Skeletal effects of early treatment of Class III malocclusion with maxillary expansion and face-mask therapy

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The effectiveness of maxillary expansion and face-mask therapy in children with Class III malocclusion was studied in a sample of 46 subjects in mixed dentition and compared with a control sample of 32 subjects with untreated Class III malocclusion. Treated and untreated samples were divided into early and late mixed-dentition groups to aid identification of the optimum timing of the orthopedic treatment of the underlying skeletal disharmony. Cephalometric analysis was based on a stable basicranial reference system, appropriate for longitudinal studies started in the early developmental ages. The level of significance for intergroup comparisons was set at a p value of 0.01. Significant forward displacement of the maxillary complex was found in the early-treatment group. The region of the pterygomaxillary suture, in particular, showed significant changes in the subjects treated during early mixed dentition. No significant maxillary modifications were recorded in the late-treatment group. Both early and late groups exhibited smaller increments in mandibular protrusion and larger increments in the intermaxillary vertical relationship compared with their respective Class III control groups. Only children treated at an early age, however, showed a significant upward and forward direction of condylar growth, leading to smaller increments in total mandibular length. These results indicate that the combination of a bonded maxillary expander and face-mask therapy is more effective in early mixed dentition than in late mixed dentition, especially with regard to the magnitude of the protraction effects on maxillary structures. (Am J Orthod Dentofacial Orthop 1998;113:333-43.)

Face-mask therapy was first described more than a century ago,[1] and since the late 1960s it has been used with increasing frequency for the correction of Class III malocclusion.[2-9] Despite this popularity, most of the literature concerning the skeletal and dental changes induced with the face mask are in the form of case reports,[5-7,10-14] with few methodologically sound clinical studies. Longitudinal cephalometric data on untreated Class III subjects to which the treatment effects produced by the facial mask can be contrasted are also scarce.

Much of the information about the skeletal effects of protraction forces still derives from animal studies. Maxillary forward movement and sutural remodeling have been the main treatment effects noted by several investigators in nonhuman primates.[15-18] Kambara[16] found changes at the circummaxillary sutures and at the maxillary tuberosity attributable to posteroanterior traction, including the opening of sutures, stretching of sutural connective-tissue fibers, new bone deposition along the stretched fibers, and apparent tissue homeostasis that maintained the sutural width. Nanda and Hickory[18] showed how the histologic modifications in the zygomaticomaxillary suture after maxillary protraction varied according to the orientation of the force system applied. Biomechanical studies on dry human skulls have demonstrated further that the application of an anteriorly directed force results in forward movement of the maxilla.[14,19,20] These investigations also showed that the direction of the force is critical in controlling rotation of the upper jaw. A force generated parallel to the maxilla or above the palatal plane produces counterclockwise rotation of the palatal plane.

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Face-mask therapy often is supplemented with maxillary expansion. Midfacial orthopedic expansion has been recommended for use in conjunction with protraction forces on the maxilla because it supposedly disrupts the circummaxillary sutural system and presumably facilitates the orthopedic effect of the face mask.[21-23] In fact, there is some evidence in the literature that maxillary expansion alone can be beneficial in the treatment of certain types of Class III malocclusion, particularly borderline malocclusions. [23] Oppenheim[10] was one of the first to observe this phenomenon, and Haas[21-22] has reported that maxillary expansion can produce a slightly forward movement of the maxilla. Dellinger[15] has also shown that this type of anterior maxillary movement can be produced in nonhuman primates. The authors of no published clinical study, however, have directly compared the treatment effects of face-mask therapy alone and face-mask therapy combined with maxillary expansion.

Surprisingly, few studies of face-mask therapy have been conducted at all, and only four of these studies are characterized by adequate sample sizes.[8,9,24,25] Still fewer investigations have involved control groups.[9,24,25] For example, Wisth and coworkers[24] contrasted treatment results with those in a control group comprising subjects with positive overjet and normal basal maxillomandibular relationships. Vasudevan[25] compared treated Chinese Class III children with untreated Chinese Class III controls, but he reported only treatment effects on the maxilla. Ngan and co-workers[9] attempted to circumvent the problem of controls with the use of a 6-month period without treatment before the beginning of therapy as a control period for each patient, thus using the individual patient as his or her own control.

Longitudinal data on untreated subjects with Class III malocclusion are virtually nonexistent. This lack of data is due to at least two factors. The first is the low prevalence of this type of malocclusion, particularly in non-Asian populations. All of the well-known "growth studies" of untreated individuals typically contain a preponderance of subjects with Class I and Class II malocclusion, as well as normal occlusion.[26-29] Class III subjects are not well-represented in these collections, even in proportion to their occurrence in the general population.

A second reason behind the lack of information about the growth of untreated Class III individuals is the well-recognized need for early intervention in such patients. Furthermore, an anterior crossbite and even an edge-to-edge incisal relationship typically are perceived to be abnormal by the lay public, as well as by health care practitioners. Thus early treatment of such conditions with the use of several treatment modalities has been advocated. The longitudinal data on untreated patients with Class III malocclusion, anterior crossbite, or both (e.g., Björk,[30] Hopkins,[31] Love et al,[32] Ngan et al,[33] Vasudevan[26]) are limited with regard to sample size and duration of longitudinal recordkeeping, with most studies featuring few patients and short observation intervals. This lack of data has been addressed in part by the cross-sectional studies of Miyajima and co-workers, [33] who analyzed more than 1,300 Japanese females with Class III malocclusion at seven different developmental stages. Although these data are useful in extrapolating the normal pattern of Class III craniofacial growth, they are of limited use in evaluating short-term studies of treatment effects. With the exception of the 25 untreated Chinese Class III subjects of Vasudevan,[26] the authors of no previous study have incorporated the analysis of longitudinal cephalometric records obtained from a matched untreated Class III sample in mixed dentition.

