Buccal alveolar bone changes following rapid maxillary expansion and fixed appliance therapy

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ABSTRACT

Objectives: To assess factors that may be associated with buccal bone changes adjacent to maxillary first molars after rapid maxillary expansion (RME) and fixed appliance therapy.

Materials and Methods: Pretreatment (T1) and posttreatment (T2) cone-beam computed tomography scans were obtained from 45 patients treated with RME and preadjusted edgewise appliances. Buccal alveolar bone thickness was measured adjacent to the mesiobuccal root of the maxillary first molar 4 mm, 6 mm, and 8 mm apical to the cementoenamel junction, and anatomic defects were recorded. Paired and unpaired t-tests were used to compare alveolar bone thickness at T1 and T2 and to determine whether teeth with posttreatment anatomic defects had thinner initial bone. Correlation analyses were used to examine relationships between buccal alveolar bone thickness changes and amount of expansion, initial bone thickness, age at T1, postexpansion retention time, and treatment time.

Results: There was a statistically significant reduction in buccal alveolar bone thickness from T1 to T2. Approximately half (47.7%) of the teeth developed anatomic defects from T1 to T2. These teeth had significantly thinner buccal bone at T1. Reduction in alveolar bone thickness was correlated with only one tested variable: initial bone thickness.

Conclusions: RME and fixed-appliance therapy can be associated with significant reduction in buccal alveolar bone thickness and an increase in anatomic defects adjacent to the expander anchor teeth. Anchor teeth with greater initial buccal bone thickness have less reduction in buccal bone thickness and are less likely to develop posttreatment anatomic defects of buccal bone.

KEY WORDS: Alveolar bone; RME

INTRODUCTION

Rapid maxillary expansion (RME) is commonly used to address transverse deficiencies of the maxilla. First described in 1860, RME has been used primarily for posterior crossbite correction. More recently, RME has also been reported to facilitate the correction of Class II and Class III malocclusions, resolve arch length discrepancies, and increase upper respiratory volume to improve airflow.

Conventional RME uses tooth-borne appliances to deliver heavy forces to the maxilla. In growing patients, the transmitted forces are sufficient to open the midpalatal suture, hold the halves of the maxilla apart, and allow subsequent callus formation. This process, known as "skeletal expansion," is typically the preferred effect of RME. However, the forces exerted on the teeth also cause dentoalveolar expansion, which comprises alveolar bending and translation, tipping, and extrusion of teeth. The dental effects are typically undesirable because they can cause an increase in vertical dimension, root resorption, and loss of periodontal attachment, including fenestration or dehiscence of the buccal cortical bone. RME is often followed by fixed appliance therapy, which,
through buccal tipping, rotation, and translation of
teeth, may also contribute to alveolar bone changes.\textsuperscript{18}

Since orthodontic treatment aims to maintain peri-
odontal health, it is essential to assess the bony
support of teeth before and after treatment. However,
conventional two-dimensional radiographs do not allow
exact identification of buccal alveolar bone. More
recently, cone-beam computed tomography (CBCT)
has been used to assess the alveolar bone changes
associated with RME.\textsuperscript{10–12,15,17} CBCT allows for more
accurate assessment of alveolar bone support by
identifying objects based on their relative density.\textsuperscript{19–21}
However, bone in areas of tooth movement undergoes
remodeling, is less mineralized, and, as a result,
appears less dense on CBCT images for 6–24 months
after tooth movement subsides.\textsuperscript{22} All current studies
have evaluated changes on CBCT scans taken 0–6
months after RME. In these studies, the limitations of
radiographic assessment of remodeling bone have to
be considered. Additionally, no studies have yet
evaluated the potential added effect of fixed appliance
therapy. The evaluation of buccal alveolar bone before
and after comprehensive orthodontic treatment may
provide more clinically relevant information on the
cumulative effects of RME and fixed appliance therapy.
So far, only one study has evaluated variables, such as
age and amount of expansion, that might help predict
the alveolar response to RME.\textsuperscript{11} Therefore, the aim of
this study was to assess whether factors such as age,
amount of expansion, treatment time, or initial bone
thickness were associated with buccal bone changes
after RME and fixed appliance therapy. The following
null hypotheses were tested: (1) there are no differ-
ences in buccal alveolar bone thickness and anatomic
defects of the buccal alveolar bone before and after
treatment with RME and fixed appliance therapy; and
(2) buccal alveolar bone thickness and anatomic
defects of the buccal alveolar bone are not correlated
with age, amount of expansion, treatment time, or initial
bone thickness.

