Cone-beam computerized tomography evaluation of the maxillary dentoskeletal complex after rapid palatal expansion

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Introduction: Rapid palatal expansion (RPE) is routinely used to correct transverse deficiencies in the maxilla, but its effects on the dentoalveolus are uncertain. The purpose of this study was to compare measurements made on cone-beam computerized tomography scans between patients with RPE treatment and controls to determine transverse dimension increases and the amounts of alveolar and dental tipping. Methods: Twenty-five patients with posterior crossbite who required RPE treatment and 25 sex- and age-matched controls (no crossbite) were orthodontically treated and received cone-beam computerized tomography scans at the beginning and middle of treatment. Transverse widths and several angulations were measured, and matched paired t tests used. Results: RPE treatment produced a significant increase in all measured transverse dimensions. Analysis of posttreatment angulation changes in the RPE group showed that the alveolus substantially tipped buccally by nearly 5.6° (measured from a horizontal reference, the base of the hard palate). The angulations of the dentition, however, remained constant before and after treatment (<1° of change) in both groups. Conclusions: These data showed no statistically significant amount of relative dental tipping after RPE treatment but significant alveolar tipping compared with the controls. (Am J Orthod Dentofacial Orthop 2010;138:486-92)

Rapid palatal expansion (RPE) appliances have routinely been used to remedy transverse deficiencies in the maxilla since their conception in the 1900s.1 The effects of RPE on the dentoskeletal complex have been studied with dental casts and lateral and posteroanterior cephalograms. Recent advances in cone-beam computerized tomography (CBCT) 3-dimensional imaging enable the capture and reproduction of a real maxillary section in all 3 planes and hence allow measurement of axial inclinations of the dentition, and changes in the transverse dimensions and the magnitude of displacement of the maxillary halves free from distortion, magnification, and superimposition.2

RPE treatment contributes to the increase in the maxillary arch by a combination of orthodontic (tipping and translation) and orthopedic (bony separation and remodeling at the suture) effects.3-7 Prior investigators noted transverse increases of 3.5 to 9.5 mm,8-15 with averages of 6.04 mm from posteroanterior cephalograms and 6.74 mm from casts.16 The resultant dental tipping ranged from 0° to 24° for both sides,9,11,12,15,17 with an average of 3.1° for 1 side.16

The objective of this study was to compare the dimensional changes of skeletal and dental structures in a group of growing patients treated for maxillary constriction before and after RPE, with a matched control group, using CBCT 3-dimensional imaging. The study quantified the increase in the transverse dimensions of the maxilla’s postpalatal expansion therapy at various levels. We attempted to show the quantity and direction of alveolar and dental responses to the therapy and compare our findings with those reported in the literature.

MATERIAL AND METHODS

Clinical treatment was rendered at the Advanced Orthodontic Clinic at the University of Southern California in Los Angeles. Twenty-five healthy patients (18 girls; mean age, 12.6 years, range, 8.8-15 years; and 7 boys; mean age, 13.2 years; range, 9.1- 15.8 years) who required RPE for unilateral or bilateral crossbite and orthodontic treatment and had CBCT imaging were selected for the study. Twenty-five controls (with
no posterior crossbite), selected for similar age and sex (18 girls; mean age, 12.7 years; range, 8.6-14.7 years; and 7 boys; mean age, 13.2 years; range, 9.2-15.7 years), had orthodontic treatment only (no RPE) and also initial and midtreatment CBCT scans (Table I).

All scans were retrieved from the archives of the department’s NewTom 3G Volume Scanner CBCT unit (QR, Verona, Italy). Clinical judgment and the patients’ age were the key factors in determining that all patients were still growing, and that the treatment preceded the fusion of their midpalatal sutures. All patients were in the late transitional or early permanent dentition stage. They had no craniofacial abnormalities, or previous surgical or extraction treatment.