Although early face-mask therapy has been suggested in several case reports, no definite indication about optimum treatment timing has ever been substantiated in the literature. In this study we attempt to further clarify the treatment effects of face-mask therapy when combined with maxillary expansion. More to the point, the aims of this study are (1) to evaluate craniofacial skeletal effects of bonded maxillary expander and facial mask therapy of Class III malocclusion in a sample of Caucasian subjects in the mixed dentition compared to a matched untreated Class III sample; and (2) to define optimum timing for the beginning of treatment of Class III malocclusion with bonded maxillary expander and face mask.

MATERIAL AND METHODS

Subjects

A parent sample of records from 105 patients with Class III malocclusion treated with maxillary expansion (bonded maxillary expander) and face-mask therapy was obtained from North American practitioners experienced in this type of treatment. The clinicians were asked to take cephalograms at the following intervals: before treatment (T_1) and after treatment (T_2). Generally, 1 or 2 months elapsed between the T_1 cephalogram and the actual start of treatment. The T_2 film was taken within 1 month of the discontinuation of face-mask wear and removal of the expander.

From the parent sample, 46 subjects (26 female and 20 male) were selected for the treatment group on the basis of inclusionary criteria. Patients were included if they were of European-American ancestry, if they presented for treatment while in the early mixed dentition (erupting permanent incisors, first permanent molars, or both) or in the late mixed dentition (erupting permanent canines, premolars, or both), and if they had the following Class III occlusal signs: anterior cross-bite, Class III deciduous or permanent canine relationship, and mesial step deciduous molar relationship or Class III permanent molar relationship. Furthermore, to be included in the study, the patient had to have a pretreatment Wits appraisal [34] of –2 mm or greater. The mean age of the treated group at T_1 was 8 years, 6 months ± 1 year, 11 months; that at T_2 was 9 years, 5 months ± 1 year, 10 months. The mean treatment period was 11 months ± 4 months.

The treated group was divided into two subgroups according to the stage of dentition. The early-treatment group comprised 23 subjects treated in the early mixed dentition; the late-treatment group included 23 subjects treated in the late mixed dentition. The mean age of patients in the early-treatment group was 6 years, 9 months ± 7 months at T_1 and 7 years, 9 months ± 7 months at T_2 , with a mean early-treatment period of 1 year ± 5 months. The mean age of patients in the late treatment group was 10 years, 3 months ± 1 year at T_1 and 11 years, 1 month ± 1 year at T_2, resulting in a mean late-treatment period of 10 months ± 3 months.

Thirty-two subjects (18 female, 14 male) with untreated Class III malocclusion were selected from the files of the Department of Orthodontics of the University of Florence to make up the control group. This sample was used as a comparison group because it matched the treated group with regard to race, stage of dental development, Class III occlusal and skeletal signs, and sex distribution. The mean age of the control group was 7 years, 11 months ± 1 year, 11 months at T_1 and 9 years, 9 months ± 2 years at T_2. The mean observation period without treatment was 1 year, 10 months ± 1 year.

It was possible to assemble a sample of untreated skeletal Class III children because several children refused therapy at the time of the first observation but made a second visit at a later age. The control group also was divided into two subgroups according to dentition. The early-control group included 17 subjects in the early mixed dentition (as defined previously), whereas the late-control group comprised 15 subjects in the late mixed dentition. The mean age of the early control patients was 6 years, 5 months ± 8 months at T_1 and 8 years, 4 months ± 1 year, 2 months at T_2 , resulting in an average observation period of 1 year, 11 months ± 1 year. The mean age of late-control patients was 9 years, 6 months ± 1 year, 6 months at T_1 and 11 years, 4 months ± 1 year, 6 months at T_2, with a mean observation period of 1 year, 8 months ± 10 months.

The two cephalograms from each subject in the treatment and control groups were taken with the use of a standardized protocol on the same radiographic unit, and the enlargement factors were similar among units (about 7.5% to 8%); thus no correction was made for enlargement in the analysis of the films. We also analyzed the dental casts of all patients to assess the stage of development.

Treatment Protocol

Orthopedic face-mask therapy in the treated group comprised a face mask (according to the design of Petit [5]; Fig. 1), a bonded maxillary acrylic splint expander with vestibular hooks[23] (Fig. 2), and heavy elastics. [23] In patients with maxillary transverse deficiency, the midline expansion screw of the bonded maxillary expander was activated once per day until the desired change in the transverse dimension was achieved (the lingual cusps of the upper posterior teeth approximating the buccal cusps of the lower posterior teeth). In instances in which no transverse change was necessary, the maxillary splint still was activated, usually once a day for 7 to 10 days, to disrupt the maxillary sutural system.

At the time of delivery of the facial mask, bilateral ⅜-inch, 8-ounce elastics typically were used for the first 1 to 2 weeks of treatment to ease the patient's adjustment to the appliance. The force generated was then increased with the use of ½-inch, 14-ounce elastics and, finally, 5⁄16-inch, 14-ounce elastics. The direction of elastic traction was forward and downward from the hooks on the bonded maxillary expander to the adjustable crossbar of the facial mask, so that the elastics did not interfere with the function of the lips (Fig. 1). Patients were instructed to wear the mask full-time except during meals, although the actual amount of appliance wear varied.

Cephalometric Analysis

Cephalometric analysis for the assessment of treatment results was based on a previously described reference system traced through craniofacial stable structures.[35,36] First, the stable basicranial line (SBL) was traced through the most superior point of the anterior wall of sella turcica at the junction with tuberculum sellae (point T [37]), drawn tangent to lamina cribrosa of the ethmoid bone (Fig. 3). These basicranial structures do not undergo remodeling after the age of 4 or 5 years.[38] Second, the vertical T (VertT), a line constructed perpendicular to SBL and passing through point T, was traced.

