point A relative to nasion perpendicular in the TG compared with the CG. The mandibular effects included significantly smaller increases in both the SNB angle (-2.6°; $P < .001$) and the sagittal position of pogonion (-3.0 mm) for the TG when compared with untreated Class III subjects. The combined contributions of the maxillary and mandibular skeletal effects resulted in significant increases in both the Wits appraisal (6.1 mm) and closure of the ANB angle (2.9°). In addition, significantly smaller increments in the maxillo-mandibular differential of the TG (-4.1 mm; $P < .01$) were noted. With the exception of the inclination of the occlusal plane to Frankfort horizontal displaying a greater decrease in the TG, no significant changes in the vertical dimension were maintained in the long term.

In the overall observation period, overjet increased significantly in the TG relative to the CG (4.4 mm), whereas the molar relationship decreased significantly (-3.9 mm). In addition, the anteroposterior position of the mandibular incisor to the Point A-pogonion line showed significant decreases in the TG ($P < .001$).

Table V. Comparison of change during maxillary expansion and protraction therapy (T1-T2)†

Cephalometric measures	TG n = 34		CG T1-T2 n = 12		TG vs CG T1-T2	
	Mean	SD	Mean	SD	Net difference	P value
Cranial base						
Cranial flexure (°)	0.1	0.9	0.2	2.2	−0.1	.834
Maxillary skeletal						
Co-Pt A (mm)	2.4	1.4	1.3	1.4	1.1	.020*
SNA (°)	1.6	1.2	0.0	1.8	1.6	.001***
Pt A to nasion perp (mm)	1.5	1.0	−0.3	1.1	1.8	.000***
Mandibular skeletal						
Co-Gn (mm)	1.5	1.6	4.0	2.4	−2.5	.000***
SNB (°)	−1.1	0.9	0.7	2.0	−1.8	.000***
Pg to nasion perp (mm)	−1.7	1.6	1.1	2.5	−2.8	.000***
Gonial angle (°)	−0.5	2.4	−1.0	2.3	0.5	.509
Maxillary/mandibular						
Wits appraisal (mm)	3.6	1.8	−0.7	1.7	4.3	.000***
Max/mand differential (mm)	−1.0	1.5	2.7	1.4	−3.7	.000***
ANB (°)	2.7	1.3	−0.7	1.3	3.4	.000***
Vertical skeletal						
FH to occlusal plane (°)	0.0	2.7	0.3	2.5	−0.3	.697
FH to palatal plane (°)	1.0	1.7	−1.0	1.4	2.0	.001***
MPA (°)	1.0	1.1	0.0	1.8	1.0	.023*
Nasion to ANS (mm)	1.2	1.2	2.1	1.6	−0.9	.039*
ANS to Me (mm)	2.4	1.4	1.5	1.6	0.9	.071
Interdental						
Overbite (mm)	1.2	1.9	0.0	0.9	1.2	.049*
Overjet (mm)	4.6	1.8	−0.2	1.3	4.8	.000***
Interincisal angle (°)	0.6	6.6	0.0	5.1	0.6	.784
Molar relationship (mm)	−3.2	1.5	0.6	1.8	−3.8	.000**
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	1.2	1.5	1.0	1.6	0.2	.675
U1 horizontal (mm)	1.2	1.7	0.8	1.5	0.4	.450
U1 vertical (mm)	0.7	1.2	0.3	1.3	0.4	.290
U6 horizontal (mm)	1.6	1.1	0.7	0.7	0.9	.006**
U6 vertical (mm)	0.4	1.3	1.1	0.6	−0.7	.066
U1 to Frankfort (°)	2.6	5.2	1.2	5.5	1.4	.434
Mandibular dentoalveolar						
L1 to Pt A Pg (mm)	−2.4	1.3	0.6	1.0	−3.0	.000***
L1 horizontal (mm)	−1.1	1.2	−0.4	1.1	−0.7	.064
L1 vertical (mm)	1.9	0.9	1.4	1.3	0.5	.158
L6 horizontal (mm)	0.7	1.0	−0.1	1.7	0.8	.116
L6 vertical (mm)	0.8	1.1	1.1	1.4	−0.3	.447
L1 to MPA (°)	−4.3	3.3	−1.3	6.2	−3.0	.039*
Soft Tissue						
UL to E-plane (mm)	1.3	1.5	0.3	2.1	1.0	.071
LL to E-plane (mm)	−0.2	1.7	1.1	2.4	−1.3	.041*
Nasolabial angle (°)	2.2	10.6	−6.0	10.3	8.2	.025*
Cant of upper lip (°)	0.3	5.3	3.7	8.1	−3.4	.102

*$P < .05$; **$P < .01$; ***$P < .001$.
†Hotelling's $T^2 = 19.611$, F = 4.903, $P = .008$; significant.

