ORIGINAL ARTICLE CE

Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion

Chun-Hsi Chung, DMD, MS,[a] and Blanca Font, DDS[b]
Philadelphia, Pa, and Palma de Mallorca, Spain

The purpose of this study was to examine the maxillary and mandibular responses to rapid palatal expansion (RPE) in all 3 dimensions. Twenty children (average age, 11.7 years) who required RPE treatment were included in this study. Pre- (T1) and post-RPE (T2) lateral and posteroanterior (PA) cephalograms and study models were taken for all patients. For each patient, lateral and PA cephalograms at T1 and T2 were traced, and the sagittal, vertical, and transverse measurements were made. In addition, on the pre- and postexpansion models, the widths between the first premolars, the first molars, and the two acrylic halves of the Haas-type expander were measured. Results showed that from T1 to T2, the mean SNA increased 0.35° ($P < .05$) and ANB increased 1.00° ($P < .05$). Both the ANS and PNS moved downward (1.30 mm and 1.43 mm, respectively, $P < .05$), and the mandibular plane angle (MP-SN) increased 1.72° ($P < .05$). The maxillary and mandibular incisors did not change significantly after RPE. After RPE, the mean increase of maxillary interpremolar width, maxillary intermolar width, maxillary width (J-J), nasal width, and interorbital width were found to be 110.7%, 104.5%, 30.1%, 23.1%, and 3.3% of the screw expansion, respectively. After RPE treatment in children, the maxilla displaced slightly forward and downward ($P < .05$); the mandible rotated downward and backward, and the anterior facial height increased significantly ($P < .05$); and the widths of the maxilla and nasal cavity increased significantly ($P < .05$). (Am J Orthod Dentofacial Orthop 2004;126: 569-75)

Rapid palatal expansion (RPE) has been widely used by many orthodontists to increase the maxillary transverse dimension in young patients. The rationale is that the orthopedic force exerted by the expander can open the midpalatal suture, which is usually patent in children, and thus the palate is expanded.[1-10] However, for a skeletally more mature adolescent or adult, the suture is often fused, and RPE tends to be much less effective.[7-9]

Many studies have been reported regarding the maxillary and mandibular responses after RPE on the sagittal and vertical dimensions (as assessed on lateral cephalograms), but their results are inconclusive. For example, Haas[1] and Davis and Kronman[5] found that the maxilla moved downward and forward after RPE with a banded (Haas-type) expander, whereas Silva Filho et al[11] found that the maxilla did not change sagittally but moved downward after RPE, displaying a downward and backward rotation in the palatal plane. Wertz[6] and Wertz and Dreskin[10] reported that the maxilla moved downward and backward in some patients and downward and forward in others after RPE treatment. Wertz[6] also reported that the maxillary incisors retroclined after RPE (1/-SN decreased). On the other hand, Sandlkçloglu and Hazar[12] reported that maxillary incisors became more proclined (1/-SN increased) after RPE. In terms of the mandibular response, some investigators found that it rotated backward, resulting in a higher mandibular plane angle and an increased lower facial height when banded RPE was used.[5,6,11,12] Using a bonded RPE appliance (with occlusal coverage), Akkaya et al[13] reported that the maxilla moved forward and the mandible moved backward. Therefore, the ANB and mandibular plane angle increased significantly after expansion. Similar results were reported by Basciftci and Karaman.[14] Nonetheless, Sarver and Johnston[15] reported that the maxilla moved forward less in the bonded RPE sample than in the banded RPE sample. They found the maxilla even moved backward in some bonded RPE patients.

