Three-dimensional assessment of buccal alveolar bone after rapid and slow maxillary expansion: A clinical trial study

Mauricio Brunetto,a Juliana da Silva Pereira Andriani,b Gerson Luiz Ulema Ribeiro,c Arno Locks,c Marcio Correa,d and Leticia Ruhland Correab
Curitiba, Paraná, and Florianópolis, Santa Catarina, Brazil

Introduction: The purposes of this study were to analyze and compare the immediate effects of rapid and slow maxillary expansion protocols, accomplished by Haas-type palatal expanders activated in different frequencies of activation on the positioning of the maxillary first permanent molars and on the buccal alveolar bones of these teeth with cone-beam computerized tomography. Methods: The sample consisted of 33 children (18 girls, 15 boys; mean age, 9 years) randomly distributed into 2 groups: rapid maxillary expansion (n = 17) and slow maxillary expansion (n = 16). Patients in the rapid maxillary expansion group received 2 turns of activation (0.4 mm) per day, and those in the slow maxillary expansion group received 2 turns of activation (0.4 mm) per week until 8 mm of expansion was achieved in both groups. Cone-beam computerized tomography images were taken before treatment and after stabilization of the jackscrews. Data were gathered through a standardized analysis of cone-beam computerized tomography images. Intrigroup statistical analysis was accomplished with the Wilcoxon matched-pairs test, and intergroup statistical analysis was accomplished with analysis of variance. Linear relationships, among all variables, were determined by Spearman correlation. Results and Conclusions: Both protocols caused buccal displacement of the maxillary first permanent molars, which had more bodily displacement in the slow maxillary expansion group, whereas more inclination was observed in the rapid maxillary expansion group. Vertical and horizontal bone losses were found in both groups; however, the slow maxillary expansion group had major bone loss. Periodontal modifications in both groups should be carefully considered because of the reduction of spatial resolution in the cone-beam computerized tomography examinations after stabilization of the jackscrews. Modifications in the frequency of activation of the palatal expander might influence the dental and periodontal effects of palatal expansion. (Am J Orthod Dentofacial Orthop 2013;143:633-44)

Correction of the maxillary transverse discrepancy is essential for treatment of various types of malocclusions. Palatal expansion is the most common method used to improve the transverse dimensions of the maxilla. Three types of protocol for palatal expansion are shown in the literature: rapid maxillary expansion,1-3 slow maxillary expansion,4-17 and semirapid maxillary expansion.15,18 The latter and its variations19 have generated less interest in orthodontics compared with the first 2 types, which are evaluated and cited more frequently.

Rapid maxillary expansion is associated with intermittent high-force systems20 and tooth-tissue-borne appliances (Haas type).1-3 Slow maxillary expansion is often associated with continuous low-force systems and quad-helix appliances or coil springs.4,5,8-11,15 Interestingly, the combination of Haas-type palatal expanders and slow maxillary expansion (ie, reduction in the frequency of activation of the jackscrew) exists but has been rarely studied.12,16,17 The advantages and disadvantages of each protocol have been analyzed for many years, yet the issue remains unclear and controversial, since different devices and methodologies interfere with the comparisons.6 Despite the polemic, the literature indicates that both protocols provide maxillary expansion, although slow maxillary expansion...
expansion has been related to more physiologic effects on sutural tissues, greater tooth movement, and lower orthopedic effects compared with rapid maxillary expansion. Additionally, both rapid and slow maxillary expansion cause lateral flexion of the alveolar processes and buccal displacement of the anchorage teeth with varying degrees of inclination.

Displacement of the teeth outside the alveolar anatomic limits can damage the periodontium, compromising tooth longevity. Few studies concerning a quantitative analysis of periodontal modifications resulting from maxillary expansion have been developed, possibly because of the difficulty of observation of the height and thickness of the alveolar bone on a conventional radiographic examination.

Recently, and because of its numerous advantages over conventional radiography and conventional computerized tomography, cone-beam computerized tomography (CBCT) has been used for quantitative analysis of skeletal, dentoalveolar, and periodontal changes from rapid and slow maxillary expansion. These latter studies indicate that both rapid maxillary expansion and slow maxillary expansion cause buccal bone loss in varying degrees; however, they used different types of appliances and analyzed individually each protocol. The literature lacks simultaneous comparative studies between the 2 protocols, especially comparisons with the same type of appliance and CBCT.

