Bone volume, tooth volume, and incisor relapse: A 3-dimensional analysis of orthodontic stability

Jeremy B. Chaison,a Curtis S. K. Chen,b Susan W. Herring,c and Anne-Marie Bollenc
Seattle, Wash

Introduction: Orthodontic relapse is a common and significant problem. Few risk factors have been identified, and the role of bone has only recently been investigated. The purpose of this study was to examine the influence of alveolar bone volume and tooth volume on dental relapse. Methods: The sample was chosen from the postretention database at the Department of Orthodontics of the University of Washington in Seattle. Based on the 10-year postretention (T3) irregularity index (II), 40 relapse subjects (T3 II > 6 mm) and the 40 most stable subjects (lowest T3 II < 1.5 mm) were identified for the study. Cone-beam computed tomography (CBCT) scans were taken of the posttreatment (T2) models. Total volume (V) was defined laterally by the distal contact points of the canines and vertically by the cusp tips of the canines to a depth 7 mm below the most inferior gingival margin. Alveolar volume (AV) was defined as the region below a vertical line at the most inferior gingival margin and tooth volume (TV) as the region above that line. The ratio TV:AV was calculated. Logistic regression analysis was used to determine the association between relapse and AV, and to adjust for potentially confounding variables (TV, initial II, sex, age, retention time, and postretention time). Mandibular cortical thickness (CT) measured on T2 lateral cephalograms was used as another measure of bone quantity. Nine patients from the graduate orthodontic clinic who had pretreatment CBCT scans were identified. V, AV, and TV were measured on both the in-vivo scans and the scans of their dental casts to verify the method. Results: The relapse group had significantly greater V and AV and significantly lower CT. TV:AV was not different between the groups. T2 II was found to be a significant predictor of relapse based on logistic regression analysis, whereas AV was not. CT was poorly correlated with AV. V and AV were highly correlated between in-vivo scans and dental cast scans, whereas TV approached significance. Conclusions: Although postretention relapse was associated with increased V and AV, when other variables were controlled, bone volume was not a significant predictor of relapse. (Am J Orthod Dentofacial Orthop 2010;138:778-86)

It has been stated that the greatest risk in orthodontic treatment is partial or total failure in accomplishing a worthwhile and lasting change in the dentition. Long-term stability, therefore, is a key objective in orthodontic treatment. However, it has been shown that 20% of patients are likely to have marked relapse of the mandibular incisors and that satisfactory alignment after retention is maintained in fewer than 30% of orthodontically treated patients. Prior research has sought to identify potential biologic or therapeutic predictors of incisor relapse, including treatment plan (extraction vs nonextraction), Angle class, sex, retention time, overbite, overjet, and arch width, but few significant predictors have been identified. Of the multitude of descriptive characteristics investigated, only increased intercanine width during treatment and initial irregularity are significant predictors. Since dental crowding is a reflection of a discrepancy between tooth size and available space in the dental arch, the proportions between these 2 measures are invariably linked to crowding. Tooth size measurements are a simple clinical measure that is routinely used in the orthodontic diagnostic process. Naturally, the relationship of mandibular incisor size and orthodontic stability has been investigated. Peck and Peck identified a ratio of mesiodistal and buccolingual widths that correlated with crowding in untreated normal subjects. Investigations involving both untreated normal subjects and postretention relapse found little significant correlation between tooth size ratios and crowding and relapse. Despite the contention of Peck and Peck that tooth morphology ratios are highly correlated to crowding, it appears that a larger than average mesiodistal tooth dimension is not a predictor for relapse.

Until recently, the role of bone in dental relapse had not been investigated, even though the teeth are housed...
in and orthodontically moved through the alveolar bone. Animal models have demonstrated that teeth move faster and show greater relapse in animals with decreased bone density. A retrospective study of orthodontically treated patients by Rothe et al showed that decreased mandibular cortical thickness, a measure of bone mass, density, and size, on panoramic and lateral cephalograms was shown to be a risk factor for incisor relapse. Fractal dimension of anterior periapical radiographs, a measure of trabecular bone quality, was not. It was further hypothesized that increased cortical thickness might contribute to stability because it is correlated with increased bone volume in the mandibular incisor region. If so, then bone size itself might have a relationship to stability.

