Postpubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances

Lorenzo Franchi, DDS, PhD,[a] Tiziano Baccetti, DDS, PhD,[b] and James A. McNamara, Jr, DDS, PhD[c]
Florence, Italy, and Ann Arbor, Mich

In this cephalometric investigation, we evaluated the correction of Class III malocclusion in subjects who had attained postpubertal skeletal maturity and considered whether treatment timing influenced favorable craniofacial modifications. All subjects (n = 50) were treated with an initial phase of rapid maxillary expansion and protraction facemask therapy, followed by a second phase of preadjusted edgewise therapy. The treated sample was divided into an early treated group (early mixed or late deciduous dentition, 33 subjects) and a late treated group (late mixed dentition, 17 subjects). Mean treatment duration times were 7 years 2 months for the early treatment group and 4 years 5 months for the late treatment group. The treated patients were matched to untreated controls (early control group, 14 subjects; late control group, 10 subjects) on the basis of race, sex, mean age at first observation, mean age at second observation, mean observation intervals, and type of malocclusion. A modified version of Johnston's pitchfork analysis, with additional angular and linear measures for mandibular size and shape and for vertical skeletal relationships, was performed. Analysis of variance was used to evaluate the difference in means for each cephalometric variable in the treated groups compared with the corresponding control groups. The findings showed that orthopedic treatment of Class III malocclusion was more effective when it was initiated at an early developmental phase of the dentition (early mixed or late deciduous) rather than during later stages with respect to untreated Class III control groups. Patients treated with rapid maxillary expansion and facemask therapy in the late mixed dentition, however, still benefited from the treatment, but to a lesser degree. Early treatment produced significant favorable postpubertal modifications in both maxillary and mandibular structures, whereas late treatment induced only a significant restriction of mandibular growth. Significant changes in mandibular size were associated with significant changes in mandibular shape only in early treated subjects. The main contribution to overall occlusal correction was related to skeletal modifications rather than dental changes in both early and late treated groups. (Am J Orthod Dentofacial Orthop 2004;126:555-68)

The use of a rapid maxillary expander with a protraction facemask (RME/FM) for treating Class III malocclusion has gained popularity among clinicians during the last 20 years. A number of studies over the past decade have described the general treatment effects of RME/FM therapy as a combination of effective skeletal and dental modifications in both the maxilla and the mandible.[1-8]

In the assessment of overall efficiency for RME/FM, an important variable is the issue of optimal timing to start orthopedic treatment in the growing patient. A sound scientific approach to this topic, even with regard to retrospective data, would require at least 3 major methodologic aspects to evaluate treatment outcomes: postpubertal assessment of treatment results, analysis of groups of subjects treated at different developmental phases, and use of control groups of untreated subjects with Class III malocclusions. In the absence of scientific evidence that fulfills these requirements, recommendations on the optimal time to treat a child with RME/FM have been based primarily on clinical impressions. Generally, the suggested time of treatment is between the ages of 6 and 8 years after the maxillary permanent first molars and incisors have erupted.[9-10]

[a]Research associate, Department of Orthodontics, University of Florence, Florence, Italy; Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor.
[b]Assistant professor, Department of Orthodontics, University of Florence, Florence, Italy; Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor.
[c]Thomas M. and Doris Graber Endowed Professor of Dentistry, Department of Orthodontics and Pediatric Dentistry, School of Dentistry; Professor of Cell and Developmental Biology, School of Medicine; Research scientist, Center for Human Growth and Development, University of Michigan, Ann Arbor; private practice, Ann Arbor, Mich.
Reprint requests to: Dr Lorenzo Franchi, Dipartimento di Odontostomatologia, Università degli Studi di Firenze, Via del Ponte di Mezzo, 46-48, 50127, Firenze, Italy, e-mail, .condax@tin.it.
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Treating at such an early age is reported to remove factors that inhibit growth and development, such as an anterior crossbite that limits normal alveolar bone growth of the maxilla.[11]

To establish a treatment protocol based on scientific data rather than anecdotal reports, investigators have conducted cephalometric studies of children treated with RME/FM to determine whether biologic indicators such as chronological age,[12-15] stage of dental development,[16,17] or skeletal age[18] impact the orthopedic effects of treatment and future growth. Based on chronological age, early treatment intervention is recommended for the orthopedic correction of Class III malocclusions.[14,15] Kapust et al[14] divided a sample of 63 non-Asian subjects into 3 treatment groups based on age: 4-7 years old, 7-10 years old, and 10-14 years old. The youngest group had the greatest treatment changes. Saadia et al[15] found significant changes to be greater for the children treated between 3 and 9 years of age when compared with the 9-12 year age group. Although these 2 studies show beneficial treatment changes for all age groups, the younger patients had the most effective response to orthopedic correction. Contrary to these reports, however, other investigators have found similar effects of RME/FM therapy for children independent of chronologic age.[12,13]

When the phases of the dentition were used as a discriminant factor for assessing optimal treatment timing in different groups of subjects treated with RME/FM, more effective craniofacial changes were described in patients treated in the early mixed dentition than the late mixed dentition.[16] A similar result was reported when the treated groups were reanalyzed a year after orthopedic treatment.[17] In a recent study that used skeletal age according to the hand-and-wrist method, no difference was found in the effects of maxillary advancement after maxillary protraction between a prepubertal growth-peak group and a pubertal growth-peak group, whereas the study reported less effective results in the postpubertal growth-peak group.[18]

Only a few studies dealing with treatment timing in Class III malocclusion compared treatment outcomes to growth changes in untreated Class III subjects, and no study evaluated a long-term observation after protraction therapy.[13,16,17] Ideally, the long-term evaluation should be performed after most of the active growth.

The aim of this investigation was to define optimal treatment timing for RME/FM therapy of Class III malocclusion in a study on the effects of this treatment protocol that includes a phase with preadjusted edgewise therapy. Peculiar features of this study are the use of control groups of subjects with untreated Class III malocclusions, the cervical vertebral maturation (CVM) method to determine the end of active skeletal growth at the final observation, and a cephalometric analysis based on superimpositions on stable craniofacial structures (Johnston's pitchfork analysis) that enables a separate appraisal of dentoalveolar and skeletal components of overall postpubertal treatment outcomes.