DISCUSSION

This study evaluated the long-term effects of RME/FM therapy in young white subjects with Class III malocclusion. Specific features of the research included the following: (1) treated subjects received an initial phase of RME/FM therapy followed by a second phase of comprehensive fixed appliance therapy; (2) the TG was compared with untreated CGs with Class III malocclusions; (3) the TG and the CGs did not have statistically significant differences as to race, sex, mean age at T1, mean age at T2, mean observation intervals, and craniofacial characteristics at T1 (this similarity

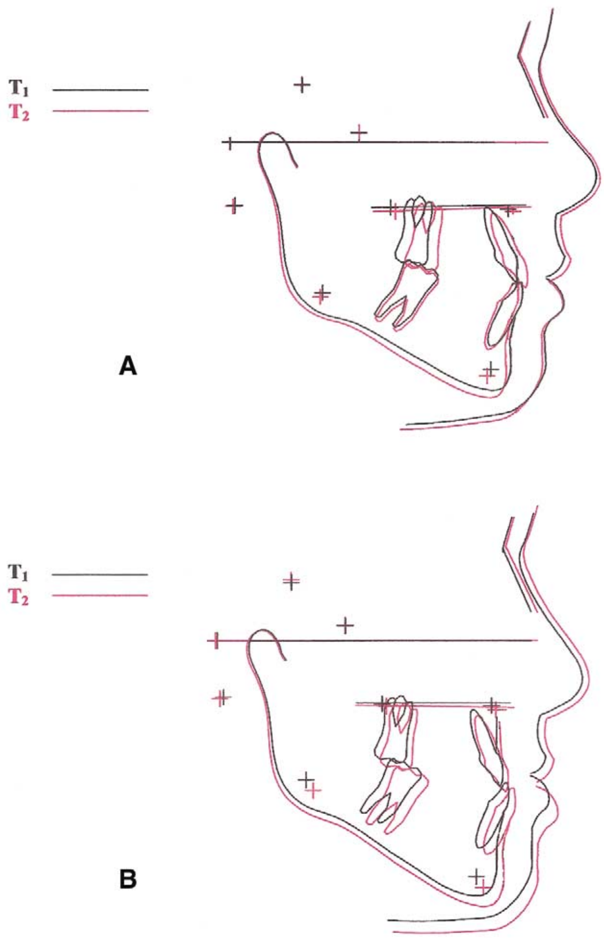

Fig 2. Craniofacial changes derived from superimpositions for T1-T2. **A,** Treated group (10 months); **B,** control group (14 months).

between groups allowed for direct comparison of treatment effects on the differences between the values at different times without annualization); and (4) each subject was evaluated at T3 after the pubertal peak of mandibular growth, as evaluated by the CVM method.[24,25]

Active treatment changes

The response of the craniofacial complex to active orthopedic treatment of Class III malocclusion with RME/FM therapy for an average of 10 months was recorded and observed. Significant favorable changes in both maxillary and mandibular skeletal components were noted. The forward movement of the maxilla measured at Point A to nasion perpendicular was 1.8 mm greater than in the untreated Class III controls, and mandibular projection also was reduced by almost 3 mm in the TG (Table V). As a result of the protraction force to the maxilla and the retraction force on the mandible, the relative sagittal intermaxillary discrepancy improved by 4.3 mm, as measured by the Wits appraisal.[42]

The treatment effects produced by the RME/FM phase of treatment generally were similar to those reported by other investigators. When compared with the annualized treatment versus Class III changes described by Macdonald et al,[11] the results of the present study show similar changes for the position of Point A to nasion perpendicular, smaller increments for the SNA angle (1.6° compared with 2.6°), and larger increments for both the Wits appraisal (4.3 mm compared with 2.7 mm) and the SNB angle (–1.8° compared with −1.2°). The changes in the TG in this study also agree with those reported in a study by Yuksel et al[13] that did not use a control group.