MATERIALS AND METHODS

This retrospective cohort study was approved by the
Institutional Review Board at the University of Minne-
sota. The pretreatment (T1) and posttreatment (T2)
CBCT scans of 45 patients (18 boys, 27 girls) were
used. The study sample was a convenience sample of
patients who underwent both RME and fixed appliance
therapy. It was believed this sample offered clinical
relevance because it represented the outcomes of
comprehensive orthodontic treatment. The patients
were treated in a university clinic by 12 orthodontic
residents under the supervision of nine faculty ortho-
dontists. Patients were excluded if they had previous
orthodontic treatment, history of periodontal disease,
incomplete treatment records, or metallic restorations
in the maxillary first molars. Descriptive patient
information is summarized in Table 1.

The patients were treated with Hyrax expanders with
soldered wires along the palatal surfaces designed to
evenly disperse force over all maxillary premolars and
first molars. The expanders were activated once daily
(0.25 mm) until the appropriate amount of expansion
was obtained. Expanders were removed after a
variable postexpansion retention period, which was at
the discretion of the supervising faculty orthodontists
(Table 1), and preadjusted edgewise appliances were
placed.

All CBCT images were full field of view (17 \times 23 \text{ cm})
scans obtained with an i-Cat Next Generation (Imaging
Sciences International, Hatfield, Pa) at 120 kV, 18.54
mA, a pulsed scan time of 8.9 seconds, and a voxel
dimension of 0.3 mm. CBCT analysis was performed
by a single examiner using Dolphin Imaging software
(v11.9, Dolphin Imaging and Management Solutions,
Chatsworth, Calif). The images were analyzed in a
random order to limit measurement bias. All measure-
ments were repeated after a 4-week washout period for
15 randomly chosen CBCT scans to assess repea-
tability of the measurements.

A multiple planar view mode was used to orient the
images. In the axial view, the buccal furcation of the
maxillary right first molar was identified. The axial
image was then oriented so that the buccal plate
adjacent to the mesiobuccal root was parallel to the
vertical axis of the image window. In the sagittal view,
a reference line was positioned on the long axis of the
mesiobuccal root of the maxillary first molar. Orienta-
tion in the axial and sagittal views resulted in a coronal
image, which was refined so that the buccal plate was
parallel to the vertical axis of the image window.

Linear measurements of alveolar bone thickness
were made at 4 mm, 6 mm, and 8 mm apical to the
buccal cementoenamel junction (CEJ) of the right and
left maxillary first molar as follows. In the coronal view,
a reference line was placed at the buccal CEJ. The line
was then moved 4 mm apically using the ruler in the
image window as a guide. The distance from the outer
surface of the mesiobuccal root to the outer surface of
the buccal cortical bone was then measured using the
software’s linear measuring tool. The same measurement was also made in the corresponding axial image for verification. The measurements were repeated at 6 mm and 8 mm apical to the CEJ using the same method (Figure 1). If the alveolar bone was not visible on the images, the site was quantitatively assessed as 0 mm and qualitatively assessed as dehiscence, fenestration, or complete disruption of the alveolar bone.

**Statistical Analysis**

Intraclass correlation coefficients were calculated to assess repeatability of the measurements. Paired t-tests were performed to determine whether right- and left-side buccal bone changes were significantly different. Because there were no significant differences, the right and left measurements for each patient were averaged separately for each level. Paired t-tests were then performed to evaluate whether the change in buccal alveolar bone thickness at each level was significant. Unpaired t-tests were performed to determine whether there was a significant difference in bone thickness at T1 between patients with and without anatomic defects at T2. Spearman correlation coefficients were calculated to examine the relationship between buccal bone thickness changes and continuous variables (amount of expansion, age at T1, time between T1 and T2, postexpansion retention time, and alveolar bone thickness at T1). Analyses were performed in SAS 9.4 (SAS Institute Inc, Cary, NC) with P values less than .05 considered statistically significant.