The recent introduction of cone-beam computed tomography (CBCT) in orthodontic diagnosis allows for 3-dimensional (3D) imaging and measurements of volume. It is fast becoming a key diagnostic tool for assessing alveolar bone height and volume in areas of dental implants or osteotomy sites. Its accuracy and reliability in linear measurements have been shown to exceed those of lateral cephalograms. Volumetric measurements of simulated bone defects in acrylic blocks have been shown to be both repeatable and accurate. This technology opens new opportunities for orthodontic stability studies by allowing volumetric measurements of teeth and their alveolar housing. This could provide new insights into the role of tooth and bone geometry in relapse, since the relationship between tooth mass and available space is invariably linked to dental crowding.

The purpose of this case-control study was to examine the influence of bone and tooth volume on dental relapse. It was hypothesized that an increased ratio of dental vs bone volume results in less stability of orthodontic treatment. Our secondary aims were to investigate the relationship between mandibular cortical thickness and 3D alveolar volume and to determine whether alveolar volume measured on dental casts is correlated to in-vivo alveolar bone volume measured on patients’ CBCT scans.

MATERIAL AND METHODS

The subjects for the case-control study were obtained from the collection of postretention records at the Department of Orthodontics at the University of Washington in Seattle. This data set includes full orthodontic records of over 900 patients obtained before treatment (T1), at the end of treatment (T2), and 10 years postretention (T3). Subjects and controls were identified by measuring Little’s irregularity index (II) on the mandibular incisors at T3, with subjects defined as having an II value more than 6.0 mm and controls as having an II value less than 3.5 mm (Fig 1). Sixty subjects and 263 controls were initially identified. T2 models were chosen for the investigation because, at this time point, all subjects had just completed orthodontic treatment and should have comparable and acceptable alignment of the mandibular incisors. To be included, the T2 model needed to be taken without a retainer, and there could be no significant gingival recession on the facial aspect of the mandibular incisors. From the overall sample, 40 subjects were identified who met the inclusion criteria, and the 40 most stable controls (lowest II at T3) were selected.

For the in-vivo comparison, all patients from the graduate orthodontic clinic at the University of Washington who had CBCT scans taken and dental casts taken within 3 months of the scan were identified. Those with appliances on during the scan were excluded. Nine subjects were identified.

The institutional committee reviewed and approved the research protocol.

Identifying information was removed from all dental casts. CBCT scans of the mandibular casts were taken with a CB MercuRay (Hitachi Medical Corporation, Tokyo, Japan) at 10 mA, 120 kVp, with field of view of 9 in and a voxel size of 0.292 mm. Ten to 12 casts were fitted into each scan by using 3 plastic platforms (Fig 2). The scans were analyzed with OnDemand3D software (Cybermed, Seoul, Korea). The threshold was set to ensure visibility of the incisor region. One examiner (J.B.C.) performed the following measurements on each cast (Fig 3).

1. Total volume (V): bounded laterally by the distal contact of both canines (when viewed from the
occlusal aspect), superiorly by the tallest cusp tip or the incisal edge of the anterior teeth, and inferiorly by a horizontal line 7 mm below the most inferior gingival margin on the facial aspect of the incisors. This inferior boundary was selected because it represented the maximum depth that could be accommodated by all casts because of varying vestibular extensions on the casts.

2. Alveolar volume (AV): the area in the total volume below a horizontal line at the most inferior gingival margin on the facial aspect of the incisors. This landmark was chosen as the demarcation point because it was easily identifiable and represents the most inferior demarcation between tooth structure and alveolar bone.

3. Tooth volume (TV): the area in the total volume above a horizontal line at the most inferior gingival margin on the facial aspect of the incisors.

4. Tooth-alveolar ratio (TV:AV): the ratio of TV to AV.

These measurements were made on all casts. The examiner was blinded to the subject or control designation of the models.

The CBCT scans of the 9 patients not identifiable. All scans were performed on the same CB device (field of view, 6 in, and voxel size, 0.200 mm; or field of view, 9 in, and voxel size, 0.292 mm) and analyzed by using the same software as the dental cast analysis. The scans were performed at 15 mA, 100 kVp (n = 4); 10 mA, 120 kVp (n = 3); or 15 mA, 120 kVp (n = 2). The scan was configured to display only hard tissue by setting the threshold to “bone” as preset in the software. Since the patients were scanned in occlusion, the mandibular incisor region was isolated from the whole image by cropping (Fig 4). From this point, the same V, AV, and TV calculations were performed by substituting the

Fig 2. Example of the CBCT scans of dental casts.

Fig 3. Frontal view of the regions measured. This region is bounded laterally by the distal contacts of the canines, superiorly by the incisal edges and cusp tips of the teeth, and inferiorly by a line 7 mm below the most inferior gingival margin. V, total volume; TV, the volume above the most inferior gingival margin; AV, the volume below the most inferior gingival margin.
most inferior alveolar bone margin on the facial aspect of the incisors for the gingival margin used in the dental cast analysis.