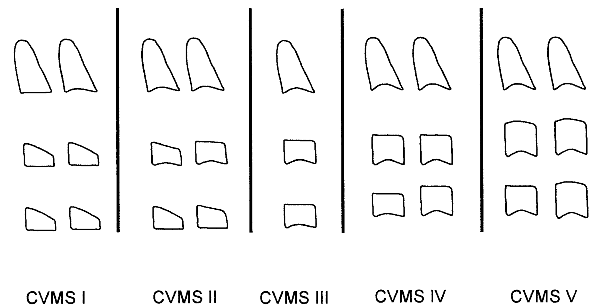

Fig 1. Stages in cervical vertebral maturation (CVMS).

MATERIAL AND METHODS

Sample selection

The parent sample consisted of cephalometric records of 102 Class III subjects treated with RME/FM followed by comprehensive preadjusted edgewise therapy collected from 3 private orthodontic practices experienced in this treatment modality. The records of additional patients were obtained from the University of Michigan Graduate Orthodontic Clinic.

From the parent sample, the treatment groups were selected by satisfying the following inclusion 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[19] of -1.5 mm or less, (3) 2-phase treatment consisting of RME/FM therapy followed by comprehensive preadjusted edgewise appliance therapy, (4) no permanent teeth congenitally missing or extracted before or during treatment, (5) cephalograms of adequate quality available at T1 and at the final observation (T2) after the 2-phase treatment, and (6) postpubertal skeletal maturation at T2 based on the CVM method of developmental staging[20] (CVMS IV or V, Fig 1).

The final sample consisted of 50 subjects (30 girls, 20 boys). Lateral cephalograms were analyzed at T1 (the start of RME/FM therapy) and at T2 (the observation after RME/FM and fixed appliance therapy, when the developmental stage of CVM was postpubertal, CVMS IV or V).

Table I. Descriptive statistics for ETG and LTG: mean starting ages and duration for each observation period

Observation period/interval	Treated groups (total n = 50)				
	n	*Mean*	*SD*	*Minimum*	*Maximum*
ETG					
T1	33	7y 5m	1y 3m	4y 7m	9y 9m
T2	33	14y 6m	1y 9m	13y 0m	17y 7m
T1–T2	33	7y 2m	2y 1m	2y 8m	11y 10m
LTG					
T1	17	10y 9m	1y 4m	8y 5m	13y 1m
T2	17	15y 2m	1y 6m	12y 10m	18y 3m
T1–T2	17	4y 5m	1y 7m	3y 1m	6y 10m

Table II. Descriptive statistics for ECG and LCG: mean starting ages and duration for each observation period

Observation period/interval	Control groups (total n = 24)				
	n	*Mean*	*SD*	*Minimum*	*Maximum*
ECG					
T1	14	7y 0m	1y 5m	4y 2m	9y 6m
T2	14	15y 0m	2y 3m	12y 0m	18y 8m
T1–T2	14	8y 0m	2y 8m	4y 8m	12y 0m
LCG					
T1	10	10y 8m	1y 10m	8y 2m	14y 2m
T2	10	16y 0m	1y 7m	13y 9m	18y 8m
T1–T2	10	5y 4m	1y 3m	3y 5m	7y 0m

To distinguish the treatment changes from normal growth changes, untreated Class III control groups matched for race, sex, mean age at observation periods, mean duration of observation intervals, CVM, and craniofacial characteristics at T1 were used as a baseline to evaluate treatment effects. Records for untreated Class III subjects were obtained from the orthodontic department at the University of Florence and the University of Michigan and 3 private orthodontic practices in Michigan. These Class III patients declined orthopedic therapy at T1 and underwent a second visit later. Magnification was corrected to an 8% enlargement for all radiographs in the control samples to match the enlargement factor of the cephalograms in the treated group.

The treated sample was divided into 2 groups according to the stage of dentitional development at T1: early treated group (ETG) if they were either in the deciduous or early mixed dentition (erupting permanent incisors and first permanent molars), and late treated group (LTG) if they were in the late mixed dentition (erupting permanent canines and premolars). The ETG comprised 33 subjects (20 girls, 13 boys); the LTG comprised 17 subjects (10 girls, 7 boys). The mean ages of both treated groups at T1 and T2 and the mean durations of the observation intervals are given in Table I.

Both the ETG and LTG were compared with 2 groups of untreated Class III subjects (early control group, ECG, 14 subjects; late control group, LCG, 10 subjects) to evaluate the effect of treatment timing on the postpubertal outcome of RME/FM therapy followed by fixed appliances. The mean age of both control groups at T1 and T2 and the mean duration of the observation intervals are shown in Table II.

Treatment protocol

The 3 components of the orthopedic facemask therapy used in this study were a maxillary expansion appliance, a facemask, and heavy elastics.[10,21] Treatment began with the placement of a bonded or banded maxillary expander to which were attached maxillary vestibular hooks extending anteriorly. Patients were instructed to activate the expander once or twice per day until the desired transverse width was achieved.

During or immediately after expansion, the patients were given facemasks with pads fitted to the chin and forehead for support. 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 force levels of 300-500 g per side. Patients were instructed to wear the facemask for at least 14 hours per day. All patients were treated to a positive dental overjet before discontinuing treatment. As usual in studies involving removable devices, patients' compliance with the instructions of the orthodontist and staff varied.

All subjects underwent a second phase of preadjusted edgewise therapy immediately after the RME/FM treatment or after an interim period during which a removable maxillary stabilization plate typically was worn. On average, fixed appliance therapy lasted 27 months and did not involve extraction of permanent teeth.

Cephalometric analysis

Serial cephalograms at T1 and T2 for each subject in all groups were traced at a single sitting by the primary investigator (L.F.) and verified for landmark identification by a second investigator (J.McN.). Fiducial markers were placed in the maxilla and the mandible on the T2 tracing and then transferred to the T1 tracing in each subject's cephalometric series. Regional superimpositions were done by hand, with the aid of these registration markers.

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 (PTM_{SP}).[22,23] These movements are depicted by the direction and magnitude of displacement of the fiducial markers in the maxilla and mandible (Fig 2, *A*). The maxillae were superimposed along the palatal plane by registering on the bony internal details superior to the incisors and the superior and inferior surfaces of the hard palate (Fig 2, *B*). 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.[22,23] 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 measured the movement of the mandibular dentition relative to the mandible (Fig 2, *C*).

