Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: A randomized clinical trial

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Introduction: The purpose of this study was to compare the transverse, vertical, and anteroposterior skeletal and dental changes in adolescents receiving expansion treatment with tooth-borne and bone-anchored expanders. Immediate and long-term changes were measured on cone-beam computed tomography (CBCT) images. Methods: Sixty-two patients needing maxillary expansion were randomly allocated to 1 of 3 groups: traditional hyrax tooth-borne expander, bone-anchored expander, and control. CBCT images were taken at baseline, immediately after expansion, after removal of the appliance (6 months), and just before fixed bonding (12 months). Repeated measures multivariate analysis of variance (MANOVA) was applied to the distances and angles measured to determine the statistical significance in the immediate and long time periods. Bonferroni post-hoc tests were used to identify significant differences between the treatment groups. Results: Immediately after expansion, the subjects in the tooth-borne expander group had significantly more expansion at the crown level of the maxillary first premolars (P < 0.003). Dental crown expansion was greater than apical expansion and skeletal expansion with both appliances. The control group showed little change (growth) over the 6-month interval. At 12 months, no group had a statistically significant difference in angle changes, suggesting symmetric expansion. Both treatment groups had significant long-term expansion at the level of the maxillary first molar crown and root apex, first premolar crown and root, alveolus in the first molar and premolar regions, and central incisor root. Tooth-borne expansion resulted in significantly more long-term expansion at the maxillary premolar crown and root than did bone-borne expansion. Conclusions: Both expanders showed similar results. The greatest changes were seen in the transverse dimension; changes in the vertical and anteroposterior dimensions were negligible. Dental expansion was also greater than skeletal expansion.

Maxillary deficiency is common in orthodontic patients and is usually accompanied by unilateral or bilateral posterior crossbite, narrow nasal cavity, and crowding.1,2 Maxillary expansion is used to correct maxillary width deficiency or posterior crossbite, expand arch perimeter (to alleviate crowding), and can even be applied to adequate arch forms to allow conservative, nonextraction treatment.3,4 Various appliances and treatment protocols have been developed and used for adolescents with constricted maxillary arches. The most common is rapid maxillary expansion (RME) performed with a tooth-anchor expander (hyrax).5-8 Disadvantages have been identified with traditional tooth-anchor appliances; tooth-borne forces lead to limited skeletal movement5 and the potential for undesirable tooth movement,6 root resorption,7 and lack of firm anchorage to retain sutural long-term expansion.8

An alternative to this method is to anchor the appliance directly to the palatal surfaces of the maxilla with either bioglass-coated aluminum oxide implants9 or osteosynthesis plates.10,11 Disadvantages of these methods are their invasiveness and higher risks of infection.10,11 Bone-anchored expanders with metal onplant discs and miniscrews as anchors are also an option for applying forces directly to the maxilla and overcoming the limitations of traditional tooth-anchored RME appliances.

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In orthodontics, common ways of determining the need for maxillary expansion and analyzing treatment results are by analysis with cephalometric radiographs (posteroanterior and lateral), occlusal radiographs, and dental casts. These diagnostic approaches provide limited information, since only 2-dimensional data can be processed from a 3-dimensional (3D) subject. Three-dimensional volumetric imaging, such as cone-beam computerized tomography (CBCT), allows the investigator to 3-dimensionally measure treatment-related bony structural changes with minimal image distortion and relatively low radiation dosages that are comparable to a full-mouth series of periapicals. CBCT also allows the use of landmarks such as dental pulp chambers that cannot be identified with 2-dimensional imaging.

The magnitude of structural changes in different space planes is still controversial when analyzing rapid maxillary treatments. In the transverse plane, 1 study reported no significant skeletal changes, but another found significant maxillary width increases. In the vertical direction, some authors have suggested that RME causes changes, whereas others have reported no statistically significant changes. In the anteroposterior direction, most studies report no significant changes after RME treatments.

The purpose of this study was to determine transverse, vertical, and anteroposterior skeletal and dental immediate and long-term changes in adolescents receiving expansion treatment with both tooth-borne and bone-anchored expanders measured on CBCT images.

**MATERIAL AND METHODS**

Subjects were recruited from the patients at the orthodontic clinic at the University of Alberta in Edmonton, Alberta, Canada, during an 18-month period. A total of 62 patients needing maxillary expansion treatment were randomly allocated into 3 groups. Sex and age distributions are shown in Table I for the groups. The control group was overall a year younger than the subjects were randomized into the groups by using a random numbers generated list. The subjects were prescribed oral antibiotics and chlorhexidine rinse for 5 days to prevent infection. A healing period of 1 week was allowed before activation of the expander. Activation consisted of 1 turn of the screw every other week was allowed before activation of the expander. After active expansion, the retention protocol was the same as in the TAME group. Both groups had CBCT images taken 4 times (baseline [T1], after activation of the appliance [T2], after removal of the appliance [6 months, T3], and before fixed bonding [12 months, T4]).

The activation protocol differed between the treatment groups, since it was necessary to take precautions to prevent possible palatal shelf fracture for the bone-anchored expanders.

Subjects in the second group received a bone-anchored maxillary expander (BAME) composed of 2 custom-milled stainless steel onplants (diameter, 8 mm; height 3 mm), 2 miniscrews (length, 12 mm; diameter, 1.5 mm; Straumann GBR-System, Andover, Mass) and an expansion screw (Palex II Extra-Mini Expander, Summit Orthodontic Services, Munroe Falls, Ohio), shown in Figure 1, B. This appliance was placed on each side between the projection of the permanent first molars and second premolar roots deep into the palatal vault and 6 mm from the suture. Before appliance placement, the patient was asked to rinse for 2 minutes with chlorhexadine (0.12%). This was followed by local anesthesia infiltration of the palatal mucosa between the first molars and second premolars. An 8-mm diameter tissue punch was used to make a circular incision. Tissue including the periosteum was removed, and the appliance was seated so that the onplant would have maximum direct contact with the bone surface of the palate. Guide drills were used to perforate the cortical plate of the bone, and miniscrews were placed to secure the appliance. Acrylic resin was used to seal the head of the screw to the stainless steel disc and prevent unwinding of the screw during appliance activation. Patients were prescribed oral antibiotics and chlorhexidine rinse for 5 days to prevent infection. A healing period of 1 week was allowed before activation of the expander. After active expansion, the retention protocol was the same as in the TAME group.