**RESULTS**

Intraclass correlation coefficients for all measurements were $\geq0.95$ (Table 2). The buccal alveolar bone thickness at each level assessed is shown in Table 3. There was a statistically significant reduction in bone thickness from T1 to T2 at all levels. The average reductions were 0.51 mm, 0.73 mm, and 0.98 mm at 4 mm, 6 mm, and 8 mm apical to the CEJ, respectively.

There was also an increase in the prevalence of anatomic defects of the buccal alveolar bone adjacent...
to the maxillary permanent first molars from T1 to T2 (Table 4). While no defects were present at T1, there were defects associated with 47.7% of the studied teeth and 60.0% of the studied patients at T2. The majority of the defects were fenestrations, accounting for 84.4% of the defects, while dehiscence and complete disruption of the buccal alveolar bone accounted for 6.7% and 8.9% of the defects, respectively. Examples of these defects are shown in Figure 2.

Teeth with defects at T2 had significantly thinner buccal alveolar bone adjacent to their mesiobuccal root at T1 than those with no defects at T2 (Table 5). The amount of bone loss was negatively correlated (P < .0001) with the bone thickness at T1. The Spearman correlation coefficients were –0.55, –0.65, and –0.79 at 4 mm, 6 mm, and 8 mm apical to the CEJ, respectively, indicating that teeth with greater initial buccal bone thickness had less reduction in buccal bone thickness. In contrast, a reduction in buccal alveolar bone thickness was not significantly correlated with the amount of expansion, age at T1, time between T1 and T2, or postexpansion retention time (P > .05; Table 6).

**DISCUSSION**

Orthodontic treatment with RME and fixed appliances causes buccal displacement of teeth, which can result in buccal alveolar bone loss. This study assessed factors that might affect buccal bone change. The principal finding was that a reduction in buccal alveolar bone thickness was related only to the pretreatment bone thickness but not to the amount of expansion, age, postexpansion retention time, or overall treatment time.

### Table 2. Intraclass Correlation Coefficients for All Repeated Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm apical CEJ</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>6 mm apical CEJ</td>
<td>0.99</td>
<td>0.95</td>
</tr>
<tr>
<td>8 mm apical CEJ</td>
<td>0.99</td>
<td>0.96</td>
</tr>
</tbody>
</table>

* CEJ indicates cementoenamel junction.

### Table 3. Buccal Alveolar Bone Thickness (mm) Pretreatment (T1) and Posttreatment (T2) at Each Vertical Level Assessed

<table>
<thead>
<tr>
<th>Level</th>
<th>T1</th>
<th>T2</th>
<th>Change T2–T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm apical CEJ</td>
<td>1.35 ± 0.57</td>
<td>0.85 ± 0.49</td>
<td>–0.51 ± 0.43***</td>
</tr>
<tr>
<td>6 mm apical CEJ</td>
<td>1.25 ± 0.70</td>
<td>0.52 ± 0.53</td>
<td>–0.73 ± 0.49***</td>
</tr>
<tr>
<td>8 mm apical CEJ</td>
<td>1.48 ± 0.90</td>
<td>0.49 ± 0.57</td>
<td>–0.98 ± 0.64***</td>
</tr>
</tbody>
</table>

* CEJ indicates cementoenamel junction.

### Table 4. Occurrence of Anatomic Defects of the Buccal Alveolar Bone Adjacent to the Maxillary Permanent First Molars Pretreatment (T1) and Posttreatment (T2)

<table>
<thead>
<tr>
<th>Type of Defect</th>
<th>Maxillary First Molars (n = 90)</th>
<th>Patients (n = 45)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>Fenestration</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Dehiscence</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Complete disruption</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

* Two teeth were associated with both a dehiscence and a fenestration of the buccal alveolar bone.