In terms of the skeletal and dental effects of RPE on

[a]Associate professor, Department of Orthodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, Pa.
[b]Private practice, Palma de Mallorca, Spain; former orthodontic resident, School of Dental Medicine, University of Pennsylvania.
Reprint requests to: Dr Chun-Hsi Chung, University of Pennsylvania School of Dental Medicine, Department of Orthodontics, The Robert Schattner Center, 240 South 40th Street, Philadelphia, PA 19104-6030; e-mail, chunc@pobox.upenn.edu.
Submitted, May 2003; revised and accepted, October 2003.
0889-5406/$30.00

doi:10.1016/j.ajodo.2003.10.035

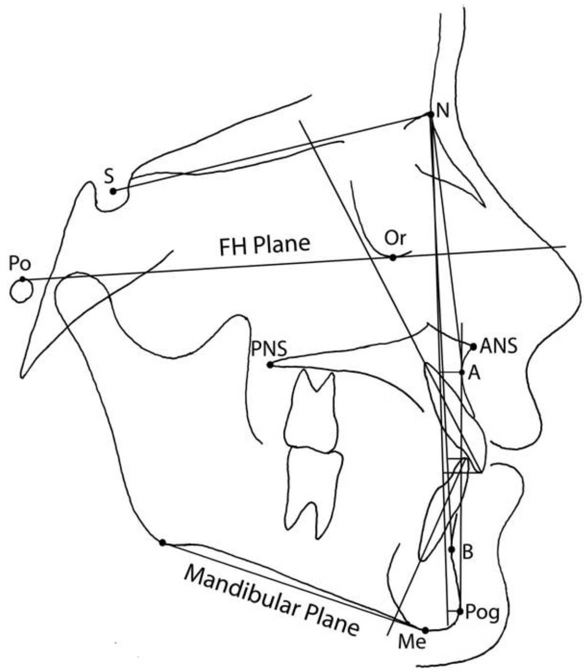

Fig 1. Cephalometric tracing illustrating measurements of SNA (in degrees), SNB (in degrees), ANB (in degrees), FH-NA (in degrees), N-A-Pog (in degrees), A-Nperp (in millimeters), Pog-Nperp (in millimeters), 1/-NA (in degrees and millimeters), 1/-SN (in degrees), 1/-Nperp (in millimeters), 1/-NB (in degrees and millimeters), and IMPA (in degrees).

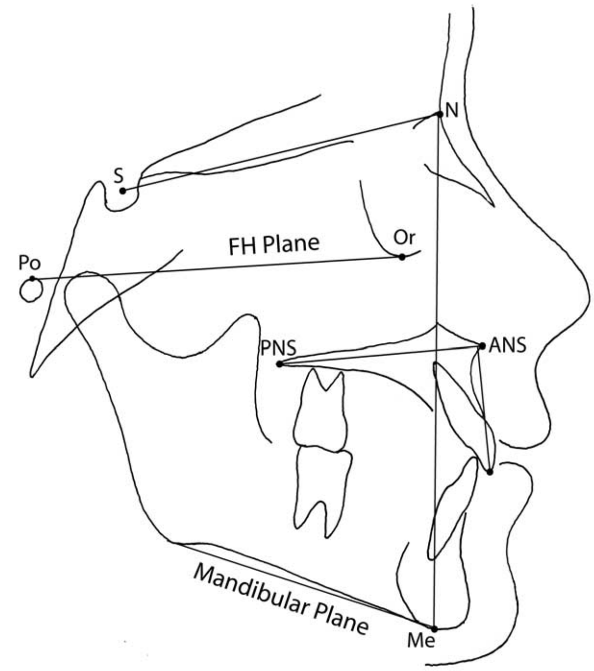

Fig 2. Cephalometric tracing illustrating measurements of ANS difference (in millimeters), PNS difference (in millimeters), PP-SN (in degrees), PP-MP (in degrees), MP-SN (in degrees), N-Me (in millimeters), 1/-PP (in millimetres). Values of ANS difference and PNS difference were calculated by superimposing lateral cephalograms (T1 and T2) on anterior cranial base and measuring distance between initial position of ANS and PNS at T1 and their final position at T2.

the transverse dimension, many studies have shown increases in the width of the maxilla, nasal cavity, and maxillary arch with use of a banded or a bonded expander.[1,5,6,10,12,16-21] However, very limited information is available in the literature regarding the amount of transverse skeletal and dental expansion in relation to the amount of appliance expansion in children.

The purpose of the study reported here was to examine in adolescents the skeletal and dental changes induced by RPE, in all 3 dimensions.