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**Table I.** Sex and age distribution of the groups

<table>
<thead>
<tr>
<th>Treatment</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAME</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>8</td>
<td>14.13</td>
<td>1.58</td>
</tr>
<tr>
<td>Girls</td>
<td>13</td>
<td>14.31</td>
<td>1.07</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>14.24</td>
<td>1.32</td>
</tr>
<tr>
<td>TAME</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>5</td>
<td>14.54</td>
<td>1.19</td>
</tr>
<tr>
<td>Girls</td>
<td>15</td>
<td>13.89</td>
<td>1.32</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>14.05</td>
<td>1.35</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>6</td>
<td>13.13</td>
<td>1.42</td>
</tr>
<tr>
<td>Girls</td>
<td>15</td>
<td>12.75</td>
<td>1.03</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>12.86</td>
<td>1.19</td>
</tr>
</tbody>
</table>

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anchored appliance because this appliance is in a trial period. Tooth-anchored expanders followed the traditional protocol of 2 turns per day.

The subjects in the third group had treatment delayed for 12 months to serve as a control group. The delay of 1 year had no negative consequences regarding the patients’ treatment outcome. CBCT images were obtained for the control group at T1, T3, and T4.

Potential risks from radiation exposure with NewTom 3D images (Aperio Services, Verona, Italy) are minimal. For the 3D image, the radiation dose can be as low as 50 μSv, and the annual effective dose limit for infrequent exposure is 5 mSv.

All CBCT images were taken with the NewTom 3G device at 110 kV, 6.19 mAs, and 8-mm aluminum filtration. Images were converted to DICOM format by using the NewTom software to a voxel size of 0.25 mm. With AMIRA software (Mercury Computer Systems, Berlin, Germany), the DICOM-formatted images were rendered into volumetric images. Sagittal, axial, and coronal volumetric slices as well as the 3D reconstructions of the images were used for determining landmark positions. The landmarks we used are defined in Table II and shown in Figure 2. Figure 3 gives an example of locating the middle of the pulp chamber of the maxillary first permanent molar in the 3 planes of space. The principal investigator (M.O.L.) located the landmarks on each image (10 images per day). Intraexaminer reliability of landmarks identification was determined by measuring 10 randomly selected images (3 times) 1 week apart. Digital spherical markers, 0.5 mm in diameter, were placed on the images to indicate the position of the landmark with the center of each marker in the exact location of the landmark. Linear distances between each landmark and its contralateral counterpart were used for analysis purposes. Distances, \( d \), were determined by using the following equation.

\[
d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}
\]

Angles were determined by using the following equation.

\[
a = \text{ACOS}((d_1 \cdot d_1 + d_3 \cdot d_3 - d_2 \cdot d_2) / (2 \cdot d_1 \cdot d_3))
\]

with \( d_1 \), \( d_2 \), and \( d_3 \) representing the 3 distances forming the triangle; their use depends on the location of the angle. Angle values were obtained in radians and

Table II. Definition of landmarks

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foramen spinosum</td>
<td>Geometric center of the smallest circumference with defined borders viewed axially on the foramen spinosum</td>
</tr>
<tr>
<td>ELSA</td>
<td>Midpoint on a line connecting left and right foramen spinosum landmarks</td>
</tr>
<tr>
<td>Pulp chamber (PC tooth #)</td>
<td>Center of pulp chamber in molars (in all 3 planes of space)</td>
</tr>
<tr>
<td></td>
<td>Tip of premolar buccal pulp horn</td>
</tr>
<tr>
<td></td>
<td>Tip of incisor pulp chamber</td>
</tr>
<tr>
<td>Mesial buccal apex (MBA tooth #)</td>
<td>Mesial buccal root apex of molars</td>
</tr>
<tr>
<td>Alveolar bone (AIB tooth #)</td>
<td>Outer cortex of alveolar bone at the vertical level of the root apex</td>
</tr>
<tr>
<td>Buccal apex (BA tooth #)</td>
<td>Buccal root apex of premolars</td>
</tr>
<tr>
<td>Apex (A tooth #)</td>
<td>Root apex of incisors</td>
</tr>
<tr>
<td>Infraorbitale (InfraO)</td>
<td>Center of infraorbital foramen outer border (in 3D reconstruction)</td>
</tr>
<tr>
<td>Mental (Me)</td>
<td>Center of mental foramen outer border (in 3D reconstruction)</td>
</tr>
<tr>
<td>Lateral pterygoid (Lpt)</td>
<td>Most posterior border of the pterygoid lateral plate at the vertical level of the palatal shelves by using an axial slice showing as much of the palate surface as possible (axial slice determined to be parallel to Frankfort horizontal plane of the patient)</td>
</tr>
</tbody>
</table>
Intraexaminer reliability values were determined with the intraclass correlation coefficient (ICC). Mean differences between 2 time points were obtained for each distance and angle measured (T2-T1, T3-T1, and T4-T1). Repeated-measures multivariate analysis of variance (MANOVA) was applied to the distances and angles in each dimension to determine the statistical significance at the immediate (T2-T1 and T3-T1) and long (T4-T1) times. If repeated-measures MANOVA showed statistical significance, MANOVA and Bonferroni post-hoc tests were used to identify the specific differences between the treatment groups at each time period (immediate and long term). A paired-samples t test was used to verify whether changes in angles used for symmetry were statistically significant.

