Cephalometric effects of combined palatal expansion and facemask therapy on Class III malocclusion

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In recent years, facemask/palatal expansion therapy has become a common technique for correcting the developing Class III malocclusion. The popularity of facemask therapy has increased due to the awareness of maxillary deficiency as all or part of the Class III structural etiology.[1-4] In addition, numerous clinical reports suggest this approach is more successful than other techniques, such as chin cup, functional appliance, or camouflage therapy. Although less than 5% of the Caucasian population exhibits skeletal Class III malocclusion,[5-9] approximately one out of three adults seeking orthognathic surgery presents with this malocclusion, pointing to the importance of early identification and treatment.[10] The incidence of Class III malocclusion also appears to be increasing in the United States due to immigrant populations with higher rates of Class III malocclusion. Experimental studies in primates demonstrate significant orthopedic effects on the maxilla by continuous protraction forces.[11-13] Clinical reports describe not only forward and downward maxillary movement, but a clockwise rotation of the mandible as the means of correction.[14-15]

Because of the low incidence of Class III in the general population and the relative newness of maxillary protraction as a treatment approach,

Abstract

The purpose of this study was to examine the cephalometric changes that occur with palatal expansion/facemask therapy for Class III malocclusion. Pretreatment and posttreatment lateral cephalograms from 21 patients were traced and analyzed by traditional cephalometric measures, an x-y coordinate system, and along the functional occlusal plane. Differences between T1 and T2 values were analyzed with paired *t*-tests. Mean ages were 7.26 years (T1) and 8.18 years (T2). Average treatment time was 11.05 months. Statistically significant anterior movement of the maxilla occurred with increases in SNA (+2.35), maxillary depth (+2.22), and ANB (+3.66), and anterior movement of A-point (+3.34 mm) and ANS (+3.17 mm). The maxilla rotated counterclockwise, with PNS moving down more than ANS (-2.21 mm and -0.82, respectively). The mandible rotated clockwise with mild decreases in SNB (-1.32) and facial depth, (-1.2) but significant downward movement at menton (-4.34 mm). Occlusal plane analysis demonstrated that the correction was due more to the maxilla than the mandible (+2.35 and -1.88 mm, respectively). The maxillary molars moved forward (+1.70 mm) as did the incisors (+1.75 mm). Soft tissue changes included the nose and upper lip moving forward (3.43 and 3.67 mm, respectively), and menton moving downward (-3.49 mm). The results indicate that facemask/palatal expansion therapy improves Class III malocclusion by a combination of skeletal and dental changes that occur in the anteroposterior dimension and in the vertical plane of space.

Key Words

Class III malocclusion • Facemask/palatal expansion • Orthopedic treatment • Maxilla • Cephalometric analysis

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Table 1
Mean changes in traditional cephalometric measures and landmarks relative to x-y axis

Variable		Mean	SE	SD	p
Maxilla AP dimension					
SNA	dgs	2.35	0.30	1.37	0.01
Maxillary depth (FH-NA)	dgs	2.22	0.44	2.03	0.01
Key ridge	mm	1.12	0.25	1.16	0.01
Orbitale	mm	2.04	0.63	2.87	0.01
PNS	mm	1.42	0.38	1.73	0.01
ANS	mm	3.17	0.44	2.03	0.01
A-point	mm	3.34	0.48	2.18	0.01
Max length (TMJ-ANS)	mm	3.53	0.53	2.41	0.01
Maxilla vertical					
Key ridge	mm	0.24	0.45	2.05	0.59
Orbitale	mm	-0.12	0.53	2.45	0.83
PNS	mm	-2.21	0.39	1.77	0.01
ANS	mm	-0.82	0.58	2.65	0.17
A-point	mm	-0.86	0.81	3.72	0.30
Palatal plane (ANS/PNS-SN)	dgs	-1.90	0.39	1.80	0.01
Mandible AP dimension					
SNB	dgs	-1.32	0.27	1.23	0.01
Facial axis (pt/Gn-FP)	dgs	-1.63	0.39	1.81	0.01
Facial depth (FH- FP)	dgs	-1.08	0.50	2.27	0.09
Mandibular length(TMJ-Gn)	mm	2.29	0.75	3.46	0.01
B-point	mm	-1.00	0.65	2.99	0.14
Menton	mm	-0.59	0.71	3.23	0.41
Pogonion	mm	-0.12	0.73	3.34	0.87
Mandible vertical					
Lower facial height (ANS-Xi-Po)	dgs	2.07	0.65	3.00	0.01
GO-GN-SN	dgs	1.59	0.32	1.46	0.01
B-point	mm	-3.85	0.83	3.78	0.01
Menton	mm	-4.34	0.89	4.09	0.01
Pogonion	mm	-4.06	0.87	3.99	0.01
Occlusal pl. angle (O Pl to SN)	dgs	-1.53	1.51	6.92	0.39
Mandibular pl. (Go/Gn-SN)	mm	1.70	0.61	2.78	0.03
Mx/Md AP relationship					
ANB	mm	3.66	0.35	1.59	0.01
Max-mand diff.	mm	-1.23	0.51	2.35	0.05