The cephalometric analysis was constructed with the following landmarks: point A (A), point B (B), Prosthion (Pr), Infradentale (Id), Gnathion (Gn), Menton (Me), Gonial intersection (Goi), Articulare (Ar), Condylion (Co), Center of the condyle (Cs) (i.e., a point equidistant from the anterior, posterior, and superior borders of the condyle head), Pterygomaxillary fissure (Ptm), Basion (Ba), Anterior Nasal Spine (ANS), and Posterior Nasal Spine (PNS). The definitions of all these landmarks correspond to those of Björk,[39] Ødegaard,[40] and Riolo and associates.[26]

We conducted the following linear measurements to assess sagittal relationships (Fig. 3): ANS–VertPtm, A–VertT, A–VertPtm, Ptm–VertT, PNS–VertPtm (VertPtm is a line parallel to VertT and passing through point Ptm), Pr–VertT, Id–VertT, B–VertT, Gn–VertT.

We conducted these linear measurements to assess midfacial length and mandibular dimensions[41] (Fig. 4): Co–A, Co–Gn, Co–Goi, Goi–Gn.

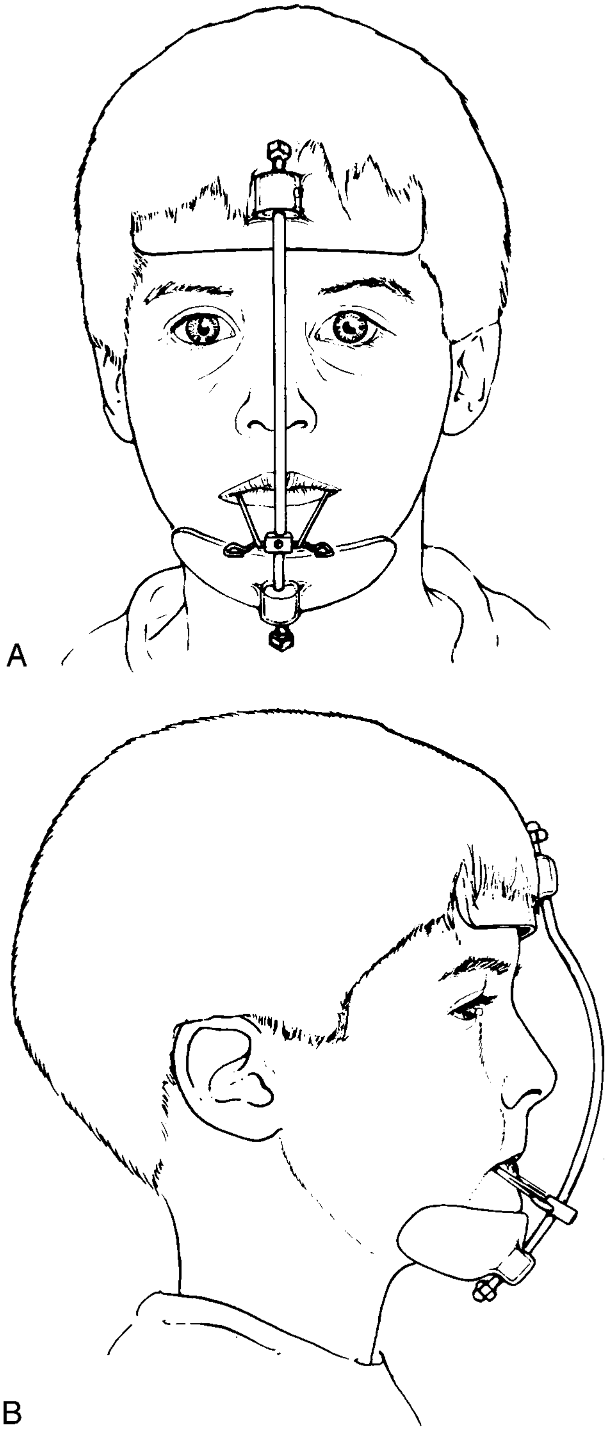

Fig. 1. Face mask according to design of Petit (Great Lakes Orthodontic Products). **A,** Frontal view; **B,** lateral view. Face mask comprises a single midline rod connected to a chinpad and a forehead pad. Elastics are connected bilaterally to an adjustable midline crossbow. (Adapted with permission from McNamara JA Jr, Brudon WL. Orthodontic and orthopedic treatment in the mixed dentition. Copyright © 1993 by Needham Press.)

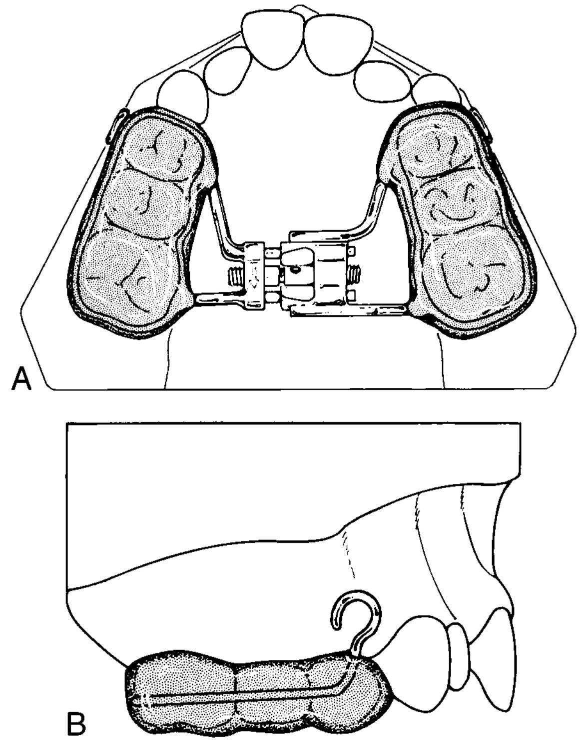

Fig. 2. Bonded maxillary expander. **A,** Occlusal view. **B,** Lateral view. This acrylic splint expander comprises a metal framework and expansion screw to which 3-mm-thick splint Biocryl has been adapted. (Modified with permission from McNamara JA Jr, Brudon WL. Orthodontic and orthopedic treatment in the mixed dentition. Copyright © 1993 by Needham Press.)

We conducted these angular measurements to assess cranial base angulation (Fig. 5): Ba–T–VertT, Ar–T–VertT.