Pain perceived by subjects during the appliance activation phase was assessed by using a 100-mm visual analog scale. Pain was recorded at every appointment when the activation was applied at the orthodontic clinic. After the activation appointment, the subjects were asked to record on the visual analog scale their overall experience of pain during the entire activation period. The patients recorded their pain at the first activation, once in the middle of expansion, and once describing the overall expansion experience. A MANOVA test was used to establish the influence of appliance type on the pain.
RESULTS

Intraexaminer reliability (ICC) for the x, y, and z coordinates for all landmarks was greater than 0.99, with an average 95% CI of 1.00. Mean measurement differences obtained from the principal investigator’s trials in all 3 axes were less than 0.7 mm.

Normal distribution was confirmed by using the Kolmogorov-Smirnov test; the values analyzed had no significant differences, giving a P >0.05. MANOVA was used at T1 to verify the homogeneity of the sample; there was no statistically significant difference (P >0.05) in these measurements of the 3 groups. The initial MANOVA was applied to the data, and the sex and the sex-treatment interactions were not significant (P >0.05) for the values analyzed; thus, sex was eliminated from the final analysis.

Immediate changes after maxillary expansion

T2-T1 changes. Tables III and IV show the changes in distance vectors and angles, respectively, immediately after expansion. After applying repeated-measures MANOVA to the dimension variables, the vertical, anteroposterior, and dental inclination variables had no statistically significant differences (P = 0.207, 0.169, and 0.087, respectively), and only transverse variables had statistically significant differences (P <0.001).

The greatest width increase occurred at the level of the first molar crowns (BAME, 5.36 ± 1.95 mm; TAME, 5.51 ± 1.79 mm). The smallest width changes were found at the level of the mandibular molars, infraorbital foramen, mental foramen, and lateral pterygoid plates. When comparing appliances, TAME had statistically significantly more expansion at the pulp chamber level of maxillary first premolars (P = 0.003). Dental crown expansion was greater than apical expansion and skeletal expansion for both appliances (Table III).

The greatest vertical changes for both appliances were at the maxillary first molar crown level ranging between 2 and 3 mm. Anteroposterior changes were small, with the highest average approximately 1 mm (Table III).

For both appliances, dental inclination was greater at the maxillary first molars (range, 8°-10°) and less at the maxillary first premolars (range, 0°-4°) (Table III).

When comparing right and left angle changes of the maxillary first molars with respect to the infraorbital foramina, neither group had a statistically significant difference in angle changes, giving a sense of symmetrical expansion (Table IV).

T3-T1 changes. Changes from T3 to T1 are the short-term treatment effects after the 6-month retention period and are shown in Tables V and VI. After applying repeated-measures MANOVA to the dimension variables, the transverse and vertical dimensions and dental inclinations had significant statistical differences (P <0.001), but the anteroposterior dimension did not (P = 0.244).

The control group showed little change (growth) over the 6-month interval. Visual inspection suggested that the values in the treated groups were similar for T2 to T1 and T3 to T1. When comparing values among the 3 groups in the transverse dimension, we found statistically significant differences in measurements related to the maxillary first molars, first premolars, and central incisors’ apices (P <0.001).

### Table III. Means, standard deviations, and mean differences of vectors and angles between BAME and TAME in all dimensions at T2 to T1

<table>
<thead>
<tr>
<th>Vector</th>
<th>BAME Mean</th>
<th>BAME SD</th>
<th>TAME Mean</th>
<th>TAME SD</th>
<th>Mean difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC16-PC26</td>
<td>5.36 1.95</td>
<td>5.51 1.79</td>
<td>−0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC46-PC36</td>
<td>−0.07 0.71</td>
<td>0.49 1.49</td>
<td>−0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC14-PC24</td>
<td>2.19 1.73</td>
<td>3.99 1.92</td>
<td>−1.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC11-PC21</td>
<td>1.24 1.25</td>
<td>2.11 1.66</td>
<td>−0.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA16-MBA26</td>
<td>1.70 1.51</td>
<td>1.62 1.44</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alb16-Alb26</td>
<td>1.30 1.38</td>
<td>1.83 1.69</td>
<td>−0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA14-BA24</td>
<td>1.57 1.55</td>
<td>2.09 1.74</td>
<td>−0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA14-Alb24</td>
<td>1.70 2.00</td>
<td>1.96 1.74</td>
<td>−0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A11-A21</td>
<td>2.11 2.13</td>
<td>2.67 1.38</td>
<td>−0.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-InfraOR</td>
<td>0.31 0.58</td>
<td>0.07 0.62</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MeL-MsR</td>
<td>0.41 0.68</td>
<td>0.11 0.51</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LpL-LpR</td>
<td>0.73 2.14</td>
<td>1.12 2.17</td>
<td>−0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-PC26</td>
<td>2.92 1.22</td>
<td>2.9 3.34</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOR-PC16</td>
<td>1.99 1.78</td>
<td>2.37 1.42</td>
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<tr>
<td>InfraOL-PC21</td>
<td>0.93 1.36</td>
<td>1.43 2.63</td>
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<td></td>
</tr>
<tr>
<td>InfraOR-PC11</td>
<td>0.23 1.21</td>
<td>1.63 2.17</td>
<td>−1.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-MsL</td>
<td>0.80 1.08</td>
<td>1.47 4.23</td>
<td>−0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOR-MsR</td>
<td>0.65 1.18</td>
<td>1.45 4.12</td>
<td>−0.79</td>
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<td></td>
</tr>
<tr>
<td>Anteroposterior (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-PC14</td>
<td>0.73 1.08</td>
<td>1.13 1.12</td>
<td>−0.40</td>
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</tr>
<tr>
<td>ELSA-PC24</td>
<td>0.80 1.05</td>
<td>1.11 0.71</td>
<td>−0.31</td>
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<td></td>
</tr>
<tr>
<td>ELSA-PC11</td>
<td>0.54 1.08</td>
<td>0.9 0.96</td>
<td>−0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-PC21</td>
<td>0.38 1.06</td>
<td>0.54 1.03</td>
<td>−0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-Alb11</td>
<td>0.96 0.96</td>
<td>0.23 1.09</td>
<td>0.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-Alb21</td>
<td>1.11 1.18</td>
<td>0.29 1.01</td>
<td>0.81</td>
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<td></td>
</tr>
<tr>
<td>ELSA-MsL</td>
<td>0.62 1.13</td>
<td>0.36 2.14</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-MsR</td>
<td>0.81 1.13</td>
<td>0.03 2.66</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dental tipping (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA16-PC16-PC26</td>
<td>−8.42 6.28</td>
<td>−9.18 5.14</td>
<td>0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA14-PC14-PC24</td>
<td>0.15 3.92</td>
<td>−3.64 5.14</td>
<td>3.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA26-PC26-PC16</td>
<td>−8.83 5.03</td>
<td>−9.18 4.92</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BA24-PC24-PC14</td>
<td>−2.79 3.14</td>
<td>−4.04 3.61</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L. Left; R. right.