Measurements of mandibular cortical thickness (MCT) were made on both lateral cephalograms and panoramic radiographs of subjects and controls at T1, T2, and T3 by a blinded, calibrated examiner during a previous study (J.B.C.).\(^16\) The modified method of Wical and Swoope\(^23\) was used on the panoramic radiographs by measuring bilateral MCT with digital calipers along a line perpendicular to the long axis of the mandible and bisecting the mental foramen.\(^24\) The values were averaged for each subject. On the lateral cephalograms, MCT was measured as the distance between the inferior and superior borders of the cortex along a line tangential to the greatest curvature of the posterior border of the mandibular symphysis and perpendicular to the mandibular plane (Fig 5).

**Statistical analysis**

Descriptive statistics were calculated for all measured variables. Independent sample, 2-tailed \(t\) tests were used to evaluate differences in the mean values between the subjects and the controls. The logistic regression analysis was performed to explore the data for associations, controlling for the potentially confounding variables of TV, sex, T2 age, postretention time, T1 II, T2 II, MCT, and retention time.

The Pearson product moment correlation coefficients were calculated to determine the correlation of true CBCT volumetric measurements and corresponding measurements on the models of live patients and the relationship between MCT and AV on the casts. Significance was set at \(P <0.05\) for all tests.

To evaluate intraexaminer error, 10 subjects and 10 controls were randomly chosen to be rescanned 10 weeks after the initial measurements. Error was calculated by using Dahlberg’s formula\(^25\) for root mean square error (RMSE), where \(D\) is the difference between duplicated measurements, and \(N\) is the number of duplicated measurements.

---

**Fig 4.** Example of a standard hard-tissue image from in-vivo CBCT and the cropped region of interest from which V, TV, and AV were calculated.

**Fig 5.** MCT on the lateral cephalogram was measured along a line perpendicular to the mandibular plane and tangential to the posterior border of the mandibular symphysis (white lines). The distance, in millimeters, between the red lines would correspond to MCT.
RESULTS

The results of the intraexaminer error analysis are listed in Table I. The RMSE values for all volumetric measurements were less than 0.10 cm³, about 0.5% of mean volume.

A summary of the relapse and stable groups is given in Table II. There were no significant differences between the 2 groups with respect to T1 age, T2 age, sex, treatment time, retention time, or postretention time. There was a statistically significant difference in T3 age ($P = 0.044$). There were also statistically significant differences in T1 II ($P = 0.000$) and T2 II ($P = 0.000$).

Comparing the mean volumetric measurements of the 2 groups showed significant differences in both V ($P = 0.039$) and AV ($P = 0.007$), with the relapse group higher in both measurements (Table III). There was no difference in either TV or TV:AV. MCT values measured on the T2 lateral cephalograms were significantly greater in the stable group ($P = 0.036$). Figure 6 shows the correlation between AV and MCT. The correlation was poor, at best, with a nonstatistically significant Pearson product moment correlation coefficient of 0.058.

To further explore the relationship of AV to relapse, a logistic regression was performed, controlling for TV, sex, T2 age, treatment time, retention time, postretention time, MCT, T1 II, and T2 II (Table IV). The only significant predictive variable in this model was T2 II ($P = 0.004$).

The correlation between the in-vivo CBCT measurements and the dental cast measurements is shown in Figure 7. Pearson product moment correlation coefficients were significant for V ($r = 0.766$, $P < 0.05$) and AV ($r = 0.859$, $P < 0.01$). Although the correlation for TV ($r = 0.635$) was not significant, it approached significance ($P = 0.066$).

DISCUSSION

The goal of this study was to investigate the relationship between alveolar bone volume, TV, and orthodontic relapse. Ideally, this would involve direct measurements
from a subject’s mandible and dentition. An alternative option would be the use of a 3D image of those structures, such as a CBCT scan. Prior studies showed that volumetric measurements taken from CBCT images are highly accurate and repeatable.20,21 Since the subjects in this retrospective study did not have CBCT images, 3D data were obtained from plaster dental casts. Unlike in-vivo CBCT scans of patients, CBCT images of dental casts have inherent disadvantages, such as expansion of the dental stone and the inability to exclude excess anatomic structures, such as the gingiva, from the image. The results of the in-vivo patient sample in this study showed that both V and AV were significantly correlated in the CBCT scans of models and in-vivo scans. TV, which was not statistically significant in its correlation, only approached significance. This was most likely due to the technical difficulty of isolating the entire mandibular dental segment, which is in occlusal contact with the maxillary teeth, in a live patient’s CBCT image. Some mandibular tooth structure is invariably lost in the cropping of the image, thus weakening correlations. Calculation of volumetric data, in particular AV, from dental casts appears to be a good substitute for direct measurements from the subjects themselves.