Patients treated with the RPE had a hyrax palatal expander banded on the maxillary first premolars and first molars. They were monitored weekly for appropriate activation of the appliance. They were advised to activate their appliance 1 or 2 times per day until the required expansion—ie, slight overcorrection of the crossbite defined as the palatal cusp of the maxillary first molar occluded with the buccal cusp of the mandibular first molar—was achieved (average time, 4-6 weeks). After this process, they were stabilized. The RPE (or a transpalatal arch) was used for retention for at least 3 months after expansion. Most patients with RPE had no orthodontic treatment until after the fixed retention period, but several had some appliances placed (such as a 2 × 4) during the fixed retention period. The control patients started orthodontic treatment at approximately the same time as the RPE group started expansion therapy. The scans of all patients were taken as part of beginning and progress records at the midpoint in treatment, which ranged from 11.5 to 24.5 months (average, 17.9 months) for the RPE patients and 11.0 to 30.6 months for the controls (average, 17.1 months). To test for differences in the time elapsed between scans, we conducted a paired t test and found no statistically significant difference between matched pairs of patients (P = 0.441). The patients were asked to put their head in Frankfort horizontal position for the scans.

The scans were imported, and cross-sectional slices were made with InVivo dental software (Anatomage, San Jose, Calif). The slices were coronal bisections through the buccal grooves and the palatal roots of the maxillary first molars. Transverse measurements (Fig 1) and angular measurements (Fig 2) were recorded for each scan.

Identification of the dentoskeletal landmarks and subsequent measurements were manually performed by 1 investigator for both groups (A.K.). Twenty patients (10 RPE treated, 10 controls) were randomly selected, and their images were resliced and remeasured by the same examiner after a 60-day interval.

### Table I. Descriptive statistics for the groups

<table>
<thead>
<tr>
<th></th>
<th>RPE group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>12.8 ± 1.84</td>
<td>12.8 ± 1.83</td>
</tr>
<tr>
<td>Sex</td>
<td>18 male, 7 female</td>
<td>18 male, 7 female</td>
</tr>
</tbody>
</table>

### Statistical analysis

Descriptive statistics (means and standard deviations) were obtained for each measurement before and after treatment. To assess differences among the matched pairs between means of continuous variables, we used the paired t test with the significance level set at 5% and the Wilcoxon signed rank test for nonparametric paired samples. Histograms and Kolmorogov-Smirnov tests were used to check for normality of the variables.

To test the reliability of the measurements, 20 patients were randomly selected, and their images were re-measured by the same examiner after a 60-day interval. The difference between the duplicate measurements was analyzed by computing intraclass correlation coefficients; their means were 0.96 ± 0.017 for the angular measurements and 0.98 ± 0.012 for the transverse measurements; these represent highly reliable measurements.

Statistical analysis was carried out with SAS software (version 9.1, SAS Institute, Cary, NC) with a significance level of 0.05.

### RESULTS

A comparison of transverse measurements at baseline (Table II) showed that the RPE group significantly differed (P < 0.05) from the control group in almost all parameters. All but 3 transverse lengths were significantly greater for the control group before treatment, as expected. At the level of the hard palate, 3.84 mm of width difference was observed between the 2 groups, indicating the extent of transverse deficiency in the RPE group before treatment.

No significant differences between the 2 groups in dental angulation were seen at baseline (Table III). Significant differences were observed between the groups in the angulations between the alveolar bone (P = 0.0002). The angle measured between the alveolus was about 8.65° more acute in the RPE group than in the control group.

In the after-treatment characteristics in absolute transverse changes, the RPE group showed substantial increases in all parameters, with all differing significantly from the control group’s absolute changes. Increases of approximately 5 mm were seen at the
dental level, with 2-mm increases at the skeletal level (Table IV).

No significant absolute angulation changes were observed in the angulations of the dentition. However, the angle of the alveolus significantly increased on average by approximately 5° in the RPE group. These increases were statistically significant when compared with the controls. Whereas the RPE group’s angulations increased, the control group’s angles decreased by an average of 2.84° (Table V).

In the after-treatment comparison of transverse measurements, the base of the maxilla showed no significant difference between the RPE and control groups; however, although the widths of the RPE group appeared to approach those of the controls, they were still smaller (Table VI). No differences were seen in the alveolar structural measurements. Statistically significant differences were seen between the 2 groups in the widths of the dental structures (comparisons of transverse measurements). The dental crown widths of the RPE group were on average 2.5 mm larger than those of the control group.

Posttreatment angular measurements showed no significant differences between the groups, indicating
that the angulations in the RPE treatment group had caught up to those in the control group (Table VII).