*Statistical significance determined by MANOVA.
dimension, only measurements related to the maxillary first molars were statistically significant ($P < 0.001$). In the anteroposterior dimension, no statistical significance was found among the 3 groups. For dental inclination, only angles related to the maxillary first molars had statistically significant differences among the 3 groups ($P < 0.001$) (Table V). Comparison among angle changes of the maxillary first molars with respect to the infraorbitales was similar on both sides for every group, with no statistically significant differences (Table VI).

Long-term changes after maxillary expansion

Long-term (after uncontrolled relapse) changes for the treatment and control groups are shown in Tables VIII and IX. After repeated-measures MANOVA to the dimension variables, the transverse and vertical dimensions and the dental inclination angles had statistically significant differences ($P < 0.001$), but the anteroposterior dimension did not ($P = 0.221$).

Statistically significant differences among the 3 groups were found for transverse measurements related to the maxillary first molar crowns and roots, first premolar crowns and roots, and central incisor apices, and alveolar bone at the level of the first premolar ($P < 0.001$). The alveolar width at the level of the maxillary first molar was not significantly different among the 3 groups, suggesting that skeletal expansion in the first molar region relapsed.

In the vertical dimension, only the maxillary left first molar and mental foramen had statistically significant differences ($P < 0.001$). In the anteroposterior dimension, only the maxillary left first molar and mental foramen had statistically significant differences ($P < 0.001$). In the anteroposterior

Table IV. Means, standard deviations, mean differences, and statistical significance of angles for symmetrical treatment changes from T2 to T1 ($^\circ$)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Angle</th>
<th>Mean</th>
<th>SD</th>
<th>Mean difference</th>
<th>$P$ value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>$-5.31$</td>
<td>$3.52$</td>
<td>$0.30$</td>
<td>$0.755$</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOR-InfraOL</td>
<td>$-5.61$</td>
<td>$3.45$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>$-8.43$</td>
<td>$3.75$</td>
<td>$-1.81$</td>
<td>$0.167$</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOR-InfraOL</td>
<td>$-6.61$</td>
<td>$3.80$</td>
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<td></td>
</tr>
</tbody>
</table>

$P$ value determined when comparing right and left angle changes.

L, Left; R, right.

Table V. Means and standard deviations of vectors and angles among the 3 groups in all dimensions from T3 to T1

<table>
<thead>
<tr>
<th>Distance</th>
<th>BAME</th>
<th>TAME</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Transverse (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC16-PC26</td>
<td>5.75</td>
<td>1.98</td>
<td>5.83</td>
</tr>
<tr>
<td>PC46-PC36</td>
<td>0.09</td>
<td>0.87</td>
<td>0.29</td>
</tr>
<tr>
<td>PC14-PC24</td>
<td>1.92</td>
<td>1.53</td>
<td>3.68</td>
</tr>
<tr>
<td>PC11-PC21</td>
<td>0.25</td>
<td>0.90</td>
<td>0.36</td>
</tr>
<tr>
<td>MBA16-MBA26</td>
<td>2.22</td>
<td>1.84</td>
<td>2.93</td>
</tr>
<tr>
<td>AIB16-AIB26</td>
<td>0.99</td>
<td>1.57</td>
<td>1.69</td>
</tr>
<tr>
<td>BA14-BA24</td>
<td>1.14</td>
<td>1.80</td>
<td>2.95</td>
</tr>
<tr>
<td>AIB14-AIB24</td>
<td>1.61</td>
<td>1.70</td>
<td>2.62</td>
</tr>
<tr>
<td>A11-A21</td>
<td>1.18</td>
<td>1.66</td>
<td>1.51</td>
</tr>
<tr>
<td>InfraOL-InfraOR</td>
<td>0.33</td>
<td>0.59</td>
<td>0.16</td>
</tr>
<tr>
<td>MeL-MeR</td>
<td>0.39</td>
<td>0.64</td>
<td>0.19</td>
</tr>
<tr>
<td>LPL-LPR</td>
<td>1.09</td>
<td>1.99</td>
<td>1.42</td>
</tr>
<tr>
<td>Vertical* (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-PC26</td>
<td>3.19</td>
<td>1.29</td>
<td>2.79</td>
</tr>
<tr>
<td>InfraOL-PC16</td>
<td>2.25</td>
<td>1.43</td>
<td>2.00</td>
</tr>
<tr>
<td>InfraOL-PC21</td>
<td>0.65</td>
<td>1.49</td>
<td>0.83</td>
</tr>
<tr>
<td>InfraOL-PC11</td>
<td>0.07</td>
<td>1.05</td>
<td>0.58</td>
</tr>
<tr>
<td>InfraOL-MeL</td>
<td>1.20</td>
<td>1.66</td>
<td>1.17</td>
</tr>
<tr>
<td>InfraOR-MeR</td>
<td>1.30</td>
<td>1.85</td>
<td>1.25</td>
</tr>
<tr>
<td>Anteroposterior (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-PC14</td>
<td>1.11</td>
<td>1.11</td>
<td>1.68</td>
</tr>
<tr>
<td>ELSA-PC24</td>
<td>1.21</td>
<td>0.71</td>
<td>1.52</td>
</tr>
<tr>
<td>ELSA-PC11</td>
<td>0.58</td>
<td>1.14</td>
<td>0.91</td>
</tr>
<tr>
<td>ELSA-PC21</td>
<td>0.63</td>
<td>1.06</td>
<td>0.58</td>
</tr>
<tr>
<td>ELSA-AIB11</td>
<td>1.09</td>
<td>1.03</td>
<td>0.57</td>
</tr>
<tr>
<td>ELSA-AIB21</td>
<td>1.20</td>
<td>0.96</td>
<td>0.84</td>
</tr>
<tr>
<td>ELSA-MeL</td>
<td>1.28</td>
<td>1.97</td>
<td>1.35</td>
</tr>
<tr>
<td>ELSA-MeR</td>
<td>1.40</td>
<td>1.68</td>
<td>1.09</td>
</tr>
<tr>
<td>Dental tipping* ($^\circ$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA16-PC16-PC26</td>
<td>$-7.88$</td>
<td>5.54</td>
<td>$-6.44$</td>
</tr>
<tr>
<td>BA14-PC14-PC24</td>
<td>$-0.75$</td>
<td>3.81</td>
<td>$-1.18$</td>
</tr>
<tr>
<td>MBA26-PC26-PC16</td>
<td>$-8.89$</td>
<td>6.69</td>
<td>$-6.97$</td>
</tr>
<tr>
<td>BA24-PC24-PC14</td>
<td>$-2.77$</td>
<td>3.16</td>
<td>$-1.68$</td>
</tr>
</tbody>
</table>