A modified version of Johnston's pitchfork analysis[24] generated 13 linear variables (Table III). These variables describe the skeletal and dental contributions to Class III correction for treatment intervals as measured from the mean functional occlusal plane (MFOP). The MFOP was constructed on the T1 tracing by superimposing the T1 and T2 tracings on the maxilla and then bisecting the 2 functional occlusal planes (Fig 2, *B*).[25] The MFOP then was transferred to each tracing in the patient series by means of maxillary superimposition with the T1 film.

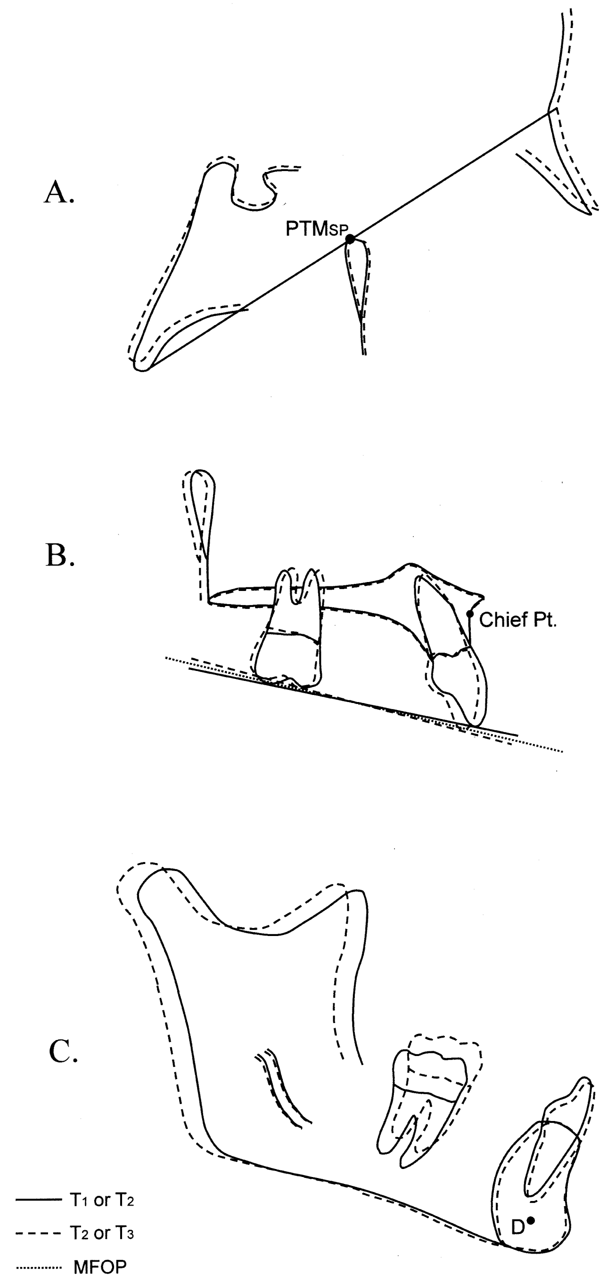

Fig 2. Regional superimpositions on stable landmarks or fiducial markers. **A**, Cranial base; **B**, maxilla, depicting construction of mean functional occlusal plane (MFOP); **C**, mandible.

Chief point (CP) (Fig 2, *B*) was identified as Point A on each T2 tracing and then transferred to the T1 tracings in the patient series by maxillary superimposition. With tracings from 2 observation periods superimposed on the cranial base, the maxillary skeletal change was measured by the displacement of CP. This

Table III. Measures for pitchfork analysis

Craniofacial relationships	*Measures*	*Abbreviation*
Skeletal changes	Maxillary skeletal change	Max (Max to C.B.)
	Mandibular skeletal change	Mand (Mand to C.B)
	Apical base change	ABCH
Maxillary dental changes	Maxillary first molar crown movement	U6 to Max.
	Maxillary first molar bodily movement	U6 (bodily)
	Maxillary first molar tipping movement	U6 (tipping)
	Maxillary central incisor movement	U1 to Max.
Mandibular dental changes	Mandibular first molar crown movement	L6 to Mand.
	Mandibular first molar bodily movement	L6 (bodily)
	Mandibular first molar tipping movement	L6 (tipping)
	Mandibular central incisor movement	L1 to Mand.
Interdental changes	Total molar correction	6/6
	Overjet correction	1/1

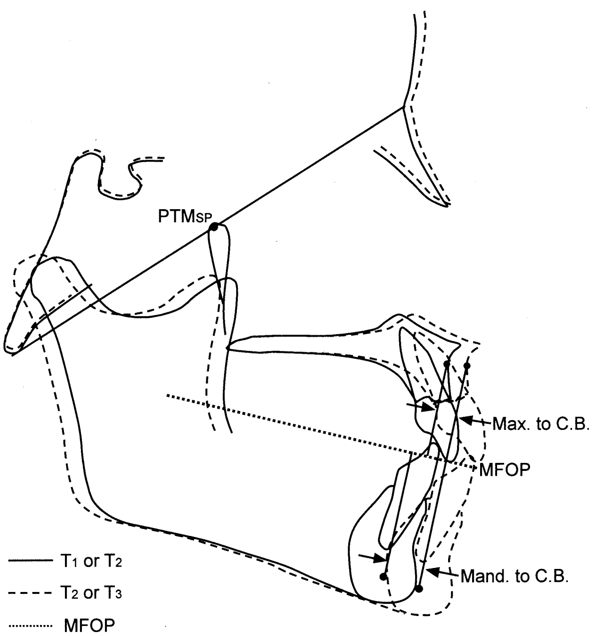

Fig 3. Displacement of maxilla (Max. to C.B.) and mandible (Mand. to C.B.) measured relative to cranial base.