Therefore, the purposes of this study were to quantitatively analyze and compare the immediate effects of rapid and slow maxillary expansion with Haas-type palatal expanders activated at different frequencies on the positions of the maxillary first permanent molars, as well as the modifications of the buccal alveolar bone of these teeth, by using CBCT. The null hypothesis was that the 2 protocols cause similar dental movements and periodontal effects.

**MATERIAL AND METHODS**

The sample was selected in a public school and from orthodontic patients who sought treatment at the Federal University of Santa Catarina in Brazil. All parents or guardians signed the informed consent form, which was duly approved by the ethics committee in human research of the university.

The inclusion criteria were a clinical maxillary transverse deficiency and age between 7 and 10 years (intertransitory period of the mixed dentition). Patients with physical or psychological limitations or metallic restorations in the first permanent molars were excluded. A sample of 59 subjects was selected and randomly divided into 2 groups: rapid maxillary expansion and slow maxillary expansion. All patients used the tooth-tissue-borne palatal expander recommended by Haas (Fig 1). Each appliance included a screw expander with a maximum aperture of 11.0 mm (Dentaurum, Inspringen, Germany) and bands in the first deciduous and first permanent molars. The subjects in both groups had an 8-mm opening of the screw, for a total of 40 activations. With a digital caliper (Ortho-pli, Philadelphia, Pa), we monitored all expansion procedures every 15 days to check the activation protocol. At the end of activation, the devices were stabilized with 0.12-mm ligature wires (Morelli, Sorocaba, Brazil) and maintained as retainers for 5 months in the rapid maxillary expansion group and for 1 month in the slow maxillary expansion group.

Patients who did not correctly follow the protocol of activation, who did not return for control dental appointments, who did not have their final examination within 7 days after screw stabilization, whose cementation of appliance failed, whose molars were exfoliated during treatment, or whose dental structures were difficult to visualize on the CBCT scans as a result of artifacts from the palatal expander were excluded.

The rapid maxillary expansion group initially comprised 28 subjects, but only 17 remained in the study (10 girls, 7 boys). Their mean age was 8.9 years, and they were treated with the rapid maxillary expansion protocol: a half turn (0.4 mm) per day. The palatal disjunctor was activated a full turn on the first day. Of the 31 subjects in the slow maxillary expansion group, only 16 were evaluated in the final sample (8 girls, 8 boys). Their mean age was 9 years, and they were treated with the slow maxillary expansion protocol: a half turn (0.4 mm) weekly. Upon cementation of the appliance, activation consisted of a half turn. The patients received a CBCT examination before orthodontic treatment (T1) and between 1 and 7 days after stabilization of the screw (T2). The appliances were not removed for the T2 examinations.

The CBCT examinations were performed with an i-CAT device (Imaging Sciences International, Hatfield, Pa) at 120 kV, 20 mA, and 14.7-second scan time. The images had a 0.25-mm thickness with 0.25-mm

![Fig 1. Palatal expander.](image-url)
isotropic voxels. After acquisition, the images were saved in digital imaging and communications in medicine (DICOM) format and were built and manipulated in layers of 0.5 mm with OsiriX Medical Imaging 32-bit software (open source; Pixmeo, Geneva, Switzerland; www.osirix-viewer.com). The same operator (M.B.) made all measurements; he was unaware of the group to which each patient belonged.

The tomographic analysis performed was similar to that proposed by Bernd. The long axis of the mesiobuccal root of the maxillary first permanent molar served as a reference for the standardization of CBCT slices made at T1 and T2. For this purpose, the images were initially viewed in the multiplanar reconstruction mode of the software. In this mode, there are 3 sections in 3 different windows (each corresponding to each plane of space) and 3 color lines (Fig 2). Each color line relates to the scrolling of the tomographic cuts in a specific plane of space; eg, orange lines refer to the sagittal plane, purple lines refer to the axial plane, and blue lines refer to the coronal plane. To scroll for tomographic cuts in the sagittal plane, the orange line must be moved into the coronal or the axial section. The same process is valid for the other 2 lines.