MATERIAL AND METHODS

Twenty healthy white children (mean age 11.7 years, range 10.0-13.5 years; 6 male, 14 female) who required RPE treatment, from the Orthodontic Clinic of the University of Pennsylvania, were selected for the study. The skeletal age of each patient was determined on the hand-wrist radiograph, according to the standards set by Greulich and Pyle.[22] The mean skeletal age of the patients was 11.9 years (range, 10.0-13.3 years).

Pretreatment (T1) orthodontic records, including posteroanterior (PA) and lateral cephalograms, were taken for all patients. For each patient, a Haas-type palatal expander was banded on the maxillary first premolars and first molars (16 patients). When the maxillary first premolars were not erupted, the expander was banded only on the maxillary first molars (4 patients). After the expander was cemented and before it was activated, a maxillary impression was taken with alginate and poured with dental stone. All the expanders were made at the in-house orthodontic laboratory of the University of Pennsylvania.

For each patient, the expander was activated 2 turns per day (0.2 mm per turn) for 2 to 4 weeks, until the required expansion was achieved. Then, the expander was tied off with a ligature wire. Postexpansion (T2) PA and lateral cephalograms were taken the day the expander was inactivated. Also, a postexpansion maxillary impression was taken with alginate and poured with dental stone. The mean interval between T1 and T2 was 96.5 days (range, 34-185 days).

All patients did not receive brackets or wires on the maxillary arch until the T2 records were taken. Four patients had mandibular appliances placed before T2 because of their treatment needs. For these patients, only maxillary measurements were analyzed because the appliances on the mandibular arch might have affected the mandibular cephalometric measurements.

The definition of the landmarks corresponded to those given by Ricketts et al[23] and Riolo et al.[24] Each cephalogram was traced by one examiner (B.F.) and verified by another (C-H.C.). All the cephalometric landmarks were in agreement with both examiners. To minimize the tracing error, the lateral cephalograms at T1 and T2 were superimposed on the cranial base to match the landmarks of porion and orbitale. The cusp tips of the maxillary first premolars and first molars on the pre-RPE model were dotted with a 0.5-mm pencil, and the same cusp tips were dotted on the post-RPE model of the same patient. Similarly, on the pre- and post-RPE models, the mesial surfaces of the two acrylic halves at the jackscrew of the appliance were marked with a 0.5-mm pencil. The following measurements were made:

1. Sagittal skeletal (Fig 1): SNA angle (in degrees), SNB angle (in degrees), ANB angle (in degrees), Frankfort horizontal plane to NA angle (FH-NA, in degrees), N-A-pogonion angle (N-A-Pog, in degrees), A-N perpendicular (A-Nperp, in millimeters), Pog-Nperp (in millimeters). Increases in angular measurements from T1 to T2 were considered positive, and decreases were considered negative. For linear measurements, a forward displacement of the skeletal structure from T1 to T2 was considered positive, whereas a backward displacement was given a negative value.
2. Sagittal dental (Fig 1): 1/-NA (in degrees and millimeters), 1/-SN (in degrees), 1/-Nperp (in millimeters), /1-NB (in degrees and millimeters), incisor-mandibular plane angle (IMPA, in degrees). Increases in angular measurements from T1 to T2, indicating maxillary incisor proclination, were considered positive, and decreases in angular measurements, indicating incisor retroclination, were considered negative. For the linear measurements, a forward movement of the maxillary incisor was considered positive, and a posterior movement was considered negative.
3. Vertical (Fig 2): ANS difference (in millimeters), PNS difference (in millimeters), palatal plane to SN (PP-SN, in degrees), PP to mandibular plane (PP-MP, in degrees), MP-SN (in degrees), N-menton (N-Me, in millimeters), 1/-PP (in millimeters). The values of the ANS difference and the PNS difference were calculated by superimposing the lateral cephalograms (T1 and T2) on the anterior cranial base and measuring the distance between the initial position of ANS and PNS at T1 and their final position at T2. If ANS and PNS moved downward from T1 to T2, the value was considered positive, and if ANS and PNS moved superiorly, the value was considered negative. If ANS moved down inferiorly more than PNS, the angle PP-SN increased and was assigned a positive value; if PNS moved down more than ANS, the angle decreased, and the value was negative. An increase in PP-MP and MP-SN angle from T1 to T2 was considered positive, and a decrease was considered negative. Increases in the N-Me and 1/-PP from T1 to T2 were considered positive, and decreases were considered negative.
4. Transverse skeletal (Fig 3): Mo-Mo (interorbital width: distance between the most medial points of the left and right orbital contours; in millimeters), Ln-Ln (nasal width: distance between the most lateral points of the nasal cavity, in millimeters), J-J (maxillary width: distance between left and right J points,[23] in millimeters), Ag-Ag (mandibular width: distance between the points located at the antegonial notch,[23] in millimeters) were measured on each PA cephalogram