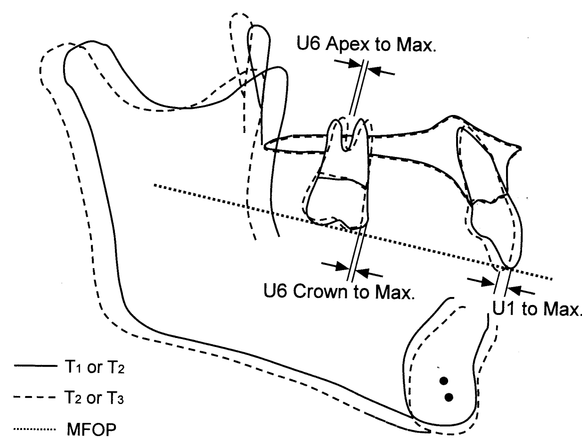

Fig 4. Maxillary regional superimposition. Movement of maxillary first molars (U6 crown to max. and U6 apex to max.) and incisors (U1 to max.) are measured relative to maxillary basal bone.

displacement of CP was measured along the MFOP by lines constructed perpendicular to it through CP (Fig 3). D-point was a marker placed in the center of the bony symphysis of the mandible on the T2 tracing and transferred to the T1 tracing in each patient series. A vertical line was constructed perpendicular to MFOP through D-point for each tracing. With tracings from T1 and T2 superimposed on the cranial base, the mandibular skeletal change was measured by the displacement of the 2 lines along the MFOP (Fig 3).

Maxillary regional superimpositions between the 2 observation periods were used to measure the maxillary dentoalveolar changes relative to maxillary basal bone. Changes were measured along the MFOP by the separation of perpendicular lines drawn through the mesial contact points and apices of the maxillary first molars, and the incisal edges of the maxillary incisor (Fig 4). Crown movement of the maxillary first molar (U6 crown to max.) was measured as the difference between the mesial contact points of the first molars. Bodily movement of the maxillary first molar (U6 apex to max.) was measured as the difference between the apices of the first molars. The amount of maxillary first molar crown movement due to tipping was calculated by subtracting the amount of bodily movement of the molar from the total crown movement. Maxillary incisor movement (U1 to max.) was measured as the distance between the incisal edges of the maxillary incisors.

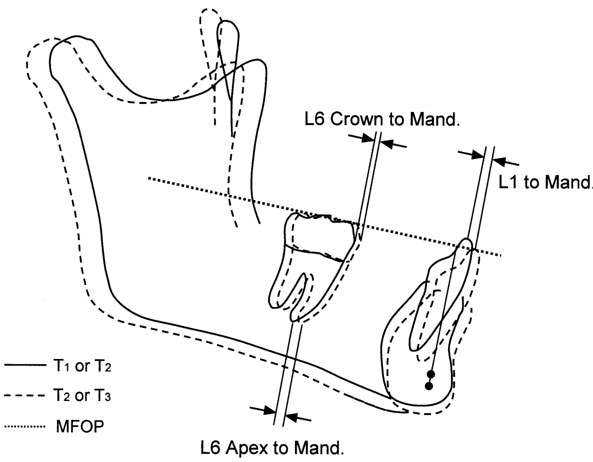

Fig 5. Mandibular regional superimposition. Movement of mandibular first molars (L6 crown to mand. and L6 apex to mand.) and incisors (L1 to mand.) measured relative to mandibular basal bone.

Mandibular dentoalveolar changes were measured from 2 tracings in a patient's series superimposed on the mandible along the MFOP registering at a line constructed perpendicular to the MFOP through D-point (Fig 5) Vertical lines were constructed perpendicular to the MFOP through the mesial contact and apex of the mandibular first molar and the incisal edge of the mandibular incisor for each tracing. The differences between these vertical lines when tracings from 2 observation periods were superimposed measured the crown movement (L6 crown to mand.) and the bodily movement (L6 apex to mand.) of the mandibular first molars. Mandibular incisor movement was measured as the difference between the incisal edges along the MFOP.

The total molar correction (6/6) was measured as the distance between the vertical lines constructed perpendicular to the MFOP through the mesial contact points of the mandibular first molar when 2 tracings were superimposed along the MFOP with registration at the mesial contact points of the maxillary first molars (Fig 6, *A*). The total overjet correction (1/1) was measured as the difference between the incisal edges of the mandibular incisors with the tracings from 2 observation periods superimposed along the MFOP with registration at the incisal edges of the maxillary incisors (Fig 6, *B*).

All measurements for the pitchfork analysis were rounded to the nearest 0.1 mm with the digitizing program Dentofacial Planner (Dentofacial Software, Toronto, Ontario, Canada). A measurement was given a positive sign when the skeletal or dental change contributed to Class III correction. A negative sign was given if the change between the 2 observation periods made the Class III

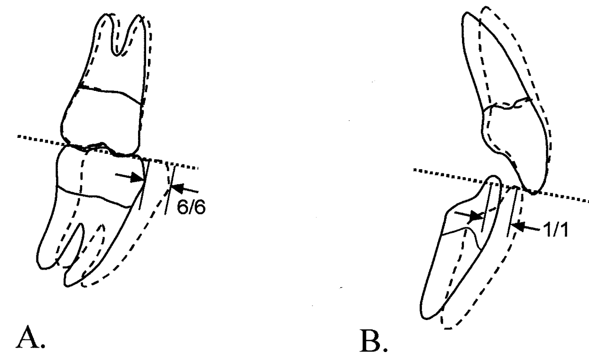

Fig 6. Dental superimposition used to measure: **A**, total molar correction (6/6), and **B**, overjet correction (1/1) at level of MFOP.

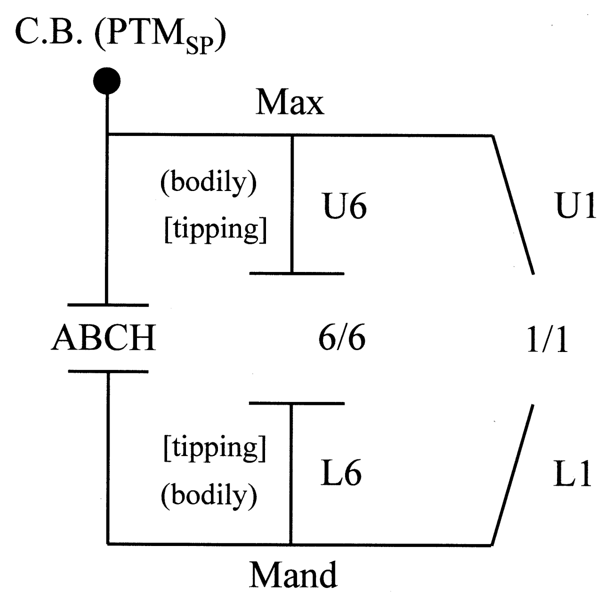

Fig 7. Pitchfork diagram of skeletal and dental changes measured along MFOP. ABCH = max + mand; U6 or L6 = tipping + bodily movements; 6/6 = ABCH + U6 + L6; 1/1 = ABCH + U1 + L1.

relationship worse. Skeletal and dental changes are depicted with a pitchfork diagram.[24,25] All alterations in apical base change, molar, and overjet should equal the sum of their individual components (Fig 7).