The first step of the method was the identification of the furcation region of the maxillary right first permanent molar in the axial section, where the buccal roots were slightly separated. In this image, the intersection of the orange and blue axes was positioned over the center of the mesiobuccal root, and the blue line was positioned following the direction of the buccolingual long axis of the root (Fig 3, A). In the next step, the inclination of the blue line was adjusted in the sagittal section so that it passed through the center of the mesiobuccal root about its long axis (Fig 3, B). Finally, in the coronal section, the position of this tooth was adjusted so that the buccal surface of the root was parallel to the tomographic vertical plane (Fig 3, C). The same patterning process was also performed for the maxillary left first permanent molar. According to these criteria, a standard image was derived in the coronal section (Fig 3, D): orthogonal to the axial and vertical plane described by the buccolingual axis of the mesiobuccal root.

From the standard image in the coronal section, variables related to the height of the buccal alveolar bone (NOVC and NOV; Fig 4, Table I) were determined in full-screen mode. For measurements related to the thickness of the buccal bone plate, a vertical line 10 mm long was drawn parallel to the tomographic vertical plane (Fig 5). The most inferior point of this line was superimposed on the buccal cementoenamel junction (CEJ). At this time, a horizontal line was traced perpendicular to and passing through the highest point of the vertical 10-mm line, determining the measurement of the CEJ 10 (Fig 6, A; Table I).
The vertical line was reduced to 5 mm and then 3 mm in length, each kept parallel to the vertical tomographic plane. Then, 2 new horizontal lines were outlined for each vertical line, determining the measurements CEJ 5 and CEJ 3, respectively (Fig 6, B and C, respectively; Table I).

In this evaluative study, we also used quantitative analysis of the inclination of the first permanent molars. For this purpose, in the axial section, the furcation areas of the maxillary right and left molars, when both buccal roots were slightly separated, were determined. In case of unevenness between the teeth, the furcation area of the right molar was determined (Fig 7, A), and leveling was accomplished by moving the purple line in the coronal section (Fig 7, B). The resulting image in the axial section (Fig 7, C and D) was used for determination of the DR measurement (Fig 8, A; Table I). Also, in the same axial image, the blue line was moved so that it passed between the mesiobuccal and distobuccal roots.
of the maxillary right and left first molars (Fig 7, E). The derived image in the coronal section (Fig 7, F) was used to determine the angle AI and measurement DC (Fig 8, B; Table I).

Statistical analysis

Statistical calculations were performed by using IBM SPSS software (version 20; SPSS, Chicago, Ill), with a $P$ value less than 0.05 indicating statistical significance. The Wilcoxon matched-pairs test determined the intra-group statistical analysis between T1 and T2. Intergroup statistical analysis was determined by analysis of variance (ANOVA) of the differences of means between T1 and T2. The power of the ANOVA test was also calculated, since the exclusion criteria reduced the sample size to 33 patients. The Spearman correlation test was used to detect any linear relationships between the variables.

For the systematic error investigation, 10 examinations of each group were randomly chosen, measured again after a minimum of 15 days, and analyzed by using an intraclass correlation coefficient (ICC).

RESULTS

Means, standard deviations, ranges, and statistical analyses for each group at T1 and T2 are shown in Tables II and III. The differences of means and statistical analyses between groups are presented in Table IV.

The results demonstrated buccal displacement of the first permanent molars in both groups. The rapid maxillary expansion group showed significant increases in the means of DC, DR, and AI (Table II). The slow maxillary expansion group showed similarly significant modification in the same variables, reported in Table III. When we compared the results of the 2 groups (Table IV), differences in tooth inclinations were minor in the region of the crowns, as shown by the small variation in DC. However, changes in the furcation area, represented by the variable DR, were lower in the rapid maxillary expansion group.

A significant increase in the means related to bone height was detected in both groups, as demonstrated by measurements NOV and NOVC (Tables II and III). Furthermore, these changes had greater intensity in the slow maxillary expansion group (Table IV).