We conducted these angular and linear measurements to assess vertical relationships (Figs. 4 and 5): mandibular line (ML)–SBL, nasal line (NL)–SBL, nasal line–mandibular line (NL-ML), gonial angle (Ar–Goi–Me), ANS–Me.

We conducted these angular measurements to assess condyle inclination (Fig. 5): condylar axis (CondAx)–SBL, CondAx–ML. The condylar axis is a line passing through Condylion and point Cs.

We used Dahlberg's formula[42] to assess the method error for all the parameters on 20 repeated measurements randomly selected from the total of the observations. The error ranged from 0.13 to 0.81 mm for the linear measurements and from 0.19° to 0.93° for the angular measurements.

Data Analysis

To assess significant differences between craniofacial starting forms at the time of the first observation, we

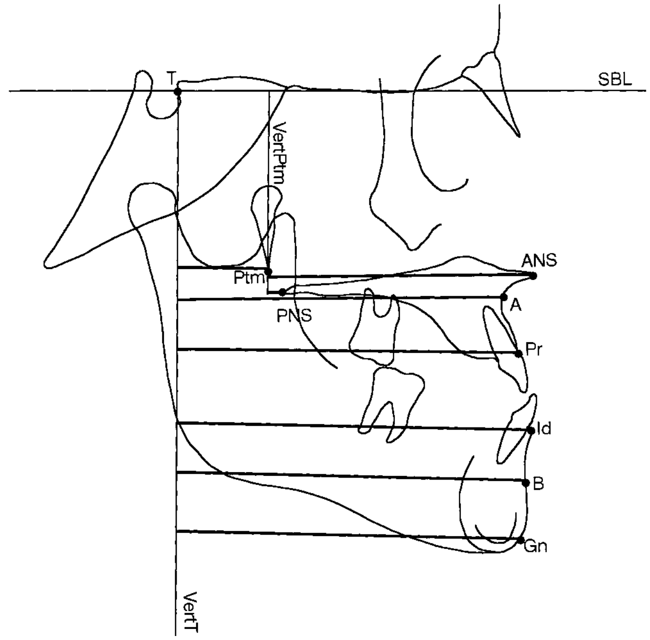

Fig. 3. Linear measurements for the assessment of sagittal relationships.

compared treatment and control groups at T_1 with the use of a nonparametric test (Mann-Whitney U test) for independent samples ($p < 0.01$) (early treatment at T_1 vs. early control at T_1; late treatment at T_1 vs. late control at T_1). We noted no significant differences for any of the cephalometric variables at T_1. The homogeneity between treated and control groups with regard to sex distribution, mean age at T_1, and craniofacial pattern at T_1 permitted comparison of the groups with regard to the differences between the values at T_2 and at T_1 for all the cephalometric variables (Mann-Whitney U test, with significance set at a p value of 0.01 for multiple comparisons).

To overcome discrepancies between treated and control groups with regard to observation period, all differences were annualized. The method error for these differences was also calculated because these values could be affected by tracing errors at T_1 and T_2 (Dahlberg's formula[42] on 10 repeated measurements). The error ranged between 0.2 and 1.04 mm for the linear measurements and between 0.26° and 0.94° for the angular measurements. Craniofacial changes in the early-treatment group were contrasted with those in the early-control group. Similarly, the changes in the late-treatment group were compared with those in late-untreated group. We compared the changes in the early-treatment group were compared with those in the late-treatment group to evaluate the effect of different treatment timing on treatment effects. Finally, the changes in the early-control group were compared with those in the late-control group as a means of assessing any significant growth differences between the two phases that could account for any differences between the early- and late-treatment groups. In these last two comparisons (early treatment vs. late treatment and early control vs. late control), we calculated changes for linear measurements as percent increments or decreases at T_2 in relation to T_1 to minimize dimensional discrepancies between early and late groups resulting from age differences.[43]

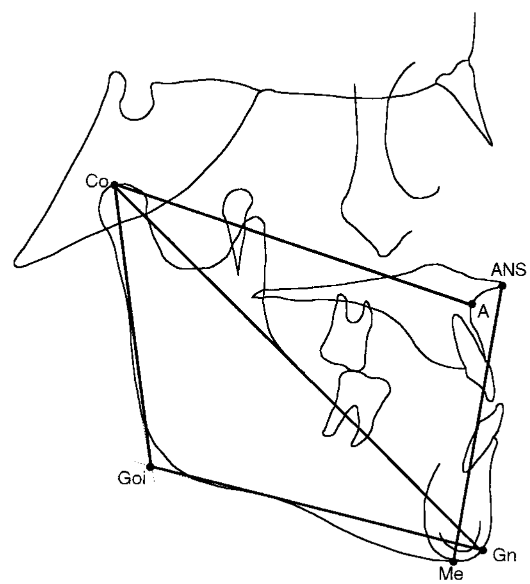

Fig. 4. Linear measurements for the assessment of midfacial length, mandibular dimensions, and lower anterior facial height.

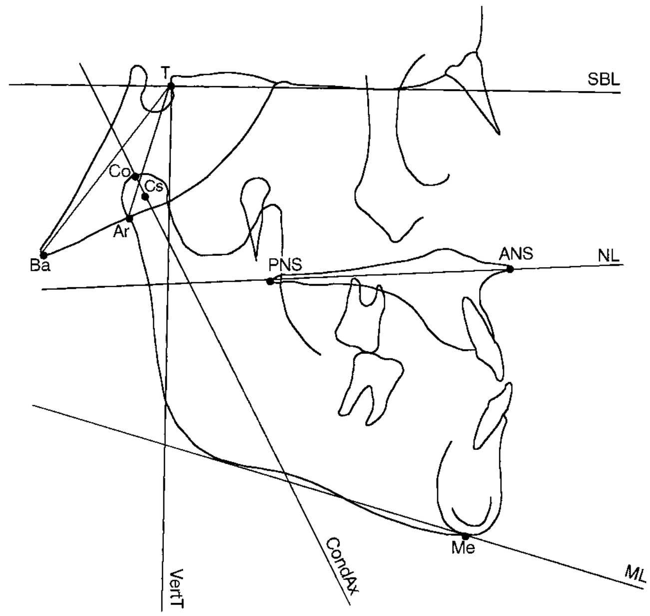

Fig. 5. Angular measurements for the assessment of vertical relationship, cranial base angulation, and condyle inclination.