In addition to the measures of the pitchfork analysis, 2 cephalometric parameters for describing dimensional and morphologic characteristics of the mandible (total mandibular length, Co-Gn, and the gonial angle, Ar-Goi-Gn) and 2 angular measurements to evaluate vertical skeletal relationships (FH to mandibular plane and FH to palatal plane) were calculated on the lateral cephalograms of all subjects in the early and late groups of the treated and untreated samples.

The analysis of cervical vertebral maturation was performed with cephalometric software (Dr. Ceph, version 8.2, FYI Technologies, Duluth, Ga). Staging of vertebral maturation was applied according to the most recent version of the method.[20]

Statistical analysis

Data were analyzed at T1 and T2 for the ETG, the ECG, the LTG, and the LCG. The Shapiro-Wilk test was performed on all groups to verify that the samples were distributed normally. The exploratory Hotelling T2 test then was used to identify significant between-group differences for comparing changes between the treated groups and their respective control samples (ETG vs ECG, and LTG vs LCG). When significant differences existed between groups as a whole, subsequent analysis of variance (ANOVA) evaluated the difference in means for each cephalometric variable in the treated group compared with the corresponding control group to ascertain where the significant differences existed. The homogeneity between treated and control groups with regard to type of malocclusion, craniofacial characteristics at T1 (data available from authors on request), mean ages at each observation time, sex distribution, and mean duration of observation intervals allowed for comparing the groups on the differences between the values at the various observation times for all cephalometric variables without annualization. All computations were performed with a software package (Version 10.0, Statistical Package for the Social Sciences, SPSS, Chicago, Ill). Statistical significance was tested at $P < .05$, $P < .01$, and $P < .001$ for each comparison.

As for method error, accuracy of linear measurements ranged from 0.1 to 0.3 mm with a SD of approximately 0.8 mm. Angular measurements varied 0.1° with a SD ranging from 0.4° to 0.6°.

RESULTS

The ETG and the ECG both had negative apical base changes (−0.8 and −7.6 mm, respectively); however, there was a significant differential between the 2 groups of approximately 7 mm ($P < .001$). The early treated patients maintained the skeletal relationship within 1 mm because of the significant favorable skeletal contributions of the maxilla and the mandible. The maxilla showed a significant forward movement of 1.8 mm more in the treated subjects ($P < .05$), and the mandible expressed a significantly smaller anterior projection (5 mm) in the same patients when compared with the untreated Class III controls ($P < .01$). Anterior mandibular movement was more than twice that of maxillary movement in the control subjects and only slightly more than 1:1 for the ETG (Fig 8 and Table IV).

The overall molar relationship improved by 1.7 mm for patients treated early, but worsened by more than 5 mm in the untreated controls. The significant differential between the 2 groups was almost 7 mm ($P < .001$). Maintenance of the apical base relationship combined with the forward movement of the maxillary molars contributed to the improvement in the molar relationship for the treated group.

Dental movements in the form of forward movement of the maxillary incisors and uprighting of the mandibular incisors contributed to a 5 mm overjet correction in the treated subjects. Similar dental movements of the incisors were reported for the untreated control group; however, the overjet worsened more than 2 mm because of the negative skeletal movements (ABCH = −7.6 mm). A significant overjet correction of more than 7 mm ($P < .001$) was achieved in the ETG when compared with the ECG during a similar observation interval.

Early treatment induced significantly smaller increases in total mandibular length with respect to the controls (−3.6 mm in about 7 years), along with significantly greater decreases of the gonial angle (−2.6°). No significant changes were recorded in the vertical skeletal relationships.

Skeletal movements could not achieve a positive change in patients treated with RME/FM therapy during the late mixed dentition. The mandible moved forward more than the maxilla in both the LTG and the LCG (1.7 and 5.3 mm, respectively). Comparison of the apical base change (ABCH) between the 2 groups, however, showed significantly smaller increments of change for treated subjects by 3.6 mm ($P < .001$), due in large part to the significant difference in forward movement of the mandible between the 2 groups (2.9 mm, $P < .05$) (Fig 9 and Table V).

The molar relationship remained virtually unchanged for the treated patients (−0.5 mm). In relation to the untreated controls, however, the molar relation was significantly more favorable by almost 3 mm ($P < .01$). A total overjet correction of 2.1 mm was achieved for treated patients by dental contributions from the forward movement of the maxillary incisors and the uprighting of the mandibular incisors (2.1 and 1.7 mm, respectively). The untreated control subjects had increases in the negative overjet of almost 2 mm, resulting in a highly significant difference of 4 mm with respect to the treated group ($P < .001$).