The mesiobuccal root of the maxillary first molar was chosen for evaluation because it is directly related to the buccal bone plate and is the anchor-tooth root that is most susceptible to changes associated with RME. CBCT was used to measure bone changes as it allowed for evaluation of buccal alveolar bone in both the coronal and axial planes. However, the scan parameters were not ideal for assessing thin anatomic structures, such as buccal alveolar bone, as the CBCT scans had been taken for general orthodontic diagnosis and treatment planning. Despite this, the measurement precision was excellent as evidenced by the high intraclass correlation coefficients.

There was a significant reduction in buccal alveolar bone thickness over the course of treatment, which agreed with findings of other studies that addressed the effects of RME. Hence, the first null hypothesis was rejected. It is well established that RME causes alveolar bending and dental tipping, which influence bone thickness. Interestingly, the reduction in bone thickness was progressively greater at more apical levels. Pure dental tipping would have caused a greater reduction at the coronal portion of the root, as this portion moves more buccally than the apex. It is conceivable that tipping was limited by the expander design and occurred paired with alveolar bending. It is also conceivable that the fixed appliance therapy that followed, using a bracket prescription with built-in buccal root torque at the maxillary first molar, may have led to a greater reduction in bone thickness at the apical portion of the root.

It must be assumed that physiologic growth and remodeling of the nasomaxillary complex occurred in the study population. Transverse maxillary growth includes sutural separation of the hemimaxillae, is greater posteriorly than anteriorly, and has been reported to occur at average rates of 0.12–0.48 mm per year. Since the present study did not include an untreated control group, it was not possible to determine whether the findings of buccal alveolar bone thickness changes, and anatomic defects of the buccal alveolar bone may be associated with physiologic growth and remodeling.
The treatment of some patients included maxillary premolar extractions and subsequent molar mesial movement during space closure. As the molar moved anteriorly in the alveolus, it may have entered a thinner or thicker area of alveolar bone, which could have influenced the buccal bone thickness measurements at T2. Vertical or rotational tooth position changes could have influenced the buccal bone thickness, too. For example, a mesially rotated molar would have thicker bone along the buccal surface of its mesiobuccal root than the same de-rotated molar in which the mesiobuccal root would have been moved into closer proximity to the buccal cortical bone. Greater rotational changes may, therefore, have resulted in greater alveolar bone thickness changes.

There was an increase in the prevalence of anatomic defects of the buccal alveolar bone associated with RME anchor teeth, which was consistent with previous research findings. The relatively high proportion of patients with posttreatment defects suggested that the occurrence of a defect after RME and fixed appliance therapy is relatively universal and not limited to a small number of predisposed patients. This finding does not, however, eliminate the potential that certain characteristics, such as thin periodontal biotype, may predispose patients to the development of anatomic defects.

Fenestrations accounted for the vast majority of the observed defects, while dehiscence and complete disruption of the buccal alveolar bone were much rarer. It is important to note that a systematic overestimation of dehiscences and fenestrations from CBCT images has been reported previously.

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### Table 5. Pretreatment (T1) Buccal Alveolar Bone Thickness (mm) Adjacent to Teeth With and Without Posttreatment (T2) Anatomic Defects

<table>
<thead>
<tr>
<th>Level</th>
<th>No Defect at T2</th>
<th>Defect at T2</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm apical CEJ</td>
<td>1.62 ± 0.67</td>
<td>1.18 ± 0.50</td>
<td>0.44*</td>
</tr>
<tr>
<td>6 mm apical CEJ</td>
<td>1.67 ± 0.75</td>
<td>0.97 ± 0.58</td>
<td>0.70***</td>
</tr>
<tr>
<td>8 mm apical CEJ</td>
<td>2.09 ± 1.02</td>
<td>1.07 ± 0.67</td>
<td>1.02***</td>
</tr>
</tbody>
</table>

* CEJ indicates cementoenamel junction.