The changes between T_2 and T_1 for all the cephalometric measurements of the 78 examined subjects (treatment and control groups) were then analyzed with the use of a multivariate statistical approach, discriminant analysis, to identify those cephalometric variables mostly reflecting skeletal changes induced by treatment. A stepwise variable selection (forward selection procedure) was performed, with the goal of obtaining a model with the smallest set of significant cephalometric variables (*F* to enter and to remove = 4). Finally, the classification power of selected cephalometric variables was tested. All computations were performed with the Statistical Package for the Social Sciences (SPSS).

RESULTS

Comparison of Early Treatment and Control Groups

We noted significant forward displacement of the maxillary complex in the early-treatment group (Table I). The measures ANS–VertPtm, A–VertPtm, A–VertT, and Pr–VertT showed significantly larger annualized increments in the treated group ($p < 0.001$). PNS–VertPtm and Ptm–VertT showed significantly larger annualized increments in the treated group ($p < 0.001$) as well. Annualized increments in midfacial length (Co–A) also were significantly larger in the early-treatment group ($p < 0.01$).

Significantly smaller annualized increments in mandibular protrusion were found as a result of early bonded maxillary expander/face-mask treatment (B–VertT, Gn–VertT, $p < 0.001$). Annualized changes for total mandibular length (Co–Gn) showed significantly smaller increments in the treated group. As for the variables for the evaluation of vertical relationships, the early-treatment group showed significantly larger increments of the inclination of the mandibular line in relation to the nasal line (NL–ML, $p < 0.01$), in association with significantly larger decreases in the inclination of the nasal line relative to the cranial base (NL–SBL, $p < 0.01$). The inclination of the condylar axis to the cranial base showed significantly smaller decreases in the early-treatment group (CondAx–SBL, $p < 0.001$), and the inclination of the condylar axis to the mandibular line exhibited significantly smaller increments in the early-treatment group (CondAx–ML, $p < 0.001$).

Comparison of Late-Treatment and Late-Control Groups

Maxillary expansion and face-mask therapy did not produce any significant change in maxillary-growth in LTG compared with LCG (Table II). Only dentoalveolar changes were recorded at the maxilla, with significant larger annualized increments in the distance from point Pr to VertT in the late-treatment group ($p < 0.01$). On the other hand, we noted significant changes in the sagittal position

Table I. Descriptive statistics and statistical comparison of annualized changes between early-treatment and early-control Class III groups

Cephalometric measurements	Annualized differences, T_2–T_1, early-treatment group (n = 23)					Annualized differences, T_2–T_1, early-control group (n = 17)					Mann-Whitney test	
	Mean	SD	Median	Maximum	Minimum	Mean	SD	Median	Maximum	Minimum	Z	p
ANS–VertPtm (mm)	2.79	1.11	2.43	5	1.20	0.76	0.79	0.81	2.79	–0.71	4.83	—*
A–VertT (mm)	4.15	1.46	3.6	7.8	2.13	0.99	0.8	0.76	3.32	–0.08	5.13	—*
A–VertPtm (mm)	2.81	0.97	2.57	4.81	1.31	0.92	0.72	0.67	3.12	0.18	4.83	—*
Co–A (mm)	3.82	1.78	3.17	8.25	1.26	2.44	1.41	2.11	5.54	0.39	2.58	–†
Ptm–VertT (mm)	1.34	0.82	1.17	4.02	0.3	0.06	0.16	0.06	0.48	–0.3	5.29	—*
PNS–VertPtm (mm)	2.11	0.89	1.95	4.26	0.67	0.04	0.29	0	0.49	–0.71	5.35	—*
Pr–VertT (mm)	4.54	1.78	4.04	9.82	1.83	1.51	0.91	1.25	3.99	0.36	4.94	—*
Id–VertT (mm)	0.60	1.16	0.59	2.92	–1.23	1.54	1.19	1.22	5.19	0.31	2.02	NS
B–VertT (mm)	–0.09	1.1	0	1.57	–2.62	1.98	1.33	1.52	5.04	0.38	4.39	—*
Gn–VertT (mm)	–0.03	1.39	0.38	1.95	–3.4	2.38	2.02	1.93	7.27	–0.03	4.01	—*
Co–Gn (mm)	1.87	2.09	1.59	6.62	–2.92	4.49	2.2	3.68	10.33	2.23	3.38	—*
Co–Goi (mm)	0.70	1.41	0.68	3.61	–2.14	1.33	1.01	1.51	3.25	–0.99	1.49	NS
Goi–Gn (mm)	2.03	1.41	1.5	5.9	0.38	2.99	1.66	2.63	6.35	0.66	2.01	NS
Ba–T–VertT (°)	–0.13	0.68	–0.12	1.62	–1.51	–0.11	0.55	–0.18	1.48	0.83	0.12	NS
Ar–T–VertT (°)	0.06	1.95	0.1	5.56	–3.04	0.49	0.89	0.46	1.96	–1.05	–1.61	NS
ML–SBL (°)	0.53	1.09	0.41	2.83	–1.68	–0.07	0.72	0.05	1.25	–1.55	1.71	NS
NL–SBL (°)	–1.42	1.64	–1.7	1.67	–6.09	–0.23	0.73	–0.09	1.36	–1.96	2.79	—†
NL–ML (°)	1.95	1.87	2.05	6.52	–1.23	0.15	0.93	0.41	1.45	–2.01	3.29	—†
Ar–Goi–Me (°)	–1.02	2.02	–0.67	2.05	–5.88	–0.25	1.19	–0.21	2.59	–2.06	1.22	NS
ANS–Me (mm)	3.21	2.24	3.03	8.31	–0.92	1.66	0.66	1.73	2.81	0.46	2.53	NS
CondAx–SBL (°)	8.31	5.97	6.7	24.36	0.02	–3.73	2.92	–3.56	0.55	–12.02	5.32	—†
CondAx–ML (°)	–7.79	5.94	–5.99	–0.06	–23.46	3.65	3.09	2.83	12.46	–1.38	5.27	—†

*$p < 0.001$.
†$p < 0.01$.

of the mandible in the late-treatment group. Treatment in the late mixed dentition induced significantly smaller annualized increments for B–VertT, Gn–VertT, and Id–VertT in the late-treatment group ($p < 0.001$). The inclination of the nasal line relative to the mandibular line exhibited significantly greater annualized increments in the late-treatment group (NL–ML, $p < 0.01$) as well.