Although changes were observed between the TG and CGs with regard to the vertical skeletal relationships, most notably, the inclination of the palatal and mandibular planes to the Frankfort horizontal and upper facial length, they did not have clinical significance (2.0° for FH-PP, 1.0° for MPA, and −0.9 mm for N-ANS). The counterclockwise rotation of the palatal plane noted by previous authors[11,14,15,19] was not found in the sample we examined. The amount of clockwise rotation of the mandibular plane was limited when compared with that found by Macdonald et al,[11] and it agreed with the previous findings of Ngan et al,[8] Baccetti et al,[14] and McGill and McNamara.[19]

The dental relationship of the incisors and the molars improved significantly, due in part to the favorable skeletal modifications of the maxilla and the mandible in all 3 planes of space. Compared with the untreated Class III CGs, the amount of favorable increase in the overjet for treated subjects was about 5 mm, occurring in association with an improvement in the molar relationship of about 4 mm. The significant advancement of the maxillary molars (1.0 mm) and the more posterior position of the mandibular incisors (L1-A-Pog, −3.0 mm), noted after active orthopedic treatment of Class III malocclusion, also contributed to the improved dental relationships. The positive overjet correction is similar to previous studies that reported dental changes.[11-19]

The soft tissue profile reflected the favorable changes noted for the skeletal and dental components of the craniofacial complex when compared with the CG. The lower lip had a more posterior position in relation to the E-plane, and soft tissue pogonion moved backward and slightly downward. Also, the nasolabial angle assumed a more normal position after protraction therapy (103° compared with 115° in the CG). The im-

Table VI. Comparison of change during postprotraction period (T2-T3)†

	TG n = 34		CG T2-T3 n = 15		TG vs CG T2-T3	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*Net difference*	P *value*
Cranial base						
Cranial flexure (°)	0.7	1.8	−0.4	2.6	1.1	.085
Maxillary skeletal						
Co-Pt A (mm)	6.8	3.5	6.2	2.7	0.6	.553
SNA (°)	0.2	1.9	1.3	1.9	−1.1	.074
Pt A to nasion perp (mm)	0.2	1.7	0.6	1.4	−0.4	.418
Mandibular skeletal						
Co-Gn (mm)	15.4	7.4	16.0	6.2	−0.6	.775
SNB (°)	1.9	2.1	3.4	2.5	−1.5	.036*
Pg to nasion perp (mm)	5.0	4.1	6.7	4.1	−1.7	.181
Gonial angle (°)	−3.6	3.0	−1.4	3.3	−2.2	.024*
Maxillary/mandibular						
Wits appraisal (mm)	−0.2	2.8	−3.0	1.7	2.8	.001***
Max/mand differential (mm)	8.6	4.6	9.8	4.0	−1.2	.364
ANB (°)	−1.6	2.0	−2.1	1.4	0.5	.427
Vertical skeletal						
FH to occlusal plane (°)	−4.5	3.5	−0.9	3.3	−3.6	.002**
FH to palatal plane (°)	−1.9	2.6	−0.1	1.8	−1.8	.023*
MPA (°)	−1.9	2.6	−2.2	3.3	0.3	.716
Nasion to ANS (mm)	6.5	3.7	5.3	3.2	1.2	.255
ANS to Me (mm)	6.4	4.0	7.4	4.5	−1.0	.423
Interdental						
Overbite (mm)	−0.6	1.7	0.9	1.9	−1.5	.011*
Overjet (mm)	−1.4	1.7	−1.2	2.4	−0.2	.726
Interincisal angle (°)	−6.5	9.6	−2.6	12.5	−3.9	.243
Molar relationship (mm)	2.7	2.6	3.7	2.4	−1.0	.220
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	1.7	1.8	2.9	2.3	−1.2	.051
U1 horizontal (mm)	2.2	1.9	3.0	2.3	−0.8	.198
U1 vertical (mm)	1.3	1.9	2.4	1.5	−1.1	.052
U6 horizontal (mm)	2.3	2.2	2.4	2.7	−0.1	.851
U6 vertical (mm)	4.6	2.2	3.8	2.0	0.8	.250
U1 to Frankfort (°)	5.9	5.8	6.8	7.2	−0.9	.630
Mandibular dentoalveolar						
L1 to Pt A Pg (mm)	1.2	2.2	1.4	2.0	−0.2	.719
L1 horizontal (mm)	−0.3	2.0	−1.2	1.3	0.9	.131
L1 vertical (mm)	4.5	2.6	4.9	2.7	−0.4	.640
L6 horizontal (mm)	1.5	1.5	0.9	2.2	0.6	.285
L6 vertical (mm)	4.3	2.6	4.8	2.6	−0.5	.556
L1 to MPA (°)	2.5	6.7	−2.0	6.4	4.5	.033*
Soft tissue						
UL to E-plane (mm)	−3.3	2.4	−3.5	2.0	0.2	.829
LL to E-plane (mm)	−2.0	2.2	−2.5	1.9	0.5	.459
Nasolabial angle (°)	−5.1	10.6	0.0	15.7	−5.1	.188
Cant of upper lip (°)	−0.4	6.8	−2.7	10.4	2.3	.360