Since RPE produces bending and tipping of the alveolar structures, it also moves the teeth they house with the same magnitude and direction. Thus, a relative tip of the posterior teeth is observed. Lagravere et al\textsuperscript{16} concluded that the dental tip produced by the RPE of only 3° was not statistically significant. If this is so, then the difference between the absolute changes in dental angulation and alveolar angulation should be similar. To determine the validity of this theory, the following equation was applied.

\[
\text{Absolute change in alveolar angulation} = \text{absolute change in dental angulation} - \text{absolute dental tip}
\]

The results (Table VIII) indicated that, in the RPE group, there was a great difference between the amounts of tipping in the alveolus and the dentition (6.56°). Therefore, the difference can be assumed to be the amount of absolute tip of the dentition. Both quantities were statistically significantly different ($P = 0.0001$). No difference was observed in the control group, as expected.

When comparing the absolute tip values of the 2 groups, we observed statistically significant differences ($P = 0.0017$; Table IX).

### DISCUSSION

Understanding the effects of RPE treatment on the skeletal and dental components is paramount for every orthodontist. Although the orthodontic literature has many reports on the effects of RPE on the craniofacial complex and the transverse changes in the dentition, few have addressed dental tipping. Lagravere et al\textsuperscript{16} in a meta-analysis of changes caused by RPE evaluated the entire RPE library and found that only a few of the studies used a stringent scientific protocol. The vast body of experimentation on the effects of RPE was conducted without control groups, precise identification of the landmarks used for measurements, and measurement reliability analyses.

An analysis of the qualifying experiments showed that on average about 6.04 mm of molar crown to molar crown expansion was produced by the RPE along with 4.4 mm of expansion measured at the root apex. Our data showed an average of 3° of molar tip (on each side), although it was statistically insignificant. Nasal cavity and interalveolar (measured from the buccal plates) width increases were about 2.14 and 2.73 mm, respectively. The purpose of our study was to further explore and determine the behavior of the alveolus and the teeth that it houses under the forces of an RPE appliance. Since we had a control group, identified the

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### Table II. Baseline comparison of transverse measurements between the groups

<table>
<thead>
<tr>
<th>Baseline parameter (mm)</th>
<th>RPE group Mean ± SD</th>
<th>Control group Mean ± SD</th>
<th>Paired t test, $P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF 64.85 ± 9.11</td>
<td>68.53 ± 5.08</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>HP 60.98 ± 6.96</td>
<td>64.82 ± 3.91</td>
<td>0.0295</td>
<td></td>
</tr>
<tr>
<td>PA 30.06 ± 3.63</td>
<td>32.80 ± 4.72</td>
<td>0.0211</td>
<td></td>
</tr>
<tr>
<td>BAC 57.21 ± 4.24</td>
<td>59.80 ± 3.76</td>
<td>0.0041</td>
<td></td>
</tr>
<tr>
<td>DA.E 51.13 ± 4.28</td>
<td>53.49 ± 3.43</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>DA.E’ 54.87 ± 4.14</td>
<td>57.46 ± 3.40</td>
<td>0.00864</td>
<td></td>
</tr>
<tr>
<td>DA.I 38.65 ± 4.03</td>
<td>40.28 ± 3.55</td>
<td>0.0868</td>
<td></td>
</tr>
<tr>
<td>DA.I’ 31.63 ± 3.67</td>
<td>33.26 ± 3.25</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>LAC 28.70 ± 3.29</td>
<td>32.49 ± 2.95</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

### Table III. Baseline comparison of angulations between the groups

<table>
<thead>
<tr>
<th>Baseline parameter (°)</th>
<th>RPE group Mean ± SD</th>
<th>Control group Mean ± SD</th>
<th>Paired t test, $P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alv 108.13 ± 5.93</td>
<td>116.78 ± 6.54</td>
<td>0.0002</td>
<td></td>
</tr>
<tr>
<td>Dent 103.43 ± 6.26</td>
<td>101.55 ± 7.18</td>
<td>0.379</td>
<td></td>
</tr>
<tr>
<td>Incl 107.78 ± 6.11</td>
<td>105.69 ± 7.47</td>
<td>0.298</td>
<td></td>
</tr>
</tbody>
</table>