$p < 0.05$ Statistically significant

clinical studies of this technique have been limited. Published reports also vary tremendously in regard to the sample, treatment protocol, and method of cephalometric analysis. For example, due to a higher incidence of Class III in the Asian population, most recently published studies have examined Asian patients only, and the results may not be applicable to other racial types.[16-18]

The appliances used for protraction may involve either reverse headgear (facemask) or a combination chin cup and reverse headgear.[19,20] Although most published reports involve the use of various expansion appliances,[16,17,18,21,22] intraoral appliances may include soldered labiolingual wires,[18,23] fixed acrylic plates,[19] or edgewise appliances.[24] The method of cephalometric analysis may include traditional cephalometric measures, some form of x-y coordinate system, or analysis along the occlusal plane. All these various factors make it difficult to compare the results of published reports.

In order to examine comprehensively the cephalometric changes associated with palatal expansion/facemask therapy, this study used traditional measures and an x-y coordinate system, and also examined changes along the functional occlusal plane. This methodology should provide a better understanding of how Class III malocclusion is corrected, while allowing the results to be compared with other studies.

Materials and methods

Pretreatment and posttreatment lateral cephalograms of 21 girls were available for study. Patients were between 3.9 and 10.8 years of age and had no craniofacial anomalies. The sample was selected from the records of private orthodontic practices and patients treated at the UCLA orthodontic clinic. The diagnosis of Class III malocclusion was based upon a mesial step of at least 3 mm and the presence of an anterior crossbite or edge-to-edge incisor relationship in the primary or permanent dentition. Patients were treated with a banded, soldered palatal expansion appliance and a reverse-pull facemask with forehead and chin support. Although the rate and amount of expansion was dependent on the individual need of each patient, most patients received two-turns-a-day activation for 7 to 10 days prior to facemask delivery, followed by one turn per day if additional expansion was necessary. Protraction forces approximated 200 to 450 grams per side. Each lateral cephalogram was traced by the same investigator on tracing film (Unitek/3M Dental Products, Monrovia, Calif) with a mechanical pencil and 0.03 mm lead. Each landmark was digitized directly with an electronic caliper.

A malocclusion is the sum of a variety of individual deviations, none of which may be remarkable alone.[25] In order to comprehensively describe changes from T1 to T2, various techniques were used, including traditional cephalometric analysis, an x-y coordinate system, and occlusal plane analysis.

Traditional cephalometric analysis (Quick Ceph Image, Orthodontic Processing Co, Chula Vista, Calif) provides the means to describe changes in routine orthodontic language. Thirty-six landmarks were used to generate measures from the Steiner,[26] McNamara,[27] and Ricketts[28] analyses. Once the lateral cephalogram was traced, each landmark was digitized and the data stored on the hard drive of an M 1297 Macintosh II computer.

An x-y coordinate system provides information about the movement of specific anatomical landmarks in the horizontal (x) and vertical (y) planes of the space. A system of 70 landmarks was digitized on each tracing and included maxillary, mandibular, cranial base, dental, and soft tissue landmarks. Points were digitized in a predetermined order using a Houston Instruments HIPAD accurate to 0.1 mm. Prior to digitizing, each tracing was superimposed on sella (S) rotated 6 degrees down from the sella-nasion line (which approximates the true horizontal). A vertical line through sella perpendicular to the horizontal line served as the vertical axis. Changes in all landmarks from T1 to T2 were determined and evaluated for statistical significance using *t*-tests.