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
†Hotelling's $T^2 = 6.307$, F = 2.102, $P = .084$; not significant.

provements in facial convexity agree with the data reported by both Macdonald et al[11] and McGill and McNamara.[19]

The period of active RME/FM treatment leads to significant improvements in Class III subjects. The treatment protocol is an effective orthopedic means to correct Class III occlusal and skeletal disharmony in the short term.

Postprotraction changes

When analyzing the posttreatment effects, the term *relapse* must be defined to provide adequate interpre-

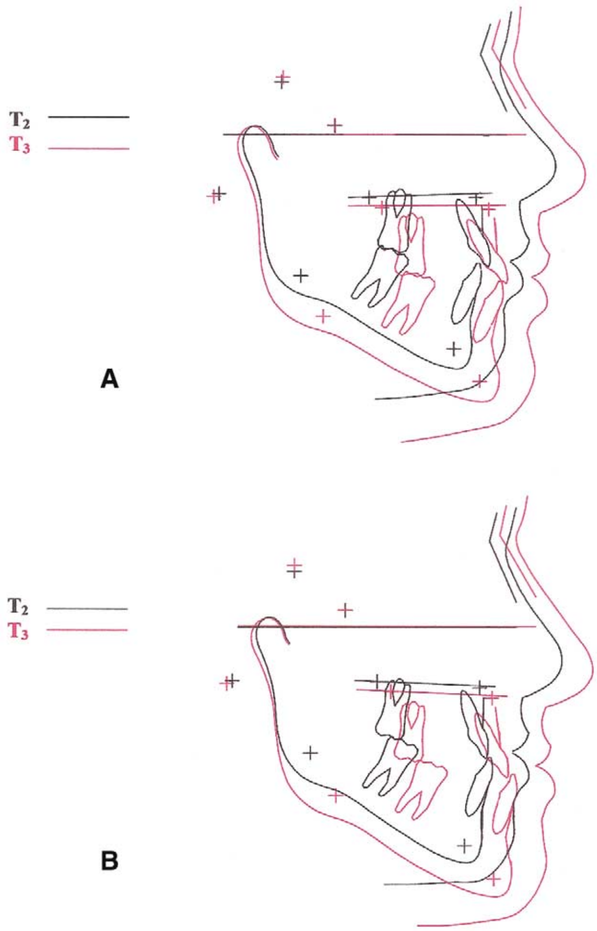

Fig 3. Craniofacial changes derived from superimpositions for T2-T3. **A,** Treated group (5 years 7 months); **B,** control group (6 years).

tation of the cephalometric data. The inclusion of untreated Class III controls in a longitudinal study allows for an appropriate definition of *relapse: unfavorable craniofacial modifications that occur during the posttreatment period in a sample of treated subjects when compared with untreated subjects with the same type of malocclusion*.[16] To date, no previous studies have dealt with the postpubertal long-term observation of treatment outcomes for RME/FM therapy as assessed in white subjects of both sexes. Furthermore, the few investigations that analyzed posttreatment changes for RME/FM therapy considered only a short time interval after protraction[9,11,16,18,19] or pertained to an Asian sample.[8,17]