Treatment in the late mixed dentition produced

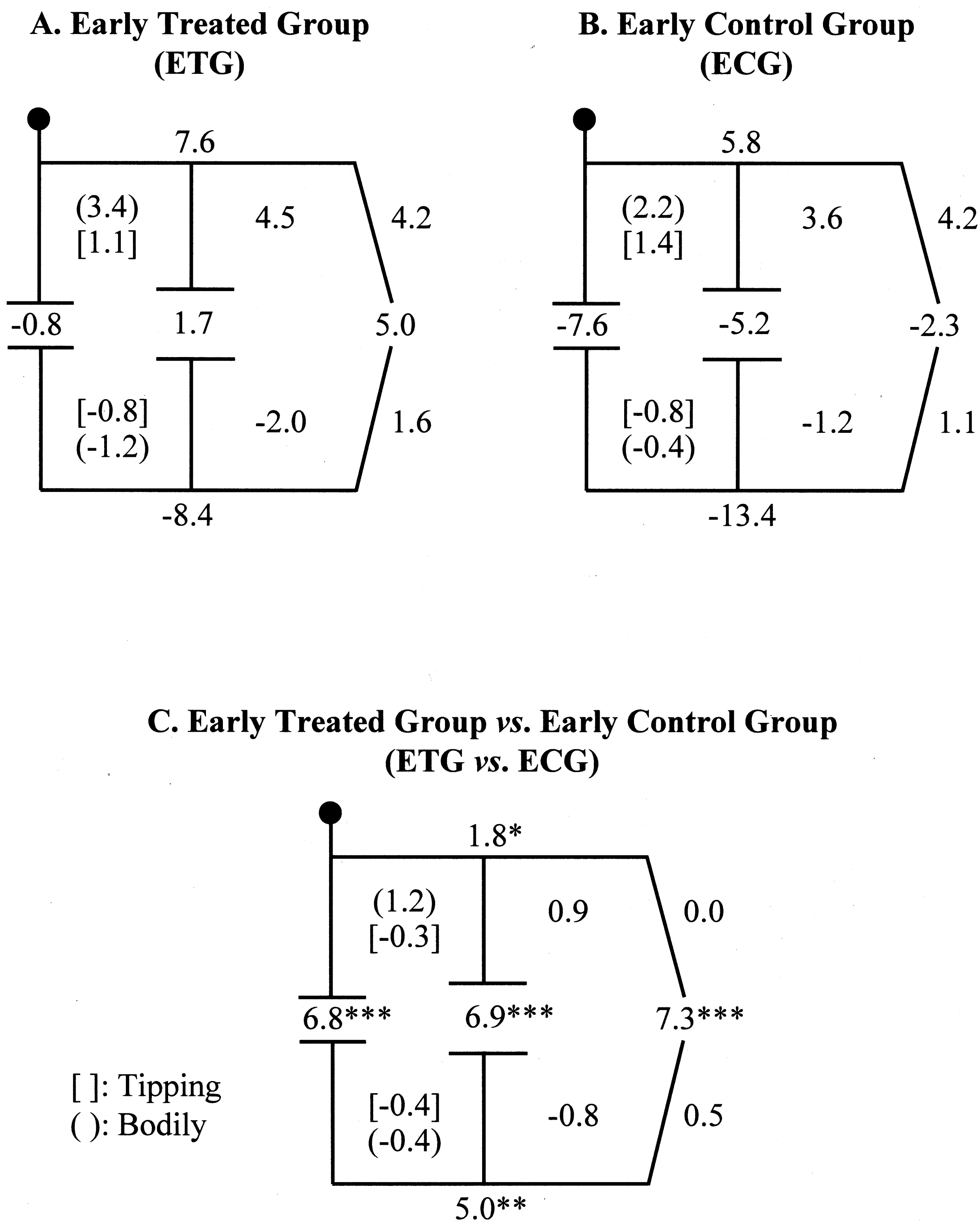

Fig 8. Skeletal and dental treatment changes measured along MFOP during overall observation period (T1 to T2) spanning 7 years 2 months for **A**, ETG; **B**, ECG; and **C**, difference between ETG and ECG Δ (ETG − ECG).

Table IV. Comparison of change between ETG and ECG during observation period (T1 to T2)

	ETG n = 33		ECG n = 14		ETG vs ECG	
Cephalometric measures	Mean	SD	Mean	SD	Net differences	P value
Pitchfork analysis						
Skeletal (mm)						
Maxilla	7.6	2.3	5.8	2.2	1.8	.048*
Mandible	−8.4	4.5	−13.4	4.3	5.0	.007**
ABCH	−0.8	2.7	−7.6	2.5	6.8	.000***
Dental (mm)						
Upper molar to maxilla						
Tipping	1.1	0.9	1.4	2.0	−0.3	.920
Bodily	3.4	1.3	2.2	1.8	1.2	.530
Total	4.5	2.0	3.6	2.4	0.9	.222
Lower molar to mandible						
Tipping	−0.8	1.6	−0.4	0.9	−0.4	.147
Bodily	−1.2	0.5	−0.8	0.3	−0.4	.271
Total	−2.0	1.2	−1.2	1.3	−0.8	.051
Upper incisor to maxilla						
Total	4.2	2.0	4.2	1.7	0.0	.989
Lower incisor to mandible						
Total	1.6	1.7	1.1	1.6	0.5	.364
Total correction (mm)						
Molar	1.7	2.3	−5.2	2.1	6.9	.000***
Incisor	5.0	2.2	−2.3	2.0	7.3	.000***
Additional measures						
Mandibular						
Co-Gn (mm)	19.2	5.7	22.8	5.3	−3.6	.045*
Ar-Goi-Gn (°)	−5.2	4.1	−2.6	3.5	−2.6	.042*
Vertical skeletal						
FH to palatal plane (°)	−1.5	2.0	−1.2	2.3	−0.3	.711
FH to mandibular plane (°)	−0.7	3.9	−1.4	2.9	0.7	.536

*P < .05;
**P < .01;
***P < .001.

significantly smaller increases in total mandibular length with respect to the controls (−4.8 mm in about 4.5 years). No significant changes were found for the gonial angle and the measurements for vertical skeletal relationships.

DISCUSSION

We studied the postpubertal dentoskeletal effects of RME/FM therapy in white subjects with Class III malocclusions to establish appropriate treatment timing for this type of malocclusion. Particular features of this research included the following:

1. The standardized treatment protocol consisted of an initial phase of RME/FM therapy followed by a second phase of comprehensive fixed appliance therapy.
2. Early and late groups were selected based on the stage of dental development at the start of orthopedic treatment in the treated and control groups.
3. The early and late treated groups were compared with corresponding untreated controls with Class III malocclusions.
4. The treated and control groups did not have statistically significant differences as to race, sex distribution, mean age at T1, mean age at T2, mean observation intervals, and craniofacial characteristics at T1.
5. The ETG and LTG comprised Class III subjects with similar severity of dentoskeletal discrepancies at T1.
6. Each treated subject was evaluated by the CVM method after the pubertal peak of mandibular growth.[20]

The use of matched controls provided longitudinal information on the Class III growth characteristics throughout the active growth period. Although much effort was made to include as many subjects as possible in this study, the limited availability of untreated white