$P$ value determined when comparing right and left angle changes.

L, Left; R, right.

*Statistical significance determined by MANOVA.
dimension, no statistically significant differences were found among the 3 groups.

The maxillary molars had significantly different crown inclinations among the 3 groups (right first molar, $P = 0.02$; left first molar, $P < 0.001$) (Table VIII). No group had statistically significant differences in angle changes, suggesting symmetric expansion.

Table X shows the mean differences among the groups with statistically significant differences from T4 to T1.

Both treatment groups had significant long-term expansion at the level of the maxillary first molar crown and root apex, first premolar crown and root, alveolus in the first molar and premolar regions, and central incisor root. TAME resulted in significantly more long-term expansion at the maxillary premolar crown and premolar root than did BAME.

Table VI. Means, standard deviations, mean differences, and statistical significance of angles for symmetrical changes in all groups from T3 to T1 ($^\circ$)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Angle</th>
<th>Mean</th>
<th>SD</th>
<th>Mean difference</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>-4.98</td>
<td>3.21</td>
<td>-0.29</td>
<td>0.713</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>-4.69</td>
<td>3.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>-6.53</td>
<td>3.92</td>
<td>-1.53</td>
<td>0.161</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>-5.00</td>
<td>4.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>PC16-InfraOR-InfraOL</td>
<td>0.31</td>
<td>2.66</td>
<td>-0.03</td>
<td>0.969</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>0.34</td>
<td>2.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$P$ value determined when comparing right and left angle changes.

Table VII. Mean differences and statistical significance of vectors and angles among the 3 groups from T3 to T1 (Bonferroni test)

<table>
<thead>
<tr>
<th>Treatment (a)</th>
<th>Treatment (b)</th>
<th>Mean difference (a–b)</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC16-PC26</td>
<td>Control</td>
<td>BAME</td>
<td>-5.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-5.93</td>
</tr>
<tr>
<td>PC14-PC24</td>
<td>BAME</td>
<td>TAME</td>
<td>-1.76</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>BAME</td>
<td>-1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-3.51</td>
</tr>
<tr>
<td>MBA16-MBA26</td>
<td>Control</td>
<td>BAME</td>
<td>-1.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-2.54</td>
</tr>
<tr>
<td>BA14-BA24</td>
<td>TAME</td>
<td>Control</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BAME</td>
<td>-1.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-2.93</td>
</tr>
<tr>
<td>A11-A21</td>
<td>Control</td>
<td>BAME</td>
<td>-1.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-1.73</td>
</tr>
<tr>
<td>Vertical (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-PC26</td>
<td>Control</td>
<td>BAME</td>
<td>-2.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-2.03</td>
</tr>
<tr>
<td>InfraOR-PC16</td>
<td>Control</td>
<td>BAME</td>
<td>-2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>-2.04</td>
</tr>
<tr>
<td>Dental tipping ($^\circ$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA16-PC16-PC26</td>
<td>Control</td>
<td>BAME</td>
<td>9.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>7.71</td>
</tr>
<tr>
<td>MBA26-PC26-PC16</td>
<td>Control</td>
<td>BAME</td>
<td>9.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>7.90</td>
</tr>
</tbody>
</table>

$L$, Left; $R$, right.

*Statistical significance at the 0.05 level.

Table X}

Both treatment groups showed significant long-term buccal maxillary molar crown inclinations compared with the control group. Long-term crown inclination was not significantly different between the 2 treatment groups.