The means of CEJ 3 and CEJ 5 decreased between T1 and T2 in both groups (Tables II and III). CEJ 10 showed a significant reduction in the slow maxillary expansion group (Table III) and an increase in the rapid maxillary expansion group (Table II). Statistical analysis between groups (Table IV) indicated significant differences between CEJ 3 (−0.88 mm in rapid maxillary expansion vs −1.36 mm in slow maxillary expansion) and CEJ

| Table I. Definitions of variables in the tomographic analysis |
|------------------|------------------|------------------|
| Variable | Definition | Purpose |
| NOV (mm) | Distance between the buccal CEJ and the most occlusal point of the buccal alveolar crest | Alveolar bone height |
| NOVC (mm) | Distance between the buccal cusp tip and the most occlusal point of the buccal alveolar crest | Alveolar bone height |
| CEJ 3 (mm) | Distance between the outer surface of the buccal alveolar plate and the outer wall of the buccal root 3 mm above the CEJ | Alveolar bone thickness |
| CEJ 5 (mm) | Distance between the outer surface of the buccal alveolar plate and the outer wall of the buccal root 5 mm above the CEJ | Alveolar bone thickness |
| CEJ 10 (mm) | Distance between the outer surface of the buccal alveolar plate and the outer wall of the buccal root 10 mm above the CEJ | Tooth inclination |
| DC (mm) | Distance between the mesiobuccal cusp tips of the maxillary first permanent molars | Tooth displacement and inclination |
| DR (mm) | Distance between the most buccal points of the root canals of the mesiobuccal roots of the maxillary first permanent molars | Tooth displacement and inclination |
| AI (°) | Angle formed by the intersection of 2 lines traced toward the midline and tangent to both mesial cusp tips of each maxillary first permanent molar | Tooth inclination |

Fig 5. Tracing of the 10-mm line parallel to the tomographic vertical plane.
All variables had values higher than 76% after calculation of the power of the ANOVA test for intergroup comparison. Measure CEJ 10 showed the lowest value (76.59%). All other measurements had values higher than 98% when rejecting the null hypothesis.

A negative linear relationship was detected between bone thickness (CEJ 3) at T1 and height of the buccal bone plate (NOV) at T2 ($r = -0.65$ in the rapid maxillary expansion group and $r = -0.77$ in the slow maxillary expansion group). Likewise, but only for the slow maxillary expansion group, there was a negative correlation between variables CEJ 5 at T1, and NOVC and NOV at T2 ($r = -0.70$ and $r = -0.72$, respectively).

Regarding systematic error, all variables showed high levels of reliability, as determined by ICC values (Table V).

**DISCUSSION**

The inclusion of a control group in this study with a similar skeletal pattern as the treated sample was not possible because of ethical concerns. The observation of untreated patients would be important to differentiate natural skeletal growth from changes derived from treatment, especially in the slow maxillary expansion group, where the opening of the screw extended over 5 months.

Standardization of the activation of palatal expanders (8 mm) and the CBCT slices (long axis of the mesiobuccal root of the maxillary first permanent molar) was necessary to reduce possible bias from varying degrees of inclination of the anchorage teeth that could be a result of palatal expansion.33

Most studies comparing rapid and slow maxillary expansion contrast the type of force delivered by each protocol: eg, high intermittent forces applied with
a jackscrew for rapid maxillary expansion and low continuous forces applied with springs or wires for slow maxillary expansion. The association of tooth-tissue-borne appliances and slow maxillary expansion has been rarely evaluated; the result is that there is no standard protocol of activation for this procedure. The expansion rate of 0.4 mm per week has been applied to the slow maxillary expansion group according to the rationale that slower rates of expansion allow more physiologic changes on tissues as well as the formation of sufficiently mature bone to maintain palatal separation. Furthermore, Proffit et al suggested that approximately 0.5 mm of expansion per week is the maximum rate at which the tissues of the midpalatal suture can adapt.

Small samples might increase the standard error of the mean, tending to accept the null hypothesis even when there is a clinically relevant difference. Hence, when applying the ANOVA test for intergroup comparisons, the power of the analysis was calculated. The results indicated that the remaining sample was sufficient to not reject the hypothesis of difference between treatments for the variables analyzed, since the smallest value found (CEJ 10) was greater than 76%.