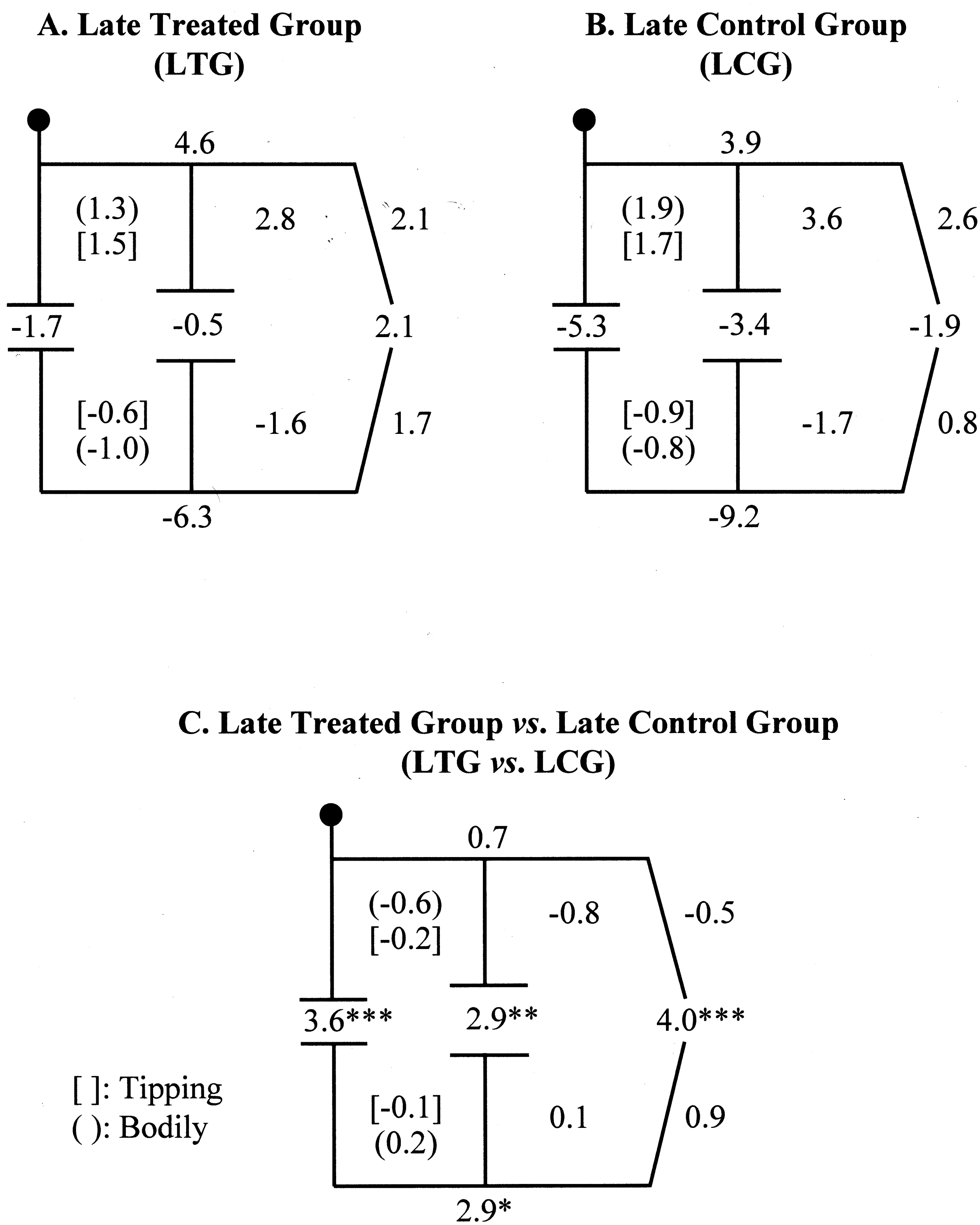

Fig 9. Skeletal and dental treatment changes measured along MFOP during overall observation period (T1 to T2) spanning 4 years 5 months for **A**, LTG; **B**, LCG; and **C**, difference between LTG and LCG Δ (LTG − LCG).

Table V. Comparison of change between LTG and LCG during observation period (T1 to T2)

	LTG n = 17		*LCG n = 10*		*LTG* vs *LCG*	
Cephalometric measures	*Mean*	*SD*	*Mean*	*SD*	*Net differences*	P *value*
Pitchfork analysis						
Skeletal (mm)						
Maxilla	4.6	2.6	3.9	1.9	0.7	.518
Mandible	−6.3	3.8	−9.2	2.0	2.9	.037*
ABCH	−1.7	2.2	−5.3	1.4	3.6	.000***
Dental (mm)						
Upper molar to maxilla						
Tipping	1.5	0.9	1.7	2.0	−0.2	.920
Bodily	1.3	1.1	1.9	1.8	−0.6	.530
Total	2.8	1.5	3.6	2.0	−0.8	.237
Lower molar to mandible						
Tipping	−0.6	1.6	−0.8	0.9	0.2	.447
Bodily	−1.0	0.5	−0.9	0.3	−0.1	.271
Total	−1.6	1.3	−1.7	1.4	0.1	.822
Upper incisor to maxilla						
Total	2.1	1.6	2.6	1.0	−0.5	.384
Lower incisor to mandible						
Total	1.7	1.8	0.8	1.4	0.9	.194
Total correction (mm)						
Molar	−0.5	2.1	−3.4	2.0	2.9	.003**
Incisor	2.1	2.2	−1.9	1.9	4.0	.000***
Additional measures						
Mandibular						
Co-Gn (mm)	10.4	5.9	15.2	5.3	−4.8	.035*
Ar-Goi-Gn (°)	−2.4	2.8	−2.3	3.2	−0.1	.878
Vertical skeletal						
FH to palatal plane (°)	0.1	1.7	0.3	1.9	−0.2	.855
FH to mandibular plane (°)	−1.3	2.0	−2.3	3.3	1.0	.294

*P < .05;
**P < .01;
***P < .001.

subjects with Class III malocclusions followed longitudinally throughout the pubertal growth peak limited the sample sizes for all control groups. The treated group comprised 2 historical cohorts. This type of research design is limited because treatment technique and data gathering (cephalograms) cannot be standardized retrospectively for each practitioner and each patient. Also, the strict inclusionary criteria, particularly regarding the long observation interval and the postpubertal skeletal maturation at T2, reduced the number of patients in the final samples from the larger parent sample.