Table XI gives the means, standard errors, and confidence intervals of pain perception by type of
Table VIII. Means and standard deviations of vectors and angles in the 3 groups in all dimensions from T4 to T1

<table>
<thead>
<tr>
<th>Distance</th>
<th>BAME Mean</th>
<th>SD</th>
<th>TAME Mean</th>
<th>SD</th>
<th>Control Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse* (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC16-PC26</td>
<td>4.03</td>
<td>1.49</td>
<td>4.24</td>
<td>1.69</td>
<td>0.02</td>
<td>0.84</td>
</tr>
<tr>
<td>PC46-PC36</td>
<td>−0.11</td>
<td>0.62</td>
<td>−0.12</td>
<td>0.78</td>
<td>−0.16</td>
<td>1.08</td>
</tr>
<tr>
<td>PC14-PC24</td>
<td>0.97</td>
<td>1.23</td>
<td>2.24</td>
<td>1.42</td>
<td>0.07</td>
<td>0.75</td>
</tr>
<tr>
<td>PC11-PC21</td>
<td>0.34</td>
<td>0.65</td>
<td>0.16</td>
<td>0.84</td>
<td>0.1</td>
<td>0.47</td>
</tr>
<tr>
<td>MBA16-MBA26</td>
<td>1.95</td>
<td>1.51</td>
<td>2.11</td>
<td>1.71</td>
<td>0.05</td>
<td>1.38</td>
</tr>
<tr>
<td>Alb16-AlB26</td>
<td>0.62</td>
<td>1.59</td>
<td>0.82</td>
<td>1.04</td>
<td>−0.18</td>
<td>1.51</td>
</tr>
<tr>
<td>BA14-BA24</td>
<td>1.15</td>
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<td>2.54</td>
<td>1.98</td>
<td>−0.36</td>
<td>1.09</td>
</tr>
<tr>
<td>Alb14-AlB24</td>
<td>1.22</td>
<td>1.49</td>
<td>2.1</td>
<td>1.85</td>
<td>−0.65</td>
<td>1.40</td>
</tr>
<tr>
<td>A11-A21</td>
<td>0.67</td>
<td>1.04</td>
<td>1.00</td>
<td>1.16</td>
<td>−0.47</td>
<td>1.01</td>
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<tr>
<td>InfraOL-InfraOR</td>
<td>0.27</td>
<td>0.72</td>
<td>0.3</td>
<td>0.67</td>
<td>−0.04</td>
<td>0.72</td>
</tr>
<tr>
<td>MeL-MeR</td>
<td>0.50</td>
<td>0.99</td>
<td>0.28</td>
<td>0.53</td>
<td>0.05</td>
<td>0.66</td>
</tr>
<tr>
<td>LPL-LPR</td>
<td>1.37</td>
<td>1.5</td>
<td>1.66</td>
<td>2.95</td>
<td>1.08</td>
<td>2.24</td>
</tr>
<tr>
<td>Vertical* (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InfraOL-PC26</td>
<td>2.86</td>
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<td>3.19</td>
<td>2.08</td>
<td>0.71</td>
<td>1.08</td>
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<tr>
<td>InfraOR-PC16</td>
<td>1.76</td>
<td>1.39</td>
<td>1.32</td>
<td>1.69</td>
<td>0.78</td>
<td>1.13</td>
</tr>
<tr>
<td>InfraOL-PC21</td>
<td>1.31</td>
<td>1.39</td>
<td>1.76</td>
<td>2.84</td>
<td>0.83</td>
<td>1.38</td>
</tr>
<tr>
<td>InfraOL-PC11</td>
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<td>1.37</td>
<td>0.53</td>
<td>1.69</td>
<td>0.73</td>
<td>1.28</td>
</tr>
<tr>
<td>InfraOL-MeL</td>
<td>0.85</td>
<td>1.00</td>
<td>2.09</td>
<td>1.99</td>
<td>1.76</td>
<td>1.69</td>
</tr>
<tr>
<td>InfraOL-MeR</td>
<td>1.18</td>
<td>1.31</td>
<td>1.32</td>
<td>1.83</td>
<td>2.07</td>
<td>2.39</td>
</tr>
<tr>
<td>Anteroposterior (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELSA-PC14</td>
<td>1.29</td>
<td>1.39</td>
<td>1.78</td>
<td>1.37</td>
<td>1.80</td>
<td>1.80</td>
</tr>
<tr>
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<td>1.68</td>
<td>1.39</td>
<td>1.59</td>
<td>1.48</td>
</tr>
<tr>
<td>ELSA-PC11</td>
<td>1.16</td>
<td>1.12</td>
<td>1.40</td>
<td>1.38</td>
<td>1.50</td>
<td>1.47</td>
</tr>
<tr>
<td>ELSA-PC21</td>
<td>1.15</td>
<td>1.43</td>
<td>1.09</td>
<td>1.66</td>
<td>1.51</td>
<td>1.42</td>
</tr>
<tr>
<td>ELSA-AlB11</td>
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<td>0.66</td>
<td>1.32</td>
<td>1.16</td>
<td>1.42</td>
</tr>
<tr>
<td>ELSA-AlB21</td>
<td>1.34</td>
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<td>1.30</td>
<td>1.08</td>
<td>1.23</td>
<td>1.47</td>
</tr>
<tr>
<td>ELSA-MeL</td>
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<td>1.69</td>
<td>1.56</td>
<td>2.37</td>
<td>1.39</td>
</tr>
<tr>
<td>ELSA-MeR</td>
<td>1.63</td>
<td>1.57</td>
<td>1.55</td>
<td>1.87</td>
<td>2.15</td>
<td>1.34</td>
</tr>
<tr>
<td>Dental tipping* (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MBA16-PC16-PC26</td>
<td>−3.91</td>
<td>4.12</td>
<td>−4.69</td>
<td>4.25</td>
<td>−0.88</td>
<td>4.42</td>
</tr>
<tr>
<td>BA14-PC14-PC24</td>
<td>1.07</td>
<td>5.70</td>
<td>0.64</td>
<td>3.89</td>
<td>−1.77</td>
<td>6.09</td>
</tr>
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<td>MBA26-PC26-PC16</td>
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<td>1.51</td>
<td>5.50</td>
</tr>
<tr>
<td>BA24-PC24-PC14</td>
<td>−0.69</td>
<td>4.15</td>
<td>0.53</td>
<td>4.29</td>
<td>−0.42</td>
<td>4.40</td>
</tr>
</tbody>
</table>

L, Left; R, right.

*Statistical significance determined by MANOVA.

appliance. Average pain recorded at any time point was in the lower quartile of the visual analog scale for both types of appliances.

After applying MANOVA, we found no statistical difference associated with the type of appliance (P = 0.547); however, the BAME appliance had a tendency for higher pain values than did the TAME appliance after the first activation.