Occlusal plane analysis

During cephalometric tracing the pre- and posttreatment films were placed side by side to provide consistent identification of landmarks common to both films. The important areas of superimposition were located at SE point (intersection of the averaged greater wings and planum of the sphenoid), the first molars (transferred with a template from the T1 cephalogram to T2 in order to avoid distortions), the functional occlusal plane, the outline of the key ridge, the PTM fissure, and the palatal and mandibular symphyseal internal trabecular architecture. During the superimposition process, three feducial lines (maxilla, mandible, and cranial base) were drawn on each tracing and transferred to the other in order to facilitate future superimposition. To determine the relative contributions of skeletal and tooth movement measured parallel to the functional occlusal plane, the method described by Johnston[25] was employed. Regional superimposition was done carefully in order to quantify as precisely as possible the amount of maxillary and mandibular movements relative to the cranial base and each other. Total molar and incisor corrections were also analyzed.

To record maxillary superimposition, the palatal plane was superimposed on ANS-PNS, the trabeculae of the palate, and the lingual palatal curvature. The two functional occlusal planes were then averaged, and the resulting mean functional occlusal plane was recorded on each tracing. Maxillary displacement relative to cranial base was measured by the shift between SE points. Mandibular superimposition was performed on natural reference structures, which included the tip of the chin, inner cortical structure at the inferior border of the symphysis, trabecular structures related to the mandibular canal, and the contour of the molar germ. D-point was an arbitrary point marked on the symphysis and was transferred to the second film during mandibular superimposition. Mandibular displacement relative to the maxilla was measured by the shift in D-point, while the mandibular displacement relative to cranial base was calculated by an algebraic subtraction of maxilla from ABCH.

By superimposing the internal structures of the maxilla, we were able to measure maxillary molar and incisor movement; the lower teeth were measured after superimposition of the mean functional occlusal plane (MFOP) on D-point. The distal contact point on each molar was the reference point for measurement. Incisor correction was measured at the incisal edge. Algebraic analysis confirmed the consistency of the results.

The measurements made with this analysis were: maxillary molar crown movement; apical base change (ABCH); maxillary translatory growth relative to the cranial base; mandibular change relative to maxilla; mandibular molar correction; total molar correction; maxillary molar correction; maxillary incisor correction; mandibular incisor correction; total incisor correction.

Since each lateral headfilm provides the basis for a carefully prepared tracing to be digitized and hand-measured, considerable attention was given to maintaining a high degree of accuracy. Duplicate tracings and digitizings were performed for 10 radiographs on a double-blind basis. Reliability was measured using Dahlberg's formula to quantify the amount of test-retest error.[29]