Comparison of Early- and Late-Treatment Groups

We found significant advancement of the maxillary structures in the early-treatment group compared with the late-treatment group (Table III); early treatment induced significantly larger annualized percent increases in ANS–VertPtm, A–VertT, A–VertPtm, PNS–VertPtm, Ptm–VertT ($p < 0.001$) in Pr–VertT ($p < 0.01$). Larger annualized decreases for CondAx–ML ($p < 0.001$) and larger annualized increments for CondAx–SBL ($p < 0.001$) revealed a significantly more upward and forward direction of condylar growth as a result of early treatment.

Comparison of Early- and Late-Control Groups

We found no statistically significant differences between the early- and late-control groups. Consequently, the results of the comparisons between them were not influenced significantly by differential growth changes in subjects with Class III malocclusion at different developmental ages.

Discriminant Analysis

Stepwise variable selection identified a significant model of four measurements that accounted for the best discriminant function between children with treated and untreated Class III malocclusion: PNS–VertPtm (*F* to remove = 31.85), B–VertT (*F* to remove = 30.35), A–VertT (*F* to remove = 23.38), Co–A (*F* to remove = 9.18). The percentage of "grouped" cases correctly classified was 98.72%. In only one treated subject did actual group not match predicted group membership.

DISCUSSION

The effects on the craniofacial skeleton induced by face-mask therapy have seldom been investigated in adequate samples,[8,9,24,25] especially with regard to the determination of optimum timing for this type of therapy. In this study, we compared the results of early intervention in the mixed dentition on Class III malocclusion with bonded maxillary expander and face mask with those of late intervention in the mixed dentition. Several features were unique to our investigation. First was the use of white subjects with

Table II. Descriptive statistics and statistical comparison of annualized changes between late treated and control Class III groups

Cephalometric measurements	*Annualized differences, T_2–T_1, late-treatment group (n = 23)*					*Annualized differences, T_2–T_1, late-control group (n = 15)*					*Mann-Whitney test*	
	Mean	*SD*	*Median*	*Maximum*	*Minimum*	*Mean*	*SD*	*Median*	*Maximum*	*Minimum*	Z	p
ANS–VertPtm (mm)	1.31	1.06	1.21	3.65	–1.06	0.8	0.67	0.73	1.82	–0.52	1.75	NS
A–VertT (mm)	2.07	1.11	1.89	5.28	0.59	1.17	0.91	1.17	2.98	–0.63	2.43	NS
A–VertPtm (mm)	1.76	1.08	1.28	4.74	0.38	1.14	0.98	0.96	3.96	–0.7	2.00	NS
Co–A (mm)	2.54	1.68	2.43	5.6	–2.28	2.18	1.24	1.78	5.5	0.79	1.18	NS
Ptm–VertT (mm)	0.29	0.43	0.24	1.1	–0.9	0.02	0.39	0.08	0.56	–1	2.42	NS
PNS–VertPtm (mm)	0.93	0.75	0.9	3.12	–0.33	0.18	0.49	0.04	1.25	–0.78	2.43	NS
Pr–VertT (mm)	2.76	1.7	2.54	7.25	0.23	1.3	0.89	1.38	3.13	–0.77	2.79	—*
Id–VertT (mm)	–0.32	2.06	–0.55	2.66	–7.65	1.97	1.16	1.98	4.38	–0.13	3.66	—†
B–VertT (mm)	–0.54	2.28	–0.54	3.55	–8.23	2.06	1.77	2.08	5.4	–0.76	3.51	—†
Gn–VertT (mm)	–0.84	2.71	–0.36	3.85	–10.48	2.19	1.84	2.32	5.42	–2.03	3.96	—†
Co–Gn (mm)	3.46	2.66	2.86	12.14	0.13	4.33	2.41	3.65	10.94	1.59	1.39	NS
Co–Goi (mm)	0.94	1.52	0.51	4.18	–1.51	1.97	1.77	1.28	5.1	0.14	1.87	NS
Goi–Gn (mm)	1.61	2.09	1.34	5.01	–4.75	3.07	2.3	2.42	8.38	–0.16	2.28	NS
Ba–T–VertT (°)	–0.29	0.64	–0.23	0.89	–1.68	–0.26	0.8	–0.33	2	–1.41	0.43	NS
Ar–T–VertT (°)	–0.03	1.15	–0.13	2.4	–1.86	0.23	0.74	0.25	1.89	–0.84	0.55	NS
ML–SBL (°)	0.91	1.79	0.49	5.11	–2.43	–0.27	0.84	–0.6	1.98	–1.09	2.16	NS
NL–SBL (°)	–1.07	2.27	–0.46	2.47	–6.1	–0.38	0.74	–0.55	1.22	–1.63	0.01	NS
NL–ML (°)	1.99	2.96	1.31	10.42	–2.43	0.11	0.92	–0.2	2.58	–0.1	2.64	—*
Ar–Goi–Me (°)	0.06	2.49	0.12	7.63	–3.36	–0.74	1.41	–0.52	1.67	–3.24	1.06	NS
ANS–Me (mm)	2.79	2.83	2.32	9.73	–1.14	1.66	1.17	1.27	3.64	–0.32	1.21	NS
CondAx–SBL (°)	–0.28	5.48	–0.28	10.9	–10.59	–3.38	6.34	–2.99	4.77	–23.54	1.51	NS
CondAx–ML (°)	1.18	4.58	1.32	9.74	–7.89	3.11	6.56	2.21	23.1	–5.38	0.79	NS

†$p < 0.01$.
*$p < 0.001$.

untreated Class III malocclusion in the early and late mixed dentitions as control groups. These groups matched treated groups as to race, gender, age at the first observation, and craniofacial characteristics at first observation.