Most clinical studies evaluating postprotraction growth characteristics indicate similar maxillary and mandibular rates of change in treated and untreated Class III subjects.[8,9,11,16-18] In accordance with the definition of *relapse* used here, the posttreatment growth characteristics observed over approximately 5.5 years in this study (including a phase of fixed appliance therapy) did not show any evidence of significant relapse in the examined cephalometric measures. On the contrary, significantly smaller increases for the SNB angle and the Wits appraisal were observed during the postprotraction period for the TG. The skeletal relationship of the maxilla to the mandible (eg, Wits appraisal) remained unchanged during this period, whereas the Class III controls had an increased skeletal discrepancy of 3.0 mm. The maintenance of the sagittal intermaxillary relationship in the TG proved to be the greatest contribution to the favorable final outcome of comprehensive Class III correction.

Overall treatment and posttreatment changes

Over 6 years 4 months (T1-T3), RME/FM therapy appears to induce significant favorable changes with respect to Class III growth in untreated subjects. The major skeletal components of long-term treatment outcome are related to significant modifications in the position of the mandible and the maxilla. The change in the position of the mandible, as measured by both the SNB angle and the distance from pogonion to nasion perpendicular, accounted for half of the favorable increase in the Wits appraisal (approximately 6 mm). The remainder of the change is accounted for by a favorable change in the forward movement of the maxilla (1.2 mm) and a leveling of the occlusal plane ($-2.4°$). The net improvement in the long-term skeletal relationship also is indicated by an increase in the ANB angle of about 3° when compared with the controls.

The residual sagittal occlusal correction consisted of 4.5 and 3.9 mm improvements for the overjet and molar relationships, respectively, in the TG when compared with the CG. A more posterior position of the mandibular incisors to the Point A-pogonion line also was recorded in the TG as a contributor to the final overjet correction during the overall observation period.

Orthopedic and orthodontic intervention in Class III patients by means of a 2-phase therapeutic approach consisting of RME/FM therapy followed by fixed appliance therapy leads to significant skeletal and dentoalveolar improvements in the long term. The correction is due mainly to favorable changes in the mandibular component of the skeletal discrepancy during RME/FM therapy, while improvements in maxillary position assume a lesser role. Although the reduction in mandibular length (about -2.5 mm) and the closing of the mandibular plane angle ($-1.2°$) along with increases in the midfacial length (1.6 mm) and