Mean parameter changes were compared by

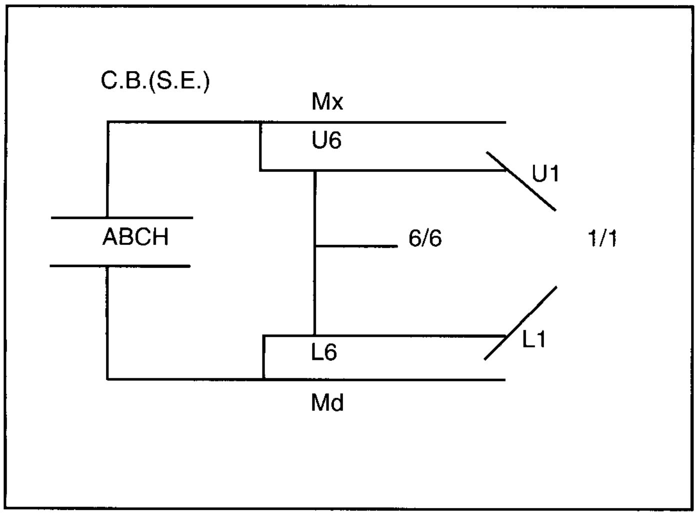

Figure 1

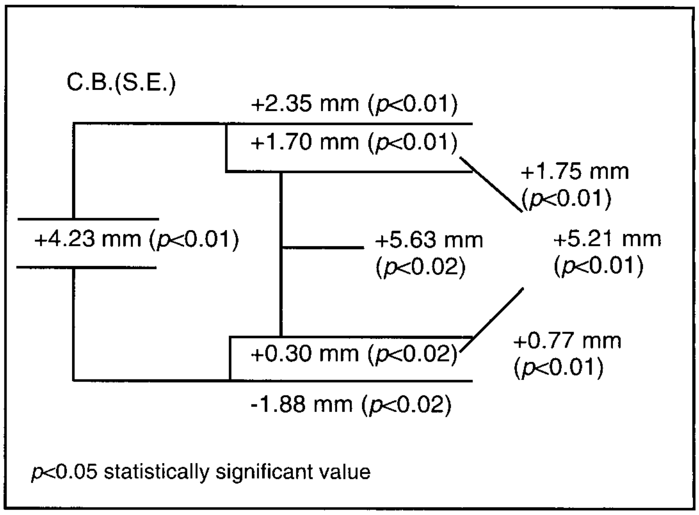

Figure 2

Figure 1
"Pitchfork" analysis showing anteroposterior skeletal and dental components of molar and overjet correction. Maxilla (Mx) + Mandible (Md) = Total Skeletal or Apical Base Change (ABCH); ABCH + Upper molar (U6) + Lower molar (L6) = Molar correction (6/6); ABCH + Upper incisor (U1) + Lower incisor (L1) = Overjet correction (1/1).

Figure 2
Mean changes along the occlusal plane.

repeated measures analysis of variance (ANOVA) and corresponding post hoc *t*-tests. Since many of the parameters could be mutually correlated, the individual ANOVA/*t*-tests were preceded by a screening multivariate ANOVA (MANOVA) in order to address the possibility of type I (false positive) significance.

Results

The treated group averaged 7.26 years at T1 and 8.18 years at T2. The mean treatment time was 11.05 mos. The results revealed statistically significant ($p<0.01$)forward movement of the maxilla, observed by changes of +3.34 mm at A-point and +3.17 mm at ANS (Table 1). In addition, SNA increased +2.35°, and maxillary depth increased +2.22°. A counterclockwise rotation of the maxilla was seen with PNS moving down (-2.21 mm, $p<0.01$) more than ANS (-0.82 mm, $p<0.17$) with a change in SN-PP of -1.90° ($p<0.01$).

The mandible moved inferiorly, with significant changes observed at B-point (-3.85 mm), menton (-4.34 mm), and pogonion (-4.06 mm). Some posterior movement of the mandible also was found, with decreases observed in SNB (-1.32°) and facial axis (-1.63°). In the vertical dimension, lower face height increased (+2.07°, $p<0.01$), as did the mandibular-plane-to-FH-angle (+1.70°, $p<0.03$). Combined maxillary and mandibular changes resulted in increases in the ANB angle (+3.66°, $p<0.01$).

Statistically significant changes were also observed along the occlusal plane (Figure 1). Total apical base change (ABCH) was +4.23 mm ($p<0.01$). The maxilla moved anteriorly +2.35 mm ($p<0.01$) while the maxillary molars moved +1.70 mm and the incisors moved +1.75 mm. The mandible showed backward movement of -1.88 mm ($p<0.02$) while the lower molars moved forward 0.30 mm and the incisors 0.77 mm ($p<0.01$, Figure 2).

Additional changes in the midface were found with statistically significant increases ($p<0.01$) in midfacial length (TMJ-ANS, +3.53 mm) and forward displacement of orbitale (+2.04 mm) and the key ridge (+1.12 mm, Table 1). The soft tissue profile revealed several statistically significant ($p<0.01$) changes (Table 2). Pronasale (nasal tip) moved forward (+3.43 mm) as did subnasale (+3.08 mm) and labrale superius (+3.67 mm). Soft tissue menton moved down -3.49 mm.

Dahlberg's[29] formula was used to determine the error standard deviations for the variables in each data set. For the traditional measures data, linear measurements had a mean error of -0.005 mm, with a standard deviation of 0.011 mm. Angular measurements had a mean error of -0.21°, with a standard deviation of 0.772°. The average error in the x-y coordinate data was 0, with a standard deviation of 0.026 mm. For measures relative to mean functional occlusal plane, the mean error was 0.009 mm, with a standard deviation of 0.035 mm.

Discussion

The results of this study demonstrate that significant orthopedic changes can occur with palatal expansion/facemask therapy. All measures of maxillary position showed statistically significant changes, with 3.17 and 3.34 mm of forward movement at ANS and A-point, respectively. These changes are larger than the 1.68 mm (ANS and A-pt.) and 1.76 mm (A-pt.) previously reported.[23,30] Studies examining changes in SNA have reported mean movements of +0.81° to +1.3°,[17,21] +1.4°,[31] and +2.04°.[20] Our findings of SNA increasing +2.35° indicate that a significant maxillary response occurred in this group of patients.