**Fig 7.** Determination of the furcation area of the maxillary first permanent molars: A, note the unevenness between both furcation areas; B, the purple line in the coronal section is moved to accomplish leveling of the furcation areas; C and D, the resulting image in the axial section, used for determination of the DR measurement; E, the blue line positioned in the axial image to pass between the mesiobuccal and distobuccal roots of the maxillary right and left permanent molars; F, the derived coronal image, used for determination of the AI angle and the DC measurement.
Concerning the movement of the maxillary first permanent molars, variations of DR, DC, and AI (Tables II-IV) confirm previous findings of displacement and buccal inclination of these teeth as a result of rapid maxillary expansion \(^{27,33,35,41,42,44,45}\) and slow maxillary expansion.\(^{8,12,15,16}\) Although indicating the same trend, the values presented here are discrepant with most of the literature. Such variations could be attributed to differences in samples (size and age),\(^ {6}\) type of appliance,\(^ {6}\) amount of activation of the screw,\(^ {6,36}\) methodology,\(^ {6}\) type of computerized tomography,\(^ {42}\) settings of the computerized tomography device,\(^ {45}\) and methodologies of tomographic analyses.\(^ {8}\) Rungcharassaeng et al\(^ {35}\) achieved increases of less magnitude (6.66 mm) in the distance and inclination (6.64 degree) of the maxillary right and left first permanent molars, possibly due to the smaller amount of opening of the expansion screw, on average 4.96 mm, against the standardized 8 mm in this study. Investigating the dental effects of slow maxillary expansion with CBCT, Corbridge et al\(^ {30}\) observed an increase of only 6.5 mm, probably because they used a different appliance (quad-helix), and measurements were made between the palatal grooves of the maxillary right and left first permanent molars. The few studies that combined Haas-type expanders with slow maxillary expansion protocols found lower values than we did for both distance and intermolar inclination \(^ {12,16}\); however, these studies used plaster models. On the other hand, Bernd\(^ {36}\) reported values of DC (9.26 mm), DR (4.86 mm), and AI (12 degree) that were close to those achieved in the rapid maxillary expansion group, possibly because of similarities with our study, including the use of a Haas-type palatal expander, the frequency of activation in the rapid maxillary expansion procedure, the amount of screw activation (8 mm), and the method of analysis of the CBCT images.

The variable DC demonstrated significant and similar increases in both groups (Tables II and III). DR showed a larger increase and the AI angle had less reduction in the slow maxillary expansion group (Tables III and IV). DR and AI variations denoted greater displacements of the vestibular region of root furcation and a lower inclination of teeth, indicating the predominance of bodily movement of the first permanent molars in the slow maxillary expansion group. It is probable that in

Table II. Means, standard deviations, ranges, and statistical significance at T1 and T2 for the rapid maxillary expansion group

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>NOV (mm)</td>
<td>0.93</td>
<td>0.25</td>
</tr>
<tr>
<td>NOVC (mm)</td>
<td>7.85</td>
<td>0.52</td>
</tr>
<tr>
<td>CEJ 3 (mm)</td>
<td>1.98</td>
<td>0.59</td>
</tr>
<tr>
<td>CEJ 5 (mm)</td>
<td>2.42</td>
<td>0.88</td>
</tr>
<tr>
<td>CEJ 10 (mm)</td>
<td>5.18</td>
<td>2.05</td>
</tr>
<tr>
<td>DR (mm)</td>
<td>47.14</td>
<td>2.19</td>
</tr>
<tr>
<td>DC (mm)</td>
<td>49.92</td>
<td>1.84</td>
</tr>
<tr>
<td>AI (°)</td>
<td>158.17</td>
<td>9.80</td>
</tr>
</tbody>
</table>

*P < 0.05.
the rapid maxillary expansion group, the large amount of force generated and suddenly directed to the crowns of the first molars caused greater inclination of the teeth, whereas in the slow maxillary expansion group, a slower rate of activation associated with the anchorage set by the structural rigidity of the palatal expander resulted in lower tooth inclination. Nevertheless, the higher inclination of the alveolar process in the rapid maxillary expansion group compared with the slow maxillary expansion group, observed in another study, might also have contributed to the amount of inclination of the maxillary first permanent molars.