Second was a cephalometric analysis based on a stable basicranial reference system, appropriate for the longitudinal evaluation of skeletal changes from the early developmental phases.[35,36] The elimination of S–N line as a reference line implied the exclusion of Nasion from the analysis; it has been demonstrated that this point can be affected by posteroanterior maxillary protraction, thus concealing actual sagittal changes of the maxilla.[24]

Third, all treated subjects underwent a concomitant treatment phase with maxillary expansion to effect disruption of the circummaxillary sutural system.

Our findings provide evidence that treatment of Class III malocclusion with bonded maxillary expander and face mask in the early mixed dentition results in more favorable craniofacial changes than treatment in the late mixed dentition. In particular, significant forward displacement of maxillary structures was achieved as an outcome of early treatment, whereas the late-treatment group showed no significant improvement in maxillary growth with respect to matched untreated controls. Significant advancements of anterior and posterior nasal spines, of point A, and of the maxillary dentition were recorded in the early-treatment group.

Posteroanterior orthopedic traction induced significant forward displacement of point Ptm in relation to the stable reference structures in the early mixed dentition; this effect was not observed in the group treated in the late mixed dentition. This finding supports, from a clinical perspective, the observations of Melsen and Melsen[44] on dry skulls and on autopsy material. According to these investigators, disarticulation of the palatal bone from the pterygoid process was possible only on skulls representing the infantile and juvenile (early mixed dentition) periods. Attempted disarticulation in the late juvenile (late mixed dentition) and adolescent periods was always accompanied by fracture of the heavily interdigitated associated osseous surfaces.

Mean annualized forward growth of the maxilla registered at point A in relation to the stable reference system was about 1 mm in both the early- and late-control groups with Class III malocclusion. In the early-treatment group, a fourfold per-year increment in sagittal maxillary growth at point A was assessed, whereas a twofold increment was found in the late-treatment group. With the division of the

Table III. Descriptive statistics and statistical comparison of annualized changes between early and late treated Class III groups; linear measurements expressed as percent changes relative to the value at T_1

Cephalometric measurements	*Annualized differences, T_2–T_1, early-treatment group (n = 23)*					*Annualized differences, T_2–T_1, late-treatment group (n = 23)*					*Mann-Whitney test*	
	Mean	*SD*	*Median*	*Maximum*	*Minimum*	*Mean*	*SD*	*Median*	*Maximum*	*Minimum*	Z	p
ANS–VertPtm (mm)	5.83	2.45	2.51	11.88	2.45	2.61	2.1	2.48	6.38	–2.44	4.03	—*
A–VertT (mm)	7.21	2.75	6.29	13.26	3.72	3.57	1.66	3.62	6.92	1.03	4.58	—*
A–VertPtm (mm)	6.38	2.39	5.6	11.29	2.94	3.83	2.08	2.72	8.49	1.06	3.55	—*
Co–A (mm)	4.91	2.36	4.04	11.13	1.31	3.12	1.96	3.19	6.86	–2.7	2.54	NS
Ptm–VertT (mm)	9.91	6.16	8.3	26.97	1.75	2.74	5.01	2.09	14.92	–10.58	4.21	—*
PNS–VertPtm (mm)	294.66	793.74	110.48	3880	–265.9	–13.1	139.73	17.83	242.7	–380.5	4.09	—*
Pr–VertT (mm)	7.78	3.15	6.58	15.26	3.75	4.59	2.45	4.72	9.03	0.39	3.15	—†
Id–VertT (mm)	1	2.12	0.94	5.36	–2.18	–0.15	3.77	–0.95	9.85	–10.43	1.7	NS
B–VertT (mm)	–0.16	2.13	0	–5.09	3	–0.68	4.24	0.83	10.23	–11.62	0.87	NS
Gn–VertT (mm)	0.03	2.92	0.76	4.9	–6.44	–1.38	5.36	–1.43	9.89	–15.03	1.35	NS
Co–Gn (mm)	1.8	2.04	1.56	6.19	–2.85	3.26	2.68	2.67	11.95	0.13	1.79	NS
Co–Goi (mm)	1.51	3	1.44	7.84	–4.3	1.84	3.02	1	7.6	–0.9	0.16	NS
Goi–Gn (mm)	2.26	1.97	2.21	8.17	0.58	1.67	2.85	1.97	7.22	–6.02	1.19	NS
Ba–T–VertT (°)	–0.13	0.68	–0.12	1.62	–1.52	–0.29	0.64	–0.23	0.89	–1.68	0.53	NS
Ar–T–VertT (°)	0.07	1.95	–0.1	5.57	–3.04	–0.03	1.15	–0.13	2.4	–1.86	0.15	NS
ML–SBL (°)	0.53	1.1	0.41	2.83	–1.68	0.91	1.79	0.49	5.11	–2.43	0.74	NS
NL–SBL (°)	–1.42	1.64	–1.7	1.67	–6.09	–1.07	2.27	–0.46	2.47	–6.1	1.28	NS
NL–ML (°)	1.95	1.87	2.05	6.52	–1.23	1.99	2.96	1.31	10.42	–2.43	0.71	NS
Ar–Goi–Me (°)	–1.02	2.02	–0.67	2.05	–5.88	0.06	2.49	0.12	7.63	–3.36	1.26	NS
ANS–Me (mm)	5.32	3.63	5.26	13.41	–1.64	4.45	4.51	3.66	16.33	–1.98	1.06	NS
CondAx–SBL (°)	8.31	5.57	6.7	24.36	0.08	–0.28	5.58	–0.28	10.9	–10.59	4.29	—*
CondAx–ML (°)	–7.79	5.94	–5.99	–0.06	–23.46	1.19	4.58	1.32	9.74	7.89	4.67	—*

*$p < 0.001$.
†$p < 0.01$.

linear measurement A–VertT into its two "components," A–VertPtm and Ptm–VertT, the weight of different forward movement of Point Ptm in the early- vs. late-treatment groups is obvious. In fact, in both untreated Class III groups, the mean sagittal forward growth at Ptm (Ptm–VertT) is almost null, whereas it is 1.3 mm/year in the early-treatment group and only 0.3 mm/year in the late-treatment group. One third of the favorable changes in maxillary growth in the early-treatment group, therefore, was due to specific treatment-induced modifications at the pterygomaxillary suture.