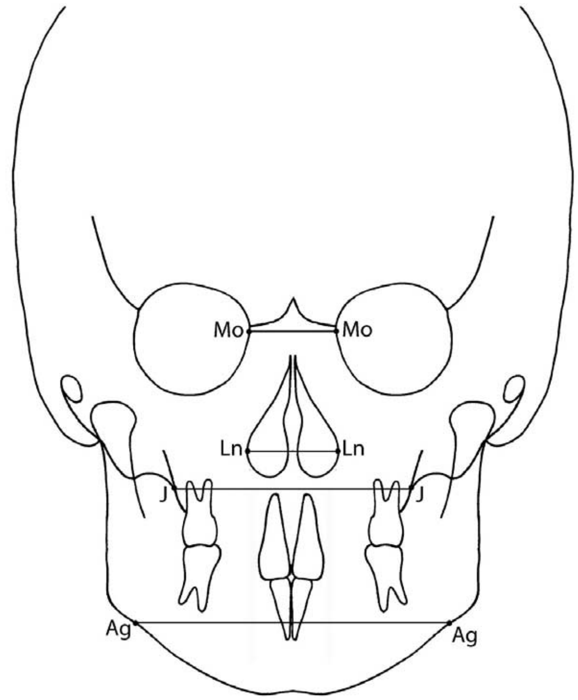

Fig 3. Cephalometric tracing illustrating measurements of Mo-Mo (medial orbital width, in millimeters), Ln-Ln (nasal width, in millimeters), J-J (maxillary width, in millimeters), and Ag-Ag (mandibular width; in millimeters).

with a digital caliper (Chicago Brand, Orthopli, Philadelphia, Pa) to the accuracy of 0.01 mm. All the transverse measurements were converted by eliminating the magnification factor of 8.5%, which was based on the standardized 13-cm object-film distance in this study.[25] The amount of expansion by the appliance was determined by comparing the distance between the acrylic halves of the appliance before and after expansion (see below). The ratio of actual transverse increase (or decrease) of Mo-Mo, Ln-Ln, J-J, interpremolar width, and intermolar width to the actual amount of appliance expansion was calculated for each measurement. Increases in width from T1 to T2 were considered positive, and decreases were considered negative.

5. Transverse dental: On the pre- and post-RPE maxillary models of each patient, the distances between the dotted cusp-tips of the first premolars, the first molars, and acrylic halves of the appliance were measured with a digital caliper (Orthopli) by one examiner (B.F.) and confirmed by another (C-H.C.). The differences between the pre- and post-RPE measurements represented the amount of expansion in the first premolars, the first molars, and the appliance. Increases in width between T1 and T2 were considered positive, and decreases were considered negative.

To test intraexaminer reliability, 10 cephalograms and 10 study models were randomly selected, retraced, and remeasured by the same examiners and compared with the original measurements. The data were tested for normality with the Kolmogorov-Smirnov method. When the data were normally distributed, a Student paired *t* test was used to determine whether the measurements at the 2 different time periods showed any significant difference. If the data were not normally distributed, a Wilcoxon signed rank test was used.

Descriptive statistics including the mean, standard deviation (SD), and ranges were calculated for the measurements at T1 and T2. The data were tested for normality with the Kolmogorov-Smirnov method. When the data were normally distributed, a Student paired *t* test was used to evaluate whether the changes from T1 to T2 were significantly different. If the data were not normally distributed, a Wilcoxon signed rank test was used. For the comparisons of the transverse dental changes of the premolar expansion, molar expansion, and appliance expansion, the data were tested for normality with the Kolmogorov-Smirnov method. When the data were normally distributed, a Student *t* test was used. If the data were not normally distributed, a Mann-Whitney rank sum test was used. Significance for all statistical tests was predetermined at $P < .05$.