In the rapid maxillary expansion group, the T2 examinations were taken at 21 to 28 days into treatment, whereas for the slow maxillary expansion group, the examinations were obtained between 141 and 148 days. This difference of 120 days might be enough to permit dental movement through the alveolar housing in the slow maxillary expansion group. Therefore, higher variations of the DR measurement in the slow maxillary expansion group might also be related to a major degree of orthodontic movement. This interpretation can invalidate the use of DR for the measurement of the pattern of buccal displacement of the root. However, variations of AI and CEJ 10 still support different types of movement of anchor teeth between the groups.

The type of movement of the first molars resulting from palatal expansion was also investigated by Rungcharassaeng et al. The absence of correlation between their weekly mean rate of activation for the jackscrew (0.83 mm, compatible with the values of rapid and slow maxillary expansion described in literature) and the variable related to dental inclination (\(D\)) associated with the higher values of dental tipping from studies with continuous low-force systems (quad-helix or coil springs) led those authors to speculate that the type of movement of the first molars might be more affected by the force delivery system (spring or jackscrew) rather than the activation protocol. In contrast, we detected differences in the inclination of the first molars as a result of the activation protocol. These conflicting data possibly relate to the fact that the slow maxillary expansion group followed a specific protocol, with 2 weekly activations, whereas Rungcharassaeng et al evaluated the mean rate of expansion of a rapid maxillary expansion procedure, which although compatible does not represent a specific slow maxillary expansion protocol.

### Table III. Means, standard deviations, ranges, and statistical significance at T1 and T2 for the slow maxillary expansion group

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1 Mean</th>
<th>T1 SD</th>
<th>T1 Minimum-maximum</th>
<th>T2 Mean</th>
<th>T2 SD</th>
<th>T2 Minimum-maximum</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOV (mm)</td>
<td>1.43</td>
<td>0.53</td>
<td>0.89-3.01</td>
<td>4.37</td>
<td>1.86</td>
<td>1.17-7.08</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>NOVC (mm)</td>
<td>7.87</td>
<td>0.81</td>
<td>6.80-9.98</td>
<td>11.15</td>
<td>2.17</td>
<td>7.52-14.66</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>CEJ 3 (mm)</td>
<td>1.68</td>
<td>0.58</td>
<td>0.43-2.75</td>
<td>0.31</td>
<td>0.45</td>
<td>0.00-1.33</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>CEJ 5 (mm)</td>
<td>2.18</td>
<td>0.71</td>
<td>1.05-3.65</td>
<td>0.69</td>
<td>0.59</td>
<td>0.00-1.90</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>CEJ 10 (mm)</td>
<td>5.65</td>
<td>1.73</td>
<td>4.16-10.33</td>
<td>3.84</td>
<td>1.96</td>
<td>1.72-9.62</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>DR (mm)</td>
<td>45.82</td>
<td>2.68</td>
<td>41.39-51.01</td>
<td>52.22</td>
<td>2.66</td>
<td>48.04-57.57</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>DC (mm)</td>
<td>48.75</td>
<td>3.16</td>
<td>44.08-53.59</td>
<td>57.78</td>
<td>3.27</td>
<td>51.80-62.68</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>AI (°)</td>
<td>155.62</td>
<td>13.52</td>
<td>127.24-179.69</td>
<td>147.75</td>
<td>14.34</td>
<td>116.98-167.33</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

*P <0.05.

### Table IV. Differences of means between T1 and T2 for both groups and statistical analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>T2-T1 Mean</th>
<th>T2-T1 SD</th>
<th>T2-T1 Minimum-maximum</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOV (mm)</td>
<td>0.75</td>
<td>0.72</td>
<td>2.94-1.74</td>
<td>0.0004*</td>
</tr>
<tr>
<td>NOVC (mm)</td>
<td>0.78</td>
<td>0.72</td>
<td>3.28-1.68</td>
<td>0.0000*</td>
</tr>
<tr>
<td>CEJ 3 (mm)</td>
<td>-0.88</td>
<td>0.28</td>
<td>-1.36-0.44</td>
<td>0.0082*</td>
</tr>
<tr>
<td>CEJ 5 (mm)</td>
<td>-0.60</td>
<td>0.25</td>
<td>-1.49-0.39</td>
<td>0.0000*</td>
</tr>
<tr>
<td>CEJ 10 (mm)</td>
<td>0.77</td>
<td>0.76</td>
<td>1.81-0.74</td>
<td>0.0000*</td>
</tr>
<tr>
<td>DR (mm)</td>
<td>4.85</td>
<td>1.31</td>
<td>6.39-1.12</td>
<td>0.0011*</td>
</tr>
<tr>
<td>DC (mm)</td>
<td>9.26</td>
<td>2.05</td>
<td>9.02-1.70</td>
<td>0.7194</td>
</tr>
<tr>
<td>AI (°)</td>
<td>-12.88</td>
<td>9.35</td>
<td>-7.87-6.80</td>
<td>0.9050</td>
</tr>
</tbody>
</table>