### Table IV. Comparison of absolute transverse changes between the groups

<table>
<thead>
<tr>
<th>Changes in parameter (mm)</th>
<th>RPE group Mean ± SD</th>
<th>Control group Mean ± SD</th>
<th>Paired t test, $P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ NF 2.08 ± 5.66</td>
<td>−0.85 ± 2.38</td>
<td>0.0155</td>
<td></td>
</tr>
<tr>
<td>Δ HP 2.25 ± 3.57</td>
<td>−0.12 ± 2.12</td>
<td>0.0023</td>
<td></td>
</tr>
<tr>
<td>Δ PA 4.40 ± 2.69</td>
<td>0.03 ± 1.71</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Δ BAC 3.00 ± 2.35</td>
<td>0.09 ± 1.00</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Δ DA.E 5.35 ± 3.79</td>
<td>0.40 ± 1.69</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>Δ DA.E’ 5.42 ± 3.02</td>
<td>0.29 ± 0.88</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Δ DA.I 4.56 ± 3.80</td>
<td>−0.08 ± 2.26</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Δ DA.I’ 4.00 ± 2.77</td>
<td>−0.19 ± 1.69</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Δ LAC 5.09 ± 3.04</td>
<td>0.02 ± 1.71</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

### Table V. Comparison of posttreatment absolute angulation changes between the groups

<table>
<thead>
<tr>
<th>Change in parameter (°)</th>
<th>RPE group Mean ± SD</th>
<th>Control group Mean ± SD</th>
<th>Paired t test, $P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Alv 5.61 ± 6.94</td>
<td>−2.84 ± 7.09</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Δ Dent −0.95 ± 4.98</td>
<td>−0.88 ± 6.06</td>
<td>0.964</td>
<td></td>
</tr>
<tr>
<td>Δ Incl −0.81 ± 6.47</td>
<td>0.32 ± 5.63</td>
<td>0.454</td>
<td></td>
</tr>
</tbody>
</table>
indicates true skeletal deficiency with a slight dental

The baseline measurements of this study showed that

After treatment, there were significant transverse in-

The diminishing magnitude of width insufficiency ob-

The width increase at the level of first molar root

At the level of the buccal alveolar crests, we ob-

When we compared the transverse dimension be-

Table VI. Posttreatment comparison of transverse di-
mensions between the groups

Table VII. Posttreatment comparison of angular mea-
surements between the groups

landmarks used for each measurement, and conducted
an error analysis, our findings can be corroborated
with the measurements reported by the meta-analysis.
The strengths of this study include the large sample
size (25 subjects in each group) and the age- and sex-
matched controls. The limitations of the study include
the following: (1) all patients were growing, based on
age and clinical judgment, and no hand-wrist x-rays
were taken; (2) the required expansion was achieved by
slight overcorrection of the crossbite, based on clin-
ical judgment that varied based on the provider; and (3)
because of scheduling issues and patients’ availability,
the midtreatment scans were not taken immediately af-
after the RPE treatment, but the elapsed time between
scans was not significantly different between groups.
The baseline measurements of this study showed that
the RPE group had a statistically significant transverse
insufficiency in all measured parameters (Table II),
as expected. At the skeletal level, patients with unilat-
eral or bilateral crossbite showed approximately
a 3.84-mm deficiency compared with the controls. At
the dental level, the deficit was about 2 to 2.5 mm.
The diminishing magnitude of width insufficiency ob-
erved from the base of the maxilla to the dental cusps
in the RPE group before treatment can be explained by
the fact that the alveolar segments were bent inward
(relative to the controls; \(P = 0.0002\)). The manifestation
indicates true skeletal deficiency with a slight dental

Table VIII. Absolute tip of the posterior dentition calcu-
drated by subtracting the absolute dental angulation
change (\(\Delta\) Dent) from the absolute alveolar change
(\(\Delta\) Alv)

Table IX. Comparison of absolute tip between the groups

compensation. The angulation measurements supported
this observation with significant differences seen in the
alveolar angulations of nearly 8.65° of acuteness and no
significant differences in the angulations of the dentition
between the groups (Table III).

After treatment, there were significant transverse in-
crease differences between the 2 groups for all widths
measured (Table IV). The RPE treatment augmented
the base of the maxilla by 2.08 mm at the nasal floor
and 2.25 mm at the hard palate. These values are
comparable with those reported by Lagravere et al.\textsuperscript{16}
The width increase at the level of first molar root
apices was 4.4 mm, an exact match with the average
of Lagravere et al.