Table I. Sagittal skeletal effects of RPE

	n	*Mean difference from T1 to T2*	*SD*	*Range*
SNA (°)	20	+0.35*	0.71	−1.50 to 1.50
SNB (°)	16†	−0.50	1.02	−2.50 to 1.00
ANB (°)	16†	+1.00*	1.08	−1.00 to 2.50
FH-NA (°)	20	+0.60*	0.77	−1.50 to 2.00
N-A-Pog (°)	16†	+2.25*	2.11	−1.50 to 2.00
A-Nperp (mm)	20	+0.58*	0.71	−0.50 to 2.00
Pog-Nperp (mm)	16†	−1.34	2.77	−6.00 to 2.50

*Statistically significant, $P < .05$.
†Four patients were excluded because mandibular appliances were placed.

RESULTS

The intraexaminer reliability test showed no statistically significant difference in the cephalometric measurements between the original tracing group and the retracing group ($P > .05$) or in the study model between the original measurements and the second measurements ($P > .05$). The difference between the original and the retracing measurements was less than 0.5° and 0.25 mm.

Sagittal skeletal effects

Sagittal skeletal effects are detailed in Table I. SNA, ANB, FH-NA, N-A-Pog, and A-Nperp increased a mean of 0.35°, 1.00°, 0.60°, 2.25°, and 0.58 mm, respectively, after RPE ($P < .05$). SNB and Pog-Nperp had a mean decrease of 0.50° and 1.34 mm, respectively, from T1 to T2, although these decreases were not statistically significant.

Sagittal dental effects

Sagittal dental effects are listed in Table II. 1/-NA (degrees), 1/-SN (degrees), and 1/-NA (millimeters) showed mean decreases of 0.75°, 0.43°, and 0.33 mm, respectively. 1/-Nperp (millimeters), /1-NB (degrees), and /1-NB (millimeters) had mean increases of 0.25 mm, 0.53°, and 0.31 mm, respectively, and IMPA had a mean decrease of 0.59°. All the sagittal dental changes from T1 to T2 were not statistically significant ($P > .05$).

Vertical skeletal effects

Vertical skeletal effects are listed in Table III. Both ANS and PNS moved significantly downward (1.30 mm for ANS and 1.43 mm for PNS). The increase of the MP-SN angle (+1.72°) suggested a downward and backward rotation of the mandible, which resulted in a

Table II. Sagittal dental effects of RPE

	n	*Mean difference from T1 to T2**	*SD*	*Range*
1/-NA (°)	20	−0.75	2.33	−4.00 to 3.50
1/-NA (mm)	20	−0.33	0.77	−1.00 to 2.00
1/-SN (°)	20	−0.43	2.27	−4.00 to 3.50
1/-Nperp (mm)	20	+ 0.25	1.20	−1.50 to 2.50
/1-NB (°)	16†	+ 0.53	2.08	−5.00 to 3.50
/1-NB (mm)	16†	+ 0.31	0.63	−1.00 to 1.00
IMPA (°)	16†	−0.59	1.83	−5.00 to 1.50

*All the differences were not statistically significant, $P > .05$.
†Four patients were excluded because mandibular appliances were placed.

Table III. Vertical effects of RPE

	n	*Mean difference from T1 to T2*	*SD*	*Range*
ANS (mm)	20	+1.30*	1.14	−0.50 to 3.50
PNS (mm)	20	+1.43*	1.00	−0.50 to 4.00
PP-SN (°)	20	+0.13	0.96	−1.00 to 2.50
PP-MP (°)	16†	+1.56*	1.72	−2.00 to 3.50
MP-SN (°)	16†	+1.72*	1.22	−0.50 to 4.00
N-Me (mm)	16†	+3.38*	1.60	1.00 to 7.50
1/-PP (mm)	20	+0.13	0.60	−1.00 to 1.00

*Statistically significant, $P < .05$.
†Four patients were excluded because mandibular appliances were placed.

significant increase of anterior facial height (N-Me, +3.38 mm). The PP-SN did not change significantly (+0.13°, $P > .05$), but the PP-MP increased significantly (+1.56°). The 1/-PP (mm) did not show significant changes (+0.13 mm, $P > .05$).