*P <0.05.
Measurements CEJ 3 and CEJ 5 are located near the occlusal edge of the alveolar bone crest; therefore, these are more directly influenced by changes in the vertical alveolar bone. CEJ 10, on the other hand, is located in an apical area that most likely experienced little influence from vertical alveolar bone changes as a result of treatment. Hence, the mean variation of CEJ 10 was associated with the measurement of inclination of the root regions of the maxillary right and left first permanent molars. The significant increase in CEJ 10 in the rapid maxillary expansion group (Tables II and IV) can be interpreted as a greater inclination in the region of the roots of the maxillary first permanent molars, whereas the significant decrease in the slow maxillary expansion group (Tables III and IV) might represent greater bodily movement of those teeth, confirming the variations in DR and AI.

Rapid maxillary expansion33-36,47 and slow maxillary expansion8 procedures have been shown to be related to the loss of buccal alveolar bone height and thickness of the anchorage teeth. The same changes represented by variations in NOV, NOVC, CEJ 3, and CEJ 5 were observed in both groups of this study (Tables II-IV). However, there are considerable variations when comparing the literature with the rapid maxillary expansion group. Differences between samples,6 methodologies,6 types of computed tomography,42 tomographic device settings,45 and evaluated tomographic slices8 might have contributed to such variations. A study using conventional computerized tomography found greater reductions in bone height (3.8 mm) in the first molars,14 and another study found smaller reductions in alveolar bone thickness (0.3-0.5 mm) of the same teeth in subjects treated with rapid maxillary expansion and hyrax-type expanders.33 Other investigations with different tomographic analysis methodologies observed more pronounced vertical (2.92 and 3.3 mm, respectively)15,47 and horizontal (1.24 mm)15 bone loss. Nevertheless, a study evaluated adults treated with hyrax-type expanders and surgically assisted rapid maxillary expansion.47 Bernd36 observed bone loss of 0.5 mm in thickness. Despite the similarities between Bernd’s study and ours, the individual characteristics of the samples represented by differences in the initial ranges and means of measurements possibly contributed to the discrepancies.

The slow maxillary expansion protocol was tested in animals,9,14 and, when tested in patients, a quad-helix appliance8,10,15 or coil springs3,11,13 were commonly used. Only 2 investigations related slow maxillary expansion procedures to Haas-type palatal expanders, although without any periodontal or radiographic examination.12,16 Ours is the first study to quantitatively assess by means of CBCT the dental and periodontal effects of slow maxillary expansion in patients treated with Haas-type expanders. Therefore, direct comparisons between the slow maxillary expansion group and the literature were not possible.

All measurements were correlated to examine possible linear relationships. The negative correlations between measurements CEJ 3 at T1 and NOV at T2 in both groups, as well as between CEJ 5 at T1 and NOV and NOVC at T2 for the slow maxillary expansion group, indicate that the greater the bone thickness at the beginning of treatment, the lower the vertical bone loss at the end of therapy. Importantly, these results agree with the results of Garib et al.34

Patients in the slow maxillary expansion group suffered major periodontal consequences (Table IV); 9 patients had signs of dehiscence. Of this total, 6 had CEJ 3 reduced to zero, and 3 had both CEJ 3 and CEJ 5 reduced to zero. The full effect of orthodontic treatment on the periodontium might not be readily noticeable40; however, changes of such magnitude would probably be discernable clinically, but that was not observed in our sample. The highest rates of periodontal bone loss, which occurred in the slow maxillary expansion group, can be attributed to the greater bodily movement of the first permanent molars combined with lower flexion of the alveolar processes and the possibility of major orthodontic movement in the slow maxillary expansion group. All of these 3 factors facilitate the approximation of the roots to the buccal alveolar bone, allowing the onset of periodontal changes.