Of equal importance are the vertical changes observed. PNS moved inferiorly 2.21 mm while ANS moved down only 0.82 mm, resulting in a counterclockwise rotation of the maxilla. Similar maxillary movement has also been observed, with slightly less downward movement of PNS (-1.3mm).[30] Downward movement of the maxilla has been observed to a much lesser extent with palatal expansion alone,[32-35] and probably contributes to the changes observed in mandibular position. In this study, menton moved down -4.34 mm while little anteroposterior change was observed at the chin. Previous studies have also reported small changes in SNB, including +0.20°,[30] +0.86°,[21] and -0.80°.[31]

Changes in mandibular position during facemask therapy may be due to factors such as the design of the facemask and intraoral appliance or the treatment time observed. Takada et al.[20] reported a greater change at SNB (-2.11°) that was probably due to the chin cup portion of the appliance, which applied a 300 to 400 g retraction force to the mandible. Backward rotation of the mandible is a common feature of Class III chin cup therapy.[36-43]

Studies with shorter treatment times may also have a tendency to report greater mandibular change. Many Class III patients with significant negative overjet will display edge-to-edge incisors within 1 to 2 weeks of the start of treatment. This rapid change in occlusion is caused primarily by a positional change in the mandible, due to the effects of palatal expansion disrupting the occlusion. Petit[24] reported that SNB changed more than SNA (-1.85° vs. +1.00°) with treatment that lasted only 4 to 21 days. Ngan et al.[21] reported almost identical changes in SNA and SNB (+0.81° and -0.86°) with patients averaging only 6 months of treatment. A subsequent study reported larger, although again almost equal, SNA and SNB changes (+1.3° and -1.7°).[17] Our study reported greater maxillary than mandibular change after 11.05 months of treatment (SNA +2.35° vs. SNB -1.32°). Longer treatment times contribute to greater maxillary movement, but also allow further mandibular growth, resulting in SNB values that return to those measured at the beginning of treatment. Other factors, such as facial pattern or initial overbite, may also affect the amount of mandibular rotation that can occur. Patients with a deep overbite and short lower face height can afford greater clockwise rotation of the mandible than those with minimal overbite and a long lower face.

Table 2
Mean changes in soft tissue landmarks relative to the x-y axis

Variables		Mean	SE	SD	*p*
Profile AP					
Pronasale	mm	3.43	0.57	2.60	0.01
Subnasale	mm	3.08	0.50	2.28	0.01
Labrale sup.	mm	3.67	0.47	2.13	0.01
B-point	mm	-0.44	0.64	2.95	0.50
Soft menton	mm	0.44	0.93	4.26	0.64
Profile vertical					
Pronasale	mm	-0.22	0.62	2.85	0.72
Subnasale	mm	-0.90	0.71	3.26	0.22
Labrale sup.	mm	-1.38	0.80	3.66	0.10
B-point	mm	-3.42	0.84	3.83	0.01
Soft menton	mm	-3.49	1.10	5.05	0.01

$p<0.05$ Statistically significant

In addition to the hard tissue changes documented in this study, significant changes in the soft tissue profile were also observed. Pronasale, subnasale, and labrale superius moved anteriorly 3.43, 3.08, and 3.67 mm, respectively. The chin maintained the same anteroposterior position, although it moved inferiorly. These changes contributed to the profile becoming more convex. Although the improvement of facial esthetics is a major objective of early orthopedic treatment, few studies have reported these changes, which are some of the most dramatic effects observed. Turley[15] reported changes that have been supported by Ngan et al.,[16] who found hard-to-soft-tissue movement of 50% to 79% in the maxilla and 71% to 81% in the mandible.

Examination of other structures revealed statistically significant anterior movement of orbitale (+2.04 mm) and key ridge (+1.12 mm). Although these structures were not examined in previous clinical studies, ample evidence to support these findings is evident from animal studies. Kambara[11] and Jackson et al.[12] reported 2.0 mm forward movement of key ridge due to apposition in the zygomaticomaxillary suture. Nanda[13] also observed forward displacement of the midface without reporting specific values. A patient in this study who wore eyeglasses developed soft tissue indentations due to the midface becoming more anteriorly positioned. Increased convexity in the midface has been previously observed.[15]