Transverse skeletal effects

Transverse skeletal effects are detailed in Table IV. There were statistically significant increases in the widths of Mo-Mo (+0.25 mm), Ln-Ln (+1.75 mm), J-J (+2.28 mm), and Ag-Ag (+0.29 mm). The mean expansion from the Haas appliance was 7.58 mm (see Table V); thus, the mean J-J increase was 30.1% of the actual appliance expansion, followed by Ln-Ln (23.1%), and Mo-Mo (3.3%).

Transverse dental effects

Transverse dental effects are listed in Table V. The measurements on the maxillary study models showed that the mean expansion for the maxillary first premolars and the first molars were 8.39 mm and 7.92 mm, respectively. Because the mean actual expansion from the Haas appliance was 7.58 mm, the expansion of 0.81 mm (9.7%) for the first premolars and 0.34 mm (4.3%) for the first molars was due to buccal crown tipping ($P > .05$).

DISCUSSION

The objective of this study was to evaluate the skeletal and dental responses in the sagittal, vertical, and transverse planes immediately after RPE treatment. Our data clearly showed that there was a statistically significant forward displacement of the maxilla in the sagittal plane (SNA increased 0.35°, FH-NA increased 0.60°, A-Nperp increased 0.58 mm). This finding was in agreement with previous reports by Haas,[1] Davis and Kronman,[5] and Akkaya et al.[13] However, our data disagreed with those of Silva Filho et al,[11] who found no sagittal change of the maxilla induced by RPE, and also with the findings of Sarver and Johnston,[15] who found a backward maxillary displacement in their sample after the bonded RPE treatment. It should be noted that in our study, the amount of maxillary forward movement was small, which might not be clinically significant. Thus, one should not anticipate the RPE to correct a skeletal Class III malocclusion by spontaneous forward maxillary displacement, as suggested by Haas.[3] The use of a reverse-pull headgear in children after RPE might be necessary for skeletal Class III correction. Indeed, Chung et al[26] also reported a statistically significant but small amount (+0.6°, $P < .05$) of forward maxillary movement immediately after surgically assisted RPE in adults.

In the present study, we found that after RPE treatment, the mandible rotated downward and backward, which resulted in a smaller SNB, higher mandibular plane angle, and longer anterior facial height. This could be due to the transverse cusp-to-cusp occlusion from overexpansion of the RPE and the downward displacement of the maxilla. Previous studies by Davis and Kronman,[5] Wertz,[6] and Silva Filho et al[11] also showed an increase in the mandibular plane angle; and Silva Filho et al[11] and Sandlkçloglu and Hazar[12] found a decrease in SNB from the RPE treatment. Sarver and Johnston[15] reported that the mandible did not rotate downward and backward after the bonded RPE treatment. On the other hand, Basciftci and Karaman[14] found that the mandible rotated downward and backward and that the lower facial height increased even though a bonded RPE was used.

Our data showed that the palatal plane displaced downward in an almost parallel manner after RPE. Similar results were reported by Haas,[1] Davis and Kronman,[5] Wertz,[6] and Wertz and Dreskin[10] in children after RPE. Chung et al[26] reported similar results in adults after surgically assisted RPE. Silva Filho et al[11] reported that ANS displaced downward more than PNS after RPE, but Basciftci and Karaman[14] found that PNS moved down more than ANS. Sarver and Johnston[15]

Table IV. Transverse skeletal effects of RPE

	n	Mean difference from T1 to T2	SD	Range	Mean/mean screw expansion (%)	Range/mean screw expansion (%)
Mo-Mo (mm)	20	+0.25*	0.35	0.00 to 0.92	3.3	0 to 16.50
Ln-Ln (mm)	20	+1.75*	0.92	0.92 to 3.23	23.1	15.90 to 37.70
J-J (mm)	20	+2.28*	0.84	0.92 to 4.61	30.1	15.70 to 43.80
Ag-Ag (mm)	16†	+0.29*	0.41	0.00 to 0.92	3.8	0 to 15.90

Mean screw expansion from appliance was 7.58 mm (see Table V).
*Statistically significant, $P < .05$.
†Four patients were excluded because mandibular appliances were placed.