CBCT technology has many advantages compared with conventional radiographic imaging8 and computerized tomography.39,48,49 A recent study showed that periodontal bone height and thickness can be measured quantitatively with great precision by using CBCT images.49 Despite this, certain characteristics and limitations of CBCT technology, particularly in the evaluation of the alveolar bone, are neither fully established nor well understood.45,49,50 The ability to differentiate between 2 distinct objects close to each other defines the spatial resolution of CBCT images; this becomes important in small measurements, such as the alveolar buccal bone.8,50,51 Spatial resolution has a multifactorial nature and can be affected by variations in shading, signal-to-noise ratio, field of view, and voxel size.45,50,51 Voxels smaller than 0.3 mm can provide better average spatial resolution for adequate visualization of the buccal bone.50 Another important factor that directly influences spatial resolution is metal artifacts. Surrounding structures of metal orthodontic braces and bands can be misrecognized or not correctly reconstructed by CBCT units; thus, spatial resolution can be compromised in this area.50
Images acquired in this study used voxels of 0.25 mm; however, the palatal expanders were not removed at the T2 examinations. This implies a reduction of spatial resolution influencing the display of images and resulting in a much more limited ability to distinguish between the root portions of the teeth and the buccal bone plates. Hence, in patients of the slow maxillary expansion group with suggestive images of dehiscence, a thin buccal alveolar bone layer probably remained; however, its correct visualization might not have been achievable because of variations in spatial resolution. This might be related to the absence of clinical signs of periodontal alterations in the patients of this group. In any case, these subjects probably had, to some extent, periodontal sequelae to the anchorage teeth of the palatal expander that can make them more susceptible to periodontal problems in the long term, as a result of traumatic brushing, periodontal disease, or occlusion trauma.10

The buccal displacement of the maxillary first permanent molars, with a consequent increase of inclination and alveolar bone loss, should be regarded as a constituent of the palatal expansion procedure.32,35 From a periodontal point of view, maxillary expansion should preferably be performed in the deciduous or early mixed dentition, because the eruption of permanent teeth can minimize the periodontal effects produced by rapid or slow maxillary expansion.34

As previously mentioned, there is no standard protocol for slow maxillary expansion with Haas-type palatal expanders. Mew,18 and Profitt et al17 recommended slow maxillary expansion with 1 mm of weekly activation. More specifically, Profitt et al suggested that activations of 0.25 mm on alternate days provide a satisfactory skeletal-to-dental ratio gain (50% each) and a more physiologic response. The recommendations of Profitt et al have recently been evaluated by Huynh et al12 and Wong et al,16 who tested slow maxillary expansion procedures with Haas-type palatal expanders. However, as previously cited, these authors collected no radiographic data regarding periodontal changes. Activations of 0.4 mm, used in our study, represent a unique situation in the current literature but from a periodontal standpoint do not seem to be the best alternative. Thus, further studies for evaluating the periodontal effects of slow maxillary expansion should be developed by testing its association with tooth-tissue-borne expanders and other frequencies of jackscrew activation.

CONCLUSIONS

After a quantitative analysis and comparison of the immediate effects of rapid and slow maxillary expansion protocols on the positioning of the maxillary first permanent molars and on the modifications of the buccal alveolar bones of these teeth, it can be concluded that the null hypothesis was rejected for the following reasons.

1. The tested rapid and slow maxillary expansion procedures caused significant buccal displacement of the maxillary first permanent molars, with a significant difference in the degree of inclination between the groups. The rapid maxillary expansion group had higher inclinations, and the results suggest greater bodily movement of the teeth in the slow maxillary expansion group.

2. Loss and reduction of height and thickness of bone were detected in both groups, with greater intensity and significance in the slow maxillary expansion group. These modifications should be carefully considered because of the reduction of the spatial resolution in CBCT examinations at T2.

3. Changes in the frequency of activation of the palatal expander might influence the dental and periodontal effects of maxillary expansion treatment.

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