Furthermore, the significant greater increments in PNS–VertPtm in the early-treatment group probably reflected enhanced growth at the posterior region of the maxillary complex as a result of bony apposition at the maxillary tuberosity. Forward displacement of PNS with respect to point Ptm was almost null in the early-control group and 0.2 mm/year in the late-control group; in the late-treatment group the increment was 0.9 mm/year, and it increased to 2.1 mm/year in the early-treatment group.

The amount of maxillary advancement in the early-treatment group slightly exceeded that recorded by Ngan et al.,[9] who treated children of an average age of 8.4 years at T_1 with banded maxillary expander and face mask and used a similar linear measurement to assess forward displacement at point A. Wisth and co-workers[24] used angular measurements involving Nasion for the evaluation of sagittal maxillary growth and consequently were not able to draw any definite conclusion about the effects of maxillary traction.

As for the effects on the mandible, both early and late face-mask treatments induced significantly smaller annualized increments in mandibular protrusion. Total mandibular length (Co–Gn), however, showed significantly smaller increments only in the early-treatment group compared with controls, whereas overall mandibular dimensions were not affected significantly by treatment in the late-treatment group. In both the early- and late-control groups, the increment in Co–Gn measurement was about 4.5 mm/year; in the late-treatment group the increment was about 3.5 mm/year, whereas in the early-treatment group the increment was about 2 mm/year. The favorable change in total mandibular length in the early-treatment group was associated with significantly smaller increments in the inclination of the condylar axis to the mandibular line in this group with respect to controls. Such a skeletal modification can be interpreted as a more upward and forward direction of condylar growth in subjects treated early. According to Lavergne and Gasson,[45] this mechanism—namely, anterior morphogenetic rotation of the mandible, is a biologic process that can "dissipate" excessive mandibular growth relative to the maxilla, and it has been reported previously as a major effect of early functional treatment of Class III malocclusion.[35,36]

In both the early- and late-treatment groups the annual increments in the inclination of the nasal line in relation to mandibular line were significantly larger compared with their respective control groups. In neither of the two treated groups was the increased intermaxillary vertical relationship due to a backward inclination of the mandibular line with respect to the cranial base. Consequently the presence of the occlusal splints of bonded maxillary expander did not significantly affect mandibular position in the vertical plane. This favorable aspect could be related to the limited extrusion of the maxillary dentition that has been documented in cases treated with bonded vs. banded maxillary expanders.[46] As already emphasized in the biomechanical studies mentioned previously, the posteroanterior traction applied to the maxilla determined a more upward inclination of the palatal plane in both treated groups, though significant only in the early-treatment group. In future clinical applications of face-mask therapy, it is recommended that the elastic traction be directed even more downward to counteract the tendency to the counterclockwise rotation of the maxilla.

To permit comparison of early- and and late-treatment groups, we used a standardized sequence of elastics in all the treated subjects. However, the use of heavier forces in subjects treated in the late mixed dentition may lead to more favorable results. This matter could be investigated in further studies dealing with different levels of forces.

The results of discriminant analysis showed that both maxillary and mandibular modifications are involved in the overall treatment effects of bonded maxillary expander and face-mask therapy. In particular, the increase in PNS–VertPtm played a major role in total skeletal changes induced by treatment.

In this study, maxillary expansion was applied before protraction forces to operate an "activation" of the maxillary sutural system, presumably facilitating the action of the face mask.[21-23] Itoh and co-workers[19] and Hata and co-workers[20] have demonstrated that anteriorly directed forces result in constriction of the maxilla in the transverse plane. These findings further support the use of the bonded maxillary expander in combination with face-mask therapy, even when a transverse discrepancy is not present at the start of treatment.

Previous investigations have shown a certain relapse tendency after the application of active force in experimental animals.[15-18] The effects of bonded maxillary expander and face-mask therapy obviously should be evaluated over the long term in human beings as well. The significantly larger magnitude of favorable maxillary skeletal changes in younger treated children, however, suggests that the appraisal of any relapse tendency to orthopedic Class III correction should be carried out separately on early- and late-treated subjects.

CONCLUSIONS

In this clinical study we evaluated the treatment effects produced by orthopedic face mask combined with a bonded maxillary expander. The records of 46 mixed-dentition Class III patients were compared with those of 32 untreated subjects with Class III malocclusion. Two subgroups were established in each study group, according to stage of dentitional development (i.e., early vs. late mixed dentition). The major findings were as follows:

1. Treatment of Class III malocclusion with maxillary expansion and a face mask in the early mixed dentition induced more favorable changes in the craniofacial skeleton compared with similar treatment started in the late mixed dentition. In particular, effective forward displacement of maxillary structures was achieved as an outcome of early treatment, whereas the late-treatment group showed no significant improvement in maxillary growth with respect to matched untreated controls.
2. Even though both early and late face-mask treatments reduced mandibular protrusion, significantly smaller increments in total mandibular length associated with more upward and forward direction of condylar growth were recorded only in the early-treatment group.
3. Discriminant analysis revealed that both maxillary and mandibular modifications concurred in the overall treatment effects of maxillary expansion and face-mask therapy.

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