Table V. Transverse dental effects of RPE on maxilla

	n	Mean difference from T1 to T2*	SD	Range
Distance between acrylic halves of the expander (mm)	20	+7.58	1.56	5.33 to 10.53
Distance 4-4 (mm)	16†	+8.39	1.82	4.99 to 11.25
Distance 6-6 (mm)	20	+7.92	2.15	5.44 to 12.15

*There was no statistically significant difference between the groups.
†Four patients were excluded because first permanent premolars had not erupted.

reported that the maxilla did not move downward after bonded RPE treatment.

In the transverse plane, our results showed that after RPE, the amount of expansion followed a triangular pattern, with the greatest increase in maxillary arch width (intermolar or interpremolar), followed by the maxillary width (J-J), the nasal width (Ln-Ln), and interorbital width (Mo-Mo). Previous studies have reported a similar pattern in the expansion of the skeletal structures after the RPE.[1,5,6,10,12,16-21] In the present study, the amount of screw expansion on the study models of each patient was measured, and the linear measurements from PA cephalograms were converted to actual lengths by eliminating the magnification factor. Thus, the relationship between the skeletal expansion and screw expansion could be established (Table IV). As far as we know, this information has not yet been reported. More studies are needed to determine the relationship between the amount of skeletal and dental expansion and the amount of screw expansion for younger and older patients.

In our study, the mean duration from the pretreatment (T1) to the postexpansion (T2) cephalograms was 96.5 days (range, 34-185 days). Thus, some of the skeletal changes in this study could be attributed to growth, although the amount is estimated to be very small.[23,24,27] The significant increase in the nasal width might support the theory that maxillary expansion increases air flow and improves nasal breathing.[1-3,21] The slight increase in mandibular width (+0.29 mm) from T1 to T2 might be due to growth.

The measurements on the pre- and postexpansion models showed that the mean increases of interpremolar width (8.39 mm) and intermolar width (7.92 mm) were greater than the mean screw expansion (7.58 mm), although the differences were not statistically significant ($P > .05$). Our data suggested that 0.81 mm (9.7%) of the interpremolar expansion and 0.34 mm (4.3%) of the intermolar expansion were due to buccal crown tipping, whereas the degree of tipping was not determined. Our findings supported those of Ciambotti et al,[28] who found 6.08° ± 6.25° of buccal crown tipping of the molars after RPE in 12 children with a mean age of 11.1 years. In addition, Chung and Goldman[29] reported 6.48° ± 2.29° of buccal crown tipping of the maxillary first premolars and 7.04° ± 4.58° of buccal crown tipping of the maxillary first molars immediately after surgically assisted RPE in adults.

CONCLUSIONS

1. There was a slight maxillary forward movement induced by RPE treatment ($P < .05$). However, the amount was small and might not be clinically significant.
2. The maxilla displaced downward after RPE ($P < .05$).

3. The mandible moved downward and backward, and the anterior facial height increased significantly after RPE ($P < .05$).
4. Rapid palatal expansion treatment increased the interorbital, maxillary, and nasal widths significantly ($P < .05$).

The authors thank Drs Solomon Katz, Francis K. Mante, and Stephen T. H. Tjoa for their help in this study.