Table VII. Comparison of change during overall observation period (T1-T3)†

Cephalometric measures	TG n = 34 Mean	TG n = 34 SD	CG T1-T3 n = 22 Mean	CG T1-T3 n = 22 SD	TG vs CG T1-T3 Net difference	TG vs CG T1-T3 P value
Cranial base						
Cranial flexure (°)	0.8	2.1	−0.6	3.0	1.4	.037*
Maxillary skeletal						
Co-Pt A (mm)	9.2	3.9	7.6	2.9	1.6	.105
SNA (°)	1.8	2.0	1.5	2.7	0.3	.628
Pt A to Nasion perp (mm)	1.7	1.8	0.5	2.1	1.2	.028*
Mandibular skeletal						
Co-Gn (mm)	16.9	7.5	19.3	6.8	−2.4	.222
SNB (°)	0.7	2.0	3.3	2.9	−2.6	.000***
Pg to Nasion perp (mm)	3.3	4.0	6.3	4.5	−3.0	.012*
Gonial angle (°)	−4.1	3.7	−2.4	3.3	−1.7	.094
Maxillary/mandibular						
Wits appraisal (mm)	3.4	2.3	−2.7	2.3	6.1	.000***
Max/Mand differential (mm)	7.6	4.5	11.7	4.7	−4.1	.002**
ANB (°)	1.0	1.5	−1.9	1.9	2.9	.000***
Vertical skeletal						
FH to occlusal plane (°)	−4.4	3.5	−2.0	3.1	−2.4	.011*
FH to palatal plane (°)	−0.9	1.9	−0.6	2.3	−0.3	.612
MPA (°)	−0.9	2.7	−2.1	3.2	1.2	.146
Nasion to ANS (mm)	7.7	3.6	6.7	4.0	1.0	.339
ANS to Me (mm)	8.9	3.8	9.8	4.9	−0.9	.449
Interdental						
Overbite (mm)	0.7	1.4	0.7	2.0	0.0	.981
Overjet (mm)	3.2	2.3	−1.2	2.7	4.4	.000***
Interincisal angle (°)	−5.8	10.2	−2.8	12.9	−3.0	.345
Molar relationship (mm)	−0.5	2.2	3.4	2.9	−3.9	.000***
Maxillary dentoalveolar						
U1 to Pt A vert (mm)	2.9	2.1	2.9	2.1	0.0	.992
U1 horizontal (mm)	3.4	2.3	3.6	2.6	−0.2	.706
U1 vertical (mm)	2.1	1.9	2.7	2.2	−0.6	.250
U6 horizontal (mm)	3.9	2.0	3.8	3.0	0.1	.920
U6 vertical (mm)	5.0	2.4	4.5	1.9	0.5	.439
U1 to Frankfort (°)	8.4	7.2	6.4	6.6	2.0	.295
Mandibular dentoalveolar						
L1 to Pt A Pg (mm)	−1.2	2.1	1.6	2.1	−2.8	.000***
L1 horizontal (mm)	−1.4	1.9	−1.1	1.6	−0.3	.545
L1 vertical (mm)	6.5	2.5	6.7	3.3	−0.2	.757
L6 horizontal (mm)	2.2	1.4	1.5	2.4	0.7	.168
L6 vertical (mm)	5.1	2.3	5.9	2.6	−0.8	.205
L1 to MPA (°)	−1.8	6.6	−1.6	7.0	−0.2	.899
Soft tissue						
UL to E-plane (mm)	−2.0	2.2	−3.2	2.4	1.2	.054
LL to E-plane (mm)	−2.2	1.9	−2.2	2.5	0.0	.947
Nasolabial angle (°)	−2.9	10.6	−2.3	13.9	−0.6	.868
Cant of upper lip (°)	−0.2	8.1	1.9	9.2	−2.1	.371

*$P < .05$; **$P < .01$; ***$P < .001$.
†Hotelling's $T^2 = 11.606$, F = 6.125, $P = .000$; significant.

upper face height (1.0 mm) were not significant independently during the long term, the cumulative effects of these modifications cannot be overlooked as contributing factors to the overall maintenance of positive dental relationships. The actual amount of improvement during the overall observation period in the TG matched the average amount of correction needed for the molar relationship. The improvement needed for the overjet at T1 (approximately 4 mm for both measurements) also resulted. Class III therapy provided an effective attainment of normal dental relationships in the long term after the pubertal growth spurt.