At the level of the buccal alveolar crests, we ob-
served a gain of 3 mm, a 0.26-mm difference with the
average of 2.74 mm by Lagravere et al.\textsuperscript{16} Measured at
the level of the lingual alveolar crests, we observed
a 5-mm width increase; this is consistent with the value
of Handelman et al.\textsuperscript{11} The transverse increases at the
levels of the buccal dental cusps reported by Lagravere
et al averaged 6.04 mm. In comparison, ours measured
5.4 mm. This value is slightly less than previous reports
by Timms\textsuperscript{10} and Chung and Font,\textsuperscript{13} who measured
dental casts, but it agrees with values measured from radi-
ographs by Baccetti et al\textsuperscript{18} and Cross and McDonald.\textsuperscript{14} In
general, more expansion was achieved at the dental
level than at the skeletal level. The ascending pattern
of width increases from maxillary base down to the den-
tal cusps is consistent with the pyramid-like configura-
tion of expansion described by Wertz\textsuperscript{2} and others.

When we compared the transverse dimension be-
tween the 2 groups at the skeletal level, we found that
the posttreatment widths of the maxilla were similar

\[\begin{array}{|c|c|c|c|}
\hline
\text{Parameter} & \text{RPE group} & \text{Control group} & \text{Paired t test,} \ P \ \text{value} \\
\hline
\text{AT} & \text{Mean} \pm \text{SD} & \text{Mean} \pm \text{SD} & \\
\hline
\text{AT} & 6.56 \pm 7.07 & -1.96 \pm 10.17 & -8.52 \pm 12.03 & 0.0017 \\
\hline
\end{array}\]
(no significant differences, Table VI); however, the RPE group still showed a slight narrowness of about 1 mm. At the dental level, significant differences were seen: the widths of the RPE group were greater than those of the controls by about 2.5 mm.

Analysis of posttreatment angulation changes showed that the alveolus substantially tipped buccally by 5.6° (Table V). The angulations of the dentition, however, remained basically unchanged before and after treatment. In other words, our study showed no statistically significant amount of relative dental tipping after RPE treatment. Whereas previous studies also found statistically insignificant amounts of dental tipping, Handelman et al11 estimated a net change of 6.2° of intermolar tip (right and left sides combined). The average of 2.5° reported by Garib et al15 for 1 side agrees with the findings of Handelman et al and the average of 3° found by Lagravere et al.16 Upon closer examination of angulation changes, we determined the amount of resultant dental tipping independent of alveolar tipping.

When the midpalatal suture is subjected to expansion forces, it separates in a nonparallel fashion. Because the maxilla articulates with bones that are not paired, the amount of separation is limited. Instead, a pyramid-like splaying of the maxillary components is seen with the fulcrum of maxillary rotation at the frontomaxillary suture.3,19 The alveolar halves splay buccally and carry the teeth with them. After expansion, the inclination change of the teeth should be similar to the inclination change of the alveolus; however, this is not the case. Table VIII shows that, although the alveolar half inclined buccally, the teeth stayed relatively constant in their angulation. The posterior teeth moved in a slightly lingual direction, with the net difference between the angles constituting an absolute tip of 6.56° from the horizontal reference. This amount of absolute tip can be attributed to denture uprighting after expansion. This finding challenges the theory that, when a vector of force is applied across the palate in a buccal direction, the teeth will also tip in that direction. As we have shown, the opposite tends to happen, with the teeth preserving their original angulation to the palate and the opposing dentition.

CONCLUSIONS

1. In this study, patients with posterior unilateral or bilateral crossbite suffered from 3.75 mm of width deficit at the base of the maxilla, and the alveolar segments were approximately 8.5° more acute than those of the controls.

2. RPE treatment augmented the base of the maxilla by 2.08 mm of width at the nasal floor and 2.25 mm of width at the hard palate. At the dental level, a 5.4-mm increase in width was achieved by RPE treatment. The ascending pattern of width increases from the maxillary base down to the dental cusps in this study is consistent with the pyramid-like configuration of sutural opening described in the literature.

3. After treatment, the base of the maxilla in the RPE patients and the alveolar angulations approached the transverse dimensions of the controls. At the dental level, the transverse widths of the RPE group were greater than those of the controls by about 2.5 mm after treatment.

4. After RPE treatment, the alveolus substantially tipped buccally by nearly 5.6°, whereas the posterior teeth showed consistency in their inclinations. After RPE treatment, the posterior teeth showed an absolute tip (difference between alveolar and dental tip) of 6.5° from the horizontal reference.

We thank Ms Michelle Bailey for providing computed tomography scanning services to our patients and processing the data.

REFERENCES