**DISCUSSION**

RME treatment-related structural changes have been measured with 2-dimensional radiographs and dental casts. Few authors have studied RME effects on the facial complex using 3D imaging. CBCT technology allows clinicians to measure distances between a subject’s anatomic landmarks, eliminating the drawbacks of traditional auxiliary examinations, thus ensuring more reliable and accurate measurements. Tausche et al used computed tomography (CT) to determine surgically assisted RME treatment-related structural changes in patients receiving BAME. Because they used a surgical approach in young adults, their treatment results could not be compared with ours. They used the midpoint on a line connecting the left and right foramina spinosum landmarks (ELSA) as the reference point, since that location had a low identification error in all planes and the cranial base structures had already completed their growth.

Garrett et al analyzed RME effects using a toothborne maxillary expander on 30 patients between 10.3 and 16.8 years old. Each patient had CBCT images taken at baseline and 3 months after completion of activation of appliance. With coronal, sagittal, and axial slices from these images, they obtained linear and angular measurements to determine the transverse changes. Although their sample was similar to the TAME sample in our study, the parameters used to determine transverse changes were different. They only analyzed skeletal transverse changes, and the guides they used to define the parameters to measure could be easily confused subjectively, since they are points located in the apex of other teeth projected to the axial slice that was used to locate both maxillary first molar furcations. Lines connecting the projected points were drawn, and the dimensions measured depended on the skeletal portion to be analyzed. Also, best-fit lines on the palatal alveolar process were used to determine palatal alveolar angular changes only at the maxillary first molar level. Dentoalveolar inclination was determined by using buccal cortical plate expansion, which was larger than sutural expansion, giving a sense of bending of the alveolar process. Although the measurement parameters in their study were different from ours, similar findings were obtained: more skeletal expansion anteriorly than posteriorly (3.04 ± 2.62 mm for the maxillary first premolars and 2.67 ± 1.6 mm for the maxillary first molars at the palatal alveolar bone) and more inclination posteriorly than anteriorly (0.84 mm at the maxillary first molar level and 0.36 mm at the maxillary first premolar level).

Garrett et al measured changes in RME using spiral CT images. Their sample involved 2 types of tooth-anchored expanders with 4 female patients in each group. CT images were taken before expansion and after a 3-month retention period. Two coronal slices were used from each image, 1 at the level of the maxillary first premolar and the other at the level of the maxillary first molar. The measurements were based on distances
determined in these 2 images. Their findings were similar to ours: dental transverse changes were greater than skeletal changes. Dental inclination was also measured by using 3 coronal slices at the level of the maxillary first molar and first and second premolars. Their findings were similar to ours, with more dental inclination at the molars than at the premolars. Tooth-inclination changes associated with both tooth-borne and bone-borne expansion devices should be considered during treatment planning. Strategies to prevent unwanted tipping—eg, palatal root torque with orthodontic bracket systems—should be planned.

We expected that the BAME appliance would produce more skeletal expansion and less dental movement than the TAME appliance. Immediately after completion of appliance activation, the skeletal and dental changes for both treatment groups were similar. The primary difference was greater expansion at the maxillary first premolars in the TAME group. After the retention period (6 months), both appliances showed significant amounts of expansion compared with the control group. Again, premolar expansion was the primary difference between TAME and BAME. This is understandable, since the TAME group had a hyrax appliance anchored on the maxillary first molars and first premolars, whereas the BAME group had the point of force application between the maxillary first molars and second premolars. Even though the TAME subjects had a rigid appliance attached to the molar and premolar, the mean buccal crown movement at the molar was approximately 2 mm more

Table IX. Means, standard deviations, mean differences, and statistical significance of angles for symmetrical changes for all groups from T4 to T1 (°)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Angle</th>
<th>Mean</th>
<th>SD</th>
<th>Mean difference</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>−3.67</td>
<td>2.57</td>
<td>0.41</td>
<td>0.546</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>−4.08</td>
<td>2.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAME</td>
<td>PC16-InfraOR-InfraOL</td>
<td>−6.43</td>
<td>2.98</td>
<td>−0.75</td>
<td>0.398</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>−5.69</td>
<td>3.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>PC16-InfraOR-InfraOL</td>
<td>−0.28</td>
<td>4.51</td>
<td>−0.31</td>
<td>0.765</td>
</tr>
<tr>
<td></td>
<td>PC26-InfraOL-InfraOR</td>
<td>0.03</td>
<td>3.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P value determined when comparing right and left angle changes.
L, Left; R, right.

Table X. Mean differences and statistical significance of vectors and angles in the 3 groups from T4 to T1 (Bonferroni test)

<table>
<thead>
<tr>
<th>Transverse (mm)</th>
<th>Treatment (a)</th>
<th>Treatment (b)</th>
<th>Mean difference (a−b)</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC16-PC26</td>
<td>Control</td>
<td>BAME</td>
<td>−4.04</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>−4.25</td>
<td>0.000</td>
</tr>
<tr>
<td>PC14-PC24</td>
<td>BAME</td>
<td>TAME</td>
<td>−1.27</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>TAME</td>
<td>−2.13</td>
<td>0.000</td>
</tr>
<tr>
<td>MBA16-MBA26</td>
<td>Control</td>
<td>BAME</td>
<td>−1.9</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>−2.06</td>
<td>0.000</td>
</tr>
<tr>
<td>BA14-BA24</td>
<td>TAME</td>
<td>BAME</td>
<td>1.39</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>TAME</td>
<td>1.39</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>BAME</td>
<td>−1.48</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>−2.81</td>
<td>0.000</td>
</tr>
<tr>
<td>A11-A21</td>
<td>Control</td>
<td>BAME</td>
<td>−1.24</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>−1.56</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vertical (mm)</th>
<th>Treatment (a)</th>
<th>Treatment (b)</th>
<th>Mean difference (a−b)</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>InfraOL-PC26</td>
<td>Control</td>
<td>BAME</td>
<td>−2.15</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>−2.48</td>
<td>0.000</td>
</tr>
<tr>
<td>InfraOL-MeL</td>
<td>BAME</td>
<td>TAME</td>
<td>−1.24</td>
<td>0.049</td>
</tr>
</tbody>
</table>