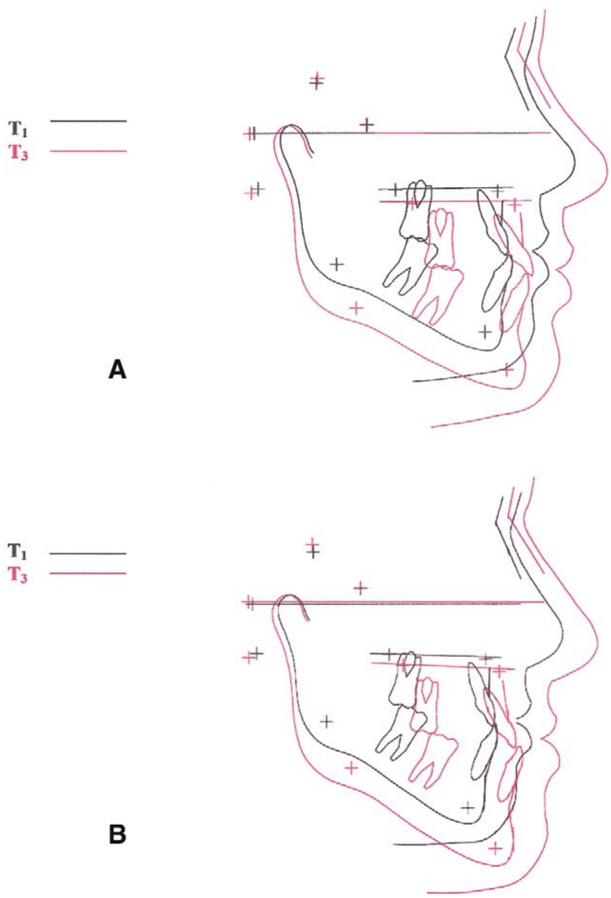

Fig 4. Craniofacial changes derived from superimpositions for T1-T3. **A,** Treated group (6 years 4 months); **B,** control group (6 years 5 months).

The data indicate that establishing a positive occlusal relationship during RME/FM therapy helps maintain a normal dental relationship 5.5 years after this initial phase of therapy. In fact, 26 of the 34 (76%) treated subjects maintained a positive overjet relationship after attaining postpubertal skeletal maturation, and 3 patients (9%) maintained edge-to-edge incisal relationships. Ngan et al[8] reported similar outcomes with respect to overjet in 75% of the 20 Chinese subjects followed for 4 years posttreatment with RME/FM therapy.[2]

Comparison with untreated Class III controls in the posttreatment period affirmed that Class III growth characteristics generally return after RME/FM. Therefore, evaluation of overall treatment and posttreatment changes clearly implies that the amount of beneficial changes to the skeletal relationship can be obtained only during active therapy with RME/FM, and the later phase of fixed appliances can maintain the dental components. About 93% of these skeletal changes that occur before the pubertal growth spurt withstand subsequent growth throughout skeletal maturity.

The findings of this study also support the recommendations of Yoshida et al[43] and McNamara and Brudon[36] that overcorrecting the Class III skeletal discrepancy with orthopedic appliances is advisable. Overall, the correction of Class III malocclusions by means of RME/FM therapy produced clinically acceptable results in 3 of 4 patients from an occlusal standpoint and soft tissue profile perspective. Patients corrected to overjets of 4.5 mm or greater during RME/FM therapy, however, all sustained favorable outcomes over the long term. The 8 subjects who could not maintain a positive overjet throughout the pubertal growth spurt, on average, had attained smaller increments of overjet change than the other patients.

Thus, it appears that the final favorable correction of the Class III skeletal disharmony is due almost entirely to the amount of orthopedic correction achieved during the first phase of treatment with the RME/FM protocol. The data indicate that, during the posttreatment period that includes the pubertal growth spurt, there is a re-establishment of growth changes in RME/FM patients that generally are similar to those in untreated Class III controls (although the sagittal relationship does not tend to worsen as occurs in the untreated sample). Therefore, aggressive overcorrection of the Class III skeletal malocclusion to an overjet of perhaps as much as 5 to 8 mm and a Class II molar relationship appears to be advisable.

CONCLUSIONS

This study compared the treatment effects produced by an initial phase of RME/FM therapy followed later by a second phase of comprehensive fixed appliance therapy with untreated Class III controls. The TG and the CGs had no statistically significant differences as to race, sex, mean age at T1, mean age at T2, mean observation intervals, and craniofacial characteristics at T1. This similarity between groups allowed for direct comparison of treatment effects on the differences between the values at different times without annualizing the data. Each subject was evaluated in the long term after the pubertal peak of mandibular growth by the CVM method.

This study showed the following treatment and posttreatment craniofacial modifications throughout an observation interval of 6 years 4 months:

1. Treatment with RME/FM therapy for 10 months (T1 to T2) induced a significant response of the craniofacial skeleton in terms of forward movement of the

maxilla and downward and backward movement of the mandible.

2. Although Class III craniofacial characteristics were re-established in the posttreatment period, postprotraction (T2 to T3) growth did not display significant relapse in any cephalometric measure.
3. Overall, RME/FM therapy was shown to be an effective treatment for correcting skeletal Class III malocclusion in the long term (T1 to T3). The favorable skeletal effects induced before the pubertal growth spurt with orthopedic facemask therapy led to the establishment of a positive overbite and overjet relationship. The occlusal relationships generally withstood subsequent Class III craniofacial growth throughout attainment of skeletal maturity as assessed by the CVM method.

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