The statistical analysis of treatment effects in the 2 groups of Class III patients treated at different stages of dental development showed that, globally considered, the favorable craniofacial modifications in the ETG appear to be greater than those in the LTG. These results confirm previous observations by Baccetti et al,[17] who applied the same criteria for the definition of treatment timing to both treated and untreated samples. The investigation of treatment timing by Kapust et al[14] also suggested that children 4 to 10 years of age respond better to treatment than children 10 to 14 years of age during the treatment phase of RME/FM. Several aspects of that study, however, differed from the present one—treatment groups based on chronological age, no evaluation of posttreatment changes, a Class I control group, and the annualization of treatment data that assumed proportional modifications for each subject throughout the therapy. On the other hand, the results by Merwin et al,[13] who found similar therapeutic responses between younger and older treated subjects, are not corroborated by the present findings. The use of chronologic age for categorizing patients and the lack of a postpubertal appraisal of dentoskeletal changes did not permit a direct comparison with this study.

A significant advancement of the maxilla that can withstand the modifications of the active growth period can be achieved orthopedically only by treating Class

III patients in the deciduous or early mixed dentition phases. About 2 mm of supplementary forward movement of the maxilla are maintained in treated patients at the completion of growth when compared with untreated subjects. These results agree with the previous findings of Melsen and Melsen[26] on human autopsy material that showed that disarticulation of the palatal bone from the pterygoid process is possible only on skulls from the infantile and juvenile (early mixed dentition) periods. Attempted disarticulation in the late juvenile (late mixed dentition) and adolescent periods often is accompanied by fracture of the heavily interdigitated osseous surfaces. In our study, Class III subjects treated during the late mixed dentition had only a 0.7 mm advancement of the maxilla at T2, an amount of growth that is not clinically or statistically significant.

If we compare the net differences between the treated and control groups in the early and late samples, we realize that greater improvement in mandibular projection occurs when treatment is performed at an earlier stage of dental development (−5 mm versus approximately −3 mm). Nevertheless, the amount of restriction in mandibular projection in subjects treated during the late mixed dentition represents a significant favorable skeletal modification when compared with untreated subjects. When the changes in the actual length of the mandible are considered, both early and late treatment exert a significant restriction of mandibular growth; this is even more accentuated in late treated subjects (−3.6 mm in about 7 years, and −4.8 mm in about 4.5 years, for early and late treated subjects, respectively). The therapeutic control of mandibular growth is associated with a significant decrease of the gonial angle in subjects treated with the RME/FM protocol in the early developmental phases of the dentition. This mechanism of favorable reshaping of the mandible has been described previously in children with Class III malocclusions treated in the deciduous or early mixed dentitions.[27,28] On the contrary, the significant restriction in total mandibular length in subjects treated during the late mixed dentition is not concurrent with a decrease in the gonial angle. Therefore, the ability of orthopedic treatment to modulate the amount of mandibular growth in late treated Class III patients is not to be ascribed to a morphologic change in the orientation of the mandibular ramus with respect to the mandibular body.

Neither the ETG nor the LTG had significant changes in vertical skeletal relationships. The favorable modifications in these patients were not associated with opening of the mandibular plane with regard to the cranial structures, a side effect that has been suggested frequently as an outcome of facemask therapy.[2-7,12-14]

The type of cephalometric analysis used in this study, a modification of Johnston's pitchfork analysis, allowed a separate evaluation of dental versus skeletal changes within the total outcomes of the RME/FM protocol. The contribution of dental movements to the overall molar and overjet correction was minimal at T2 in both the ETG and the LTG. The favorable modifications in occlusal relationships are due almost entirely to the adaptations of the skeletal bases to orthopedic therapy.

The use of subjects with untreated Class III malocclusions as controls for assessing treatment timing allowed us to investigate the craniofacial growth characteristics for this type of skeletal discrepancy. There are few data in the literature describing the growth changes in white subjects with Class III molar relationships and anterior crossbites. The interest here is increased by the availability of observations on Class III subjects that go beyond the pubertal peak in skeletal maturation. The changes in the dentoskeletal measurements during the overall observation period in both the ECG and the LCG strongly suggest that the skeletal imbalance in Class III malocclusion is established early in life and is not self-correcting during development.[29]

In this study, the differential between maxillary and mandibular projections is aggravated by approximately 7.5 mm in 7 years in subjects with Class III malocclusions observed initially during the deciduous or early mixed dentitions, and by more than 5 mm in 4.5 years in Class III subjects observed initially in the late mixed dentition. Similarly, Class III occlusal relationships tend to worsen along with growth. These data support the findings of previous cross-sectional[30] and short-term longitudinal[27,28] studies. The evidence for the aggravation of both skeletal and dentoalveolar features with growth emphasizes the importance of an adequate treatment plan for correcting a Class III malocclusion during the early developmental stage. A proper evaluation of treatment effectiveness and the definition of optimal treatment timing can provide helpful information for reasonable expectations of treatment outcome.

We recommend early intervention for Class III malocclusion with an orthopedic therapeutical approach to achieve a more effective amount of maxillary advancement, a more significant efficiency in restricting mandibular forward position, and a more favorable correction of occlusal relationships. Although Class III patients treated during the late mixed dentition still benefit from RME/FM therapy, the optimal time to start treatment of the Class III disharmony with this orthopedic protocol is in the early mixed dentition (or late deciduous dentition).

All patients treated at these early developmental phases in this study showed a prepubertal stage in CVM (CVMS I). On the contrary, about 70% of the subjects in the LTG received orthopedic treatment during the growth spurt in skeletal maturation (CVMS II at initiation of therapy). Therefore, along with the recommendation to start Class III orthopedic treatment before the accelerative portion of the pubertal growth spurt, an additional clinical hint can be derived from the recorded data. In patients who receive the first phase of treatment at prepubertal development and do not achieve a completely satisfactory correction of the malocclusion (about 25% of patients, according to the results of a previous long-term study[8]), a second phase of RME/FM therapy can be accomplished at the peak in skeletal growth with the more limited aim of restricting mandibular projection.

CONCLUSIONS

Treatment with RME/FM is most effective when it begins at an early developmental phase of the dentition (early mixed or late deciduous) rather than during later stages with respect to untreated Class III control groups. Patients treated with RME/FM therapy in the late mixed dentition, however, still benefit from the treatment, but to a lesser degree.

Early treatment produces significant favorable postpubertal modifications in both maxillary and mandibular structures, whereas late treatment induces only a significant restriction of mandibular growth. Regardless of treatment timing, the correction of occlusal relationships in Class III patients treated with RME/FM therapy followed by fixed appliances is due almost entirely to adaptations in the skeletal bases rather than to dentoalveolar movements.

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