In comparing the results of our study with previous studies, differences in appliance design, sample size, age and sex, force level, hours of wear per day, as well as overall treatment time, must be taken into account. Most previous studies of facemask/palatal expansion report shorter treatment times than the 11.05 months averaged in this study. This difference may be due to practitioner preference for when to cease treatment and obtain the second radiograph. For example, overcorrection may result in the second film being obtained some months after normal overjet has been obtained. Jackson et al.[12] showed a significant relapse potential in the first months following treatment, when no orthopedic retention was used. Many patients in this study were overcorrected, approaching an end-to-end canine relationship followed by nighttime wear for 3 to 6 months.[44]

The amount of maxillary movement observed in this study is among the highest reported and may be due to a number of factors. Palatal expansion alone usually initiates forward maxillary movement[32-35] and may assist further movement by initiating activity in the circummaxillary sutures. Baik demonstrated greater maxillary movement when the facemask was used with palatal expansion as compared with a labiolingual appliance.[18] A longer treatment time (11.05 months), as well as greater number of hours of wear per day may also be significant. The patients in this study were instructed to wear the appliance full-time for the first month of treatment, and we suspect at least 16 to 20 hours/day was the norm for most patients. Most studies report 8 to 12 hours/day facemask wear.[16,17,20,21]

The amount of dental movement contributing to the Class III correction is identical to that reported by Ngan et al.,[17] who found 1.6 and 1.7 mm forward movement of the maxillary molar and incisor, matching our results of 1.7 and 1.75 mm for the same teeth. However, in many of the cases, skeletal versus dental change could not be determined with certainty. Many patients started treatment in the primary dentition, hence pretreatment incisor position could not be compared with posttreatment position due to the exfoliation and then normal eruption of the incisors. Similarly, first permanent molars were often not yet erupted at the start of treatment, making it impossible to determine precise molar movement with treatment. However, the results do indicate that although some dental movement occurs with treatment, the majority of the correction is skeletal in nature.

The occlusal plane analysis requires the mandible, maxilla, and greater wings of the sphenoid to be individually superimposed. This method helps determine the relative contribution of each skeletal and dental component to the Class III correction. The process of creating an averaged occlusal plane as a reference line to measure changes may have some shortcomings, however. For example, none of the patients in this study had fixed appliance therapy in the lower arch during the first phase of treatment. Superimposing on mandibular structures via the method of Björk[45] often showed minimal changes in the position of the lower teeth. Using the averaged occlusal plane as a reference plane often showed considerable movement of the mandibular dentition in the same cases. Comparing molar and incisor movement with these two methods, and only in patients where these teeth have erupted to the occlusal plane prior to treatment, might provide the most accurate estimate of dental change with treatment.

It is important to remember that the changes observed from T1 to T2 are a combination of treatment effects and normal growth. To determine normal growth changes, we attempted to accumulate a sample of Class III patients from existing growth studies in the United States and Canada. Of the 12 centers contacted, only three agreed to make records available. When cases were screened to match for age, sex, and race, only 8 cases met the criteria. We did not think it was appropriate to compare our sample of mostly Caucasian patients with available samples of other ethnic types (i.e., Japanese or Chinese). Studies on normal growth have shown that angular measures of maxillary and mandibular position show minimal change with increasing age. Gallagher[30] and Ngan et al.[21] examined untreated Class I and III controls, respectively, and reported small decreases in SNA (-0.9° and -0.76°) and negligible changes in SNB (+0.30° and -0.26°) after 9 and 6 months of growth. Data on normal annual growth from the Bolton study revealed a change of -0.5° for SNA and no change for SNB.[45] The University of Michigan sample shows SNB increasing only 1.3° from age 6 to 11 in females and SNA remaining relatively unchanged (+0.4°) during the same period.[47] These negligible changes with normal growth further illustrate the significance of the treatment effects seen in this sample of patients.

Summary and conclusions

This study attempted to comprehensively describe the cephalometric changes that occur with facemask/palatal expansion therapy by using traditional cephalometric measures, an x-y coordinate system, and functional occlusal plane analysis. The results demonstrate that the correction of Class III malocclusion occurs by a combination of skeletal and dental movements that occur not only in the anteroposterior dimension, but also in the vertical plane of the space. When evaluating the relative contribution of orthopedic versus orthodontic movements, we found that the majority of Class III correction occurs by orthopedic movement, with most of the change in the maxilla.

The combined skeletal and dental effects contributed to the profile becoming more convex, with the midface approximately 3.5 mm farther forward than at the start of treatment and the chin displaced a similar amount vertically. These changes are ideally suited for the patient who initially presents with deep overbite, anteroposterior and vertical maxillary deficiency, and normal to mildly prognathic mandibular dimensions.

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