### Table 6. Spearman Correlation Coefficients Describing the Associations Between Change in Buccal Alveolar Bone Thickness at the Levels Evaluated and Amount of Expansion, Age at T1, Time Between T1 and T2, and Postexpansion Retention Time

<table>
<thead>
<tr>
<th>Variable</th>
<th>4 mm Apical CEJ</th>
<th>6 mm Apical CEJ</th>
<th>8 mm Apical CEJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of expansion</td>
<td>-0.00963</td>
<td>-0.02236</td>
<td>0.08548</td>
</tr>
<tr>
<td>Age at T1</td>
<td>0.03112</td>
<td>0.10558</td>
<td>0.28155</td>
</tr>
<tr>
<td>Time between T1 and T2</td>
<td>-0.01931</td>
<td>-0.02220</td>
<td>0.03538</td>
</tr>
<tr>
<td>Postexpansion retention time</td>
<td>-0.13295</td>
<td>-0.00103</td>
<td>-0.05228</td>
</tr>
</tbody>
</table>

* CEJ indicates cementoenamel junction.
instance, in a study by Sun et al.,\textsuperscript{29} alveolar defects were confirmed in only 75% and 16% of patients when dehiscence and fenestrations, respectively, were found on CBCT. These findings suggest that CBCT evaluation of alveolar bone may result in systematic overreporting of anatomic defects, particularly fenestrations. The spatial resolution of the CBCT scans used in this study was likely not adequate to visualize thin buccal alveolar bone and, therefore, may have contributed to overreporting of defects. Even so, it is likely that RME and fixed appliance therapy contributed to the formation of some anatomic defects, which can lead to gingival recession and periodontal instability.

Teeth with posttreatment defects of the buccal bone plate were found to have significantly thinner bone pretreatment. Since orthodontic tooth movement involves bone resorption at the compression side, it appears logical that teeth in closer proximity to the buccal bone plate would allow less buccal movement before resorption of the cortical bone occurs. An evaluation of pretreatment bone thickness adjacent to RME anchor teeth may help determine patient-specific susceptibility to the development of defects of the buccal alveolar bone.

The initial bone thickness was significantly negatively correlated with the amount of bone change indicating that teeth with initially thicker buccal alveolar bone experienced less reduction in buccal bone thickness during treatment. This finding is logical from a morphologic standpoint. Patients with greater initial bone thickness are often more brachyfacial, with broader apical bases, less buccally inclined teeth, and possibly thicker cortical plates. These patients are typically at less risk of hard and soft tissue loss than those who are more dolichofacial, have a narrower apical base, and have more buccally inclined teeth. It is also conceivable that a greater initial buccal bone thickness could provide more resistance to lateral dental movements. This would include potentially thicker cortical bone, which remodels less readily than trabecular bone.

It was somewhat surprising, and partially in disagreement with findings of earlier studies,\textsuperscript{11} that the amount of expansion, age, postexpansion retention time, and overall treatment time were not correlated with buccal bone loss. Although this supports the second null hypothesis for these variables, it would appear logical that, with an increased amount of expansion and increased sutural resistance at an older age, the proportion of dentoalveolar expansion would increase too, leading to buccal alveolar bone loss. It is conceivable that this effect was washed out by the added effect of fixed appliance therapy in the present sample. However, the finding that postexpansion retention time had no significant association with buccal alveolar bone loss was consistent with results of previous studies.\textsuperscript{11} While, theoretically, a shorter postexpansion retention period could allow for more relapse of dental tipping and subsequent buccal bone deposition, factors such as archform during fixed appliance therapy likely played a greater role in the relapse of dental tipping. Because retention time did not have a significant impact on buccal bone changes, the RME appliance should be retained in place for an adequate time to allow for bony fill of the separated midpalatal suture.

CONCLUSIONS

- Treatment with RME and fixed appliances can be associated with significant reduction in buccal alveolar bone thickness and an increase in anatomic defects adjacent to the mesiobuccal root of the maxillary first molar.
- RME anchor teeth with greater initial buccal bone thickness are less likely to lose buccal bone and develop posttreatment anatomic defects.
- The amount of expansion, age, postexpansion retention time, and overall treatment time are not predictive factors of the reduction in buccal alveolar bone thickness.

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