REFERENCES

1. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. Angle Orthod 1961;31:73-90.
2. Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthod 1965;35:200-17.
3. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. Am J Orthod 1970;57:219-55.
4. Krebs A. Midpalatal suture expansion studied by the implant method over a seven-year period. Trans Eur Orthod Soc 1964;40:131-42.
5. Davis WM, Kronman JH. Anatomical changes induced by splitting the midpalatal suture. Angle Orthod 1969;39:126-32.
6. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. Am J Orthod 1970;58:41-66.
7. Isaacson RJ, Ingram AH. Forces produced by rapid maxillary expansion. II. Forces present during treatment. Angle Orthod 1964;34:261-70.
8. Zimring JF, Isaacson RJ. Forces produced by rapid maxillary expansion. III. Forces present during retention. Angle Orthod 1965;35:178-86.
9. Melsen B. A histological study of the influence of sutural morphology and skeletal maturation on rapid palatal expansion in children. Trans Eur Orthod Soc 1972;48:499-507.
10. Wertz R, Dreskin M. Midpalatal suture opening: a normative study. Am J Orthod 1977;71:367-81.
11. Silva Filho OG, Villas Boas MC, Capelozza Filho L. Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation. Am J Orthod Dentofacial Orthop 1991;100:171-81.
12. Sandlkçloglu M, Hazar S. Skeletal and dental changes after maxillary expansion in the mixed dentition. Am J Orthod Dentofacial Orthop 1997;111:321-7.
13. Akkaya S, Lorenzon S, Üçem TT. A comparison of sagittal and vertical effects between bonded rapid and slow maxillary expansion procedures. Eur J Orthod 1999;21:175-80.
14. Basciftci FA, Karaman AI. Effects of a modified acrylic bonded rapid maxillary expansion appliance and vertical chin cap on dentofacial structures. Angle Orthod 2002;72:61-71.
15. Sarver DM, Johnston MW. Skeletal changes in vertical and anterior displacement of the maxilla with bonded rapid palatal expansion appliances. Am J Orthod Dentofacial Orthop 1989;95:462-6.
16. Silva Filho OG, Prado Montes LA, Torelly LF. Rapid maxillary expansion in the deciduous and mixed dentition evaluated through posteroanterior cephalometric analysis. Am J Orthod Dentofacial Orthop 1995;107:268-75.
17. Timms DJ. A study of basal movement with rapid maxillary expansion. Am J Orthod 1980;77:500-7.
18. Memikoglu TU, Iseri H. Effect of a bonded rapid maxillary expansion appliance during orthodontic treatment. Angle Orthod 1999;69:251-6.
19. Cross DL, McDonald JP. Effect of rapid maxillary expansion on skeletal, dental, and nasal structures: a postero-anterior cephalometric study. Eur J Orthod 2000;22:519-28.
20. Baccetti T, Franchi L, Cameron CG, McNamara JA Jr. Treatment timing for rapid maxillary expansion. Angle Orthod 2001;71:343-50.
21. Basciftci FA, Mutlu N, Karaman AI, Malkoc S, Küçükkolbasi H. Does the timing and method of rapid maxillary expansion have an effect on the changes in the nasal dimension? Angle Orthod 2002;72:118-23.
22. Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. 2nd ed. Stanford: Stanford University Press; 1959.
23. Ricketts RM, Roth RH, Chaconas SJ, Schulhof RJ, Engel GA. Orthodontic diagnosis and planning. Denver: Rocky Mountain Data Systems; 1982.
24. Riolo ML, Moyers RE, McNamara JA, Hunter WS. An atlas of craniofacial growth: cephalometric standards from the University School Growth Study. Monograph 2, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan; 1974.
25. Ghafari J, Cater PE, Shofer FS. Effect of film-object distance on posteroanterior cephalometric measurements: suggestions for standardized cephalometric methods. Am J Orthod Dentofacial Orthop 1995;108:30-7.
26. Chung C-H, Woo A, Zagarinsky J, Vanarsdall RL, Fonseca RJ. Maxillary sagittal and vertical displacement induced by surgically assisted rapid palatal expansion. Am J Orthod Dentofacial Orthop 2001;120:144-8.
27. Ricketts RM. Perspectives in the clinical application of cephalometrics: the first fifty years. Angle Orthod 1981;51:115-50.
28. Ciambotti C, Ngan P, Durkee M, Kohli K, Kim H. A comparison of dental and dentoalveolar changes between rapid palatal expansion and nickel-titanium palatal expansion appliances. Am J Orthod Dentofacial Orthop 2001;119:11-20.
29. Chung C-H, Goldman AM. Dental tipping and rotation immediately after surgically assisted rapid palatal expansion. Eur J Orthod 2003;25:353-8.