**Table IX**

<table>
<thead>
<tr>
<th>Dental tipping (°)</th>
<th>Treatment (a)</th>
<th>Treatment (b)</th>
<th>Mean difference</th>
<th>P value (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBA16-PC16-PC26</td>
<td>Control</td>
<td>TAME</td>
<td>3.82</td>
<td>0.019</td>
</tr>
<tr>
<td>MBA26-PC26-PC16</td>
<td>Control</td>
<td>BAME</td>
<td>7.19</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAME</td>
<td>6.31</td>
<td>0.001</td>
</tr>
</tbody>
</table>

L, Left; R, right.

*Statistical significance at the 0.05 level.
than at the premolar. Root apex expansion was less than crown expansion for both the BAME and the TAME subjects; this resulted in significant buccal crown inclination. This result for the BAME was surprising, since there was no direct force application to the teeth. Little if any crown inclination with BAME was expected. Neither the BAME nor the TAME group demonstrated significant skeletal expansion. Both groups had significant molar extrusion after the retention phase compared with the control group. Although the mean vertical change at the molar was approximately 2 mm, there was no significant increase in the vertical position (displacement) of the mandible itself (mental foramen). The vertical change at the level of the molar pulp chamber might result from buccal crown inclination rather than true dental extrusion.

When visually comparing changes between the differences at T2 to T1 and T3 to T1, primary relapse occurred at the level of the incisor crowns. This was expected because the transeptal periodontal fibers move the crowns back together during the retention phase, whereas the root apaxes are fixed in bone.

Significant expansion at the maxillary molar apex was still present after the retention period. In the TAME group, the rigidity of the hyrax appliance resulted in some buccal root movement by controlled inclination of the teeth. With the BAME appliance, it is possible that application of expansion force at the bone surface near the maxillary molar root caused bone bending with movement of the root apex relative to the outer surface of the alveolus. Expansion at the outside of the alveolus was not significant with BAME or TAME. It appears that there is thinning of the bone between the molar root apex and the subperiosteal bone surface. Occlusal movement of the BAME appliance during treatment was not observed.

Consistent with previous research involving TAME, there was no significant anterior skeletal or dental movement with either the TAME or the BAME. Growth during the 6-month interval was not significantly different than movement related to treatment. Six months of growth was not expected to result in clinically significant changes.

Midpalatal suture separation was observed on the CBCT images for both TAME and BAME subjects. At the level of the pterygoid plates, there were no significant changes between the expansion groups and the control group. The pterygoid plates are part of the sphenoid bone and are far from the point of force application, thus limiting the effect of expansion on them. Also, the maxilla is surrounded by several bony structures separated by sutures. These sutures are already heavily interdigitated at the ages of the subjects in this clinical trial. This causes these bony structures contacting the maxilla to resist displacement of the maxilla.

In this study, approximately 4 mm (70%) of long-term (postrelapse) expansion was maintained at the maxillary molar with both appliances. The expansion was not significantly different between appliances. The TAME appliance had significant long-term expansion at the maxillary premolar crown but not at the level of the root apex. Vertical increase at the maxillary first molar at the postrelapse time period was still significant and appeared to be unchanged from the end of retention. There was continued buccal crown inclination for both appliances that appeared to be unchanged during the relapse period.

The ideology of using a bone-anchored device for expansion in adolescents was to eliminate some negative effects (more dental expansion than skeletal, periodontal recession, and root resorption). According to our study, tooth- and bone-borne RME results are similar. Negative periodontal consequences were not observed in either experimental group during the study. The TAME appliance produced thinning of the alveolar at the level of the premolar. Hygiene was better for BAME appliances, since they were smaller and permitted brushing and flossing on all teeth compared with the TAME appliances. Root resorption was not observed in either experimental group. BAME was not more painful than TAME, and both had average pain scores lower than extraction of teeth or placement of separators.

The decision to use TAME or BAME in adolescents should be based on operator preference and specific patient variables. BAME appliances are indicated when the patient is missing permanent posterior teeth or the health of the teeth can be compromised. BAME will also allow full bonded orthodontic therapy at the same time as the expansion. This could shorten total treatment time. TAME is indicated in situations requiring more aggressive expansion of the first premolar.

*Table XI. Estimated marginal mean of pain values reported*

<table>
<thead>
<tr>
<th>Group</th>
<th>Measurement</th>
<th>Mean</th>
<th>SE</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAME</td>
<td>A1</td>
<td>13.5</td>
<td>3.6</td>
<td>6.1</td>
<td>20.9</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>14.9</td>
<td>3.3</td>
<td>8.3</td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>24</td>
<td>4.1</td>
<td>15.6</td>
<td>32.4</td>
</tr>
<tr>
<td>TAME</td>
<td>A1</td>
<td>17.9</td>
<td>3.9</td>
<td>10</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>7.4</td>
<td>3.6</td>
<td>0.2</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>19.7</td>
<td>4.5</td>
<td>10.7</td>
<td>28.8</td>
</tr>
</tbody>
</table>

A1, At the first activation; A2, in the middle of expansion; O, overall expansion experience.
CONCLUSIONS

When measuring 3D maxillary complex structural changes during maxillary expansion treatments with CBCT, both TAME and BAME showed similar results. The greatest changes happened in the transverse dimension, whereas changes in the vertical and anteroposterior dimension were negligible. Dental expansion was also greater than skeletal expansion.

We suggest from these findings that BAME can be considered as an alternative choice for TAME.

REFERENCES

35. Waitzman AA, Posnick JC, Armstrong DC, Pron GE. Craniofacial skeletal measurements based on computed tomography: part II.