In the results of the volumetric comparison of the relapse and stable groups, a significantly larger V was seen in the relapse group. Breaking down the subcomponents of V showed that there was no significant difference in TV, while AV was significantly larger for the relapse group. Although the difference in V and AV was significant between the groups, the differences in the means were only 0.194 and 0.166 cm³, respectively. Whereas this volume might appear to be small, it is about 5% to 7% of the total value measured for V and cannot be simply discounted. Because the vertical component of AV is fixed, the only way for it to be increased would be to increase the faciolingual dimension or the lateral dimension (distance between the distal contacts of the canines). Increased intercanine width, therefore, could increase AV in the relapse group and might explain the association of AV and relapse.

Since the method inherently prevents separating AV into tooth root volume and actual alveolar volume, attempts were made to account for the influence of the tooth root volume on AV. First, the ratio TV:AV was calculated and compared. Although it was hypothesized that the relapse group would have a larger TV:AV ratio, or more tooth structure for a given volume of alveolar bone, no significant difference was found between the groups. In fact, the relapse group showed a trend toward a lower TV:AV ratio. The second attempt to account for the influence of tooth structure on the measure AV was in the logistic regression model. TV, the volume of the tooth crowns alone, was included in the regression model as a potentially confounding variable. As a result, increased AV was shown not to be a significant predictor for being in the relapse group. Thus, the statistically significant, albeit small, increase in AV in the relapse group did not appear to have a significant effect on relapse status when controlled for potentially confounding variables, including TV.

A study by Rothe et al16 showed that thinner MCT, measured below the mental foramen on lateral cephalograms, was a significant predictor of relapse status. MCT was used as a measure for the overall amount of bone in the mandible, and it was suggested that this might also be correlated with increased bone support for the mandibular incisors. The rationale came from other reports showing MCT to be significantly correlated with bone density, mass, and size as well as height of the alveolar ridge.26-28 Whereas the results of this study confirm the significant relationship between thinner MCT and increased relapse found by Rothe et al,16 the hypothesized correlation between MCT and AV was not found, and MCT was also shown not to be a predictor of relapse when included in the logistic regression with AV. It appears that, although MCT might be correlated with overall mandibular size, it is not correlated with the volume of alveolar bone in the incisor region, as measured by AV.

Comparing the characteristics of the relapse and the stable groups, the mean ages at T1 and T2 were not significantly different, but age at T3 was significantly greater for the relapse group. The treatment, retention, and postretention times were also not significantly different. The postretention time was almost 1.5 years longer in the relapse group, and this difference approached significance ($P = 0.060$). It could be argued

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OR</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV</td>
<td>6.591</td>
<td>0.207-209.643</td>
<td>0.285</td>
</tr>
<tr>
<td>TV</td>
<td>0.144</td>
<td>0.004-4.818</td>
<td>0.279</td>
</tr>
<tr>
<td>T1 II</td>
<td>1.117</td>
<td>0.867-1.439</td>
<td>0.392</td>
</tr>
<tr>
<td>T2 II</td>
<td>7.960</td>
<td>1.934-32.763</td>
<td>0.004*</td>
</tr>
<tr>
<td>Female</td>
<td>0.647</td>
<td>0.300-6.936</td>
<td>0.647</td>
</tr>
<tr>
<td>Age at T2</td>
<td>1.009</td>
<td>0.977-1.041</td>
<td>0.588</td>
</tr>
<tr>
<td>Retention time</td>
<td>1.004</td>
<td>0.967-1.042</td>
<td>0.833</td>
</tr>
<tr>
<td>Postretention time</td>
<td>1.009</td>
<td>0.991-1.028</td>
<td>0.338</td>
</tr>
<tr>
<td>CT</td>
<td>0.569</td>
<td>0.209-1.554</td>
<td>0.271</td>
</tr>
</tbody>
</table>

*Statistically significant.

**Table IV.** Logistic regression model evaluating the association between relapse and AV at T2, adjusting for confounding variables TV, T1 II, T2 II, sex, T2 age, retention time, postretention time, and CT.
that the relapse group had higher T3 II because of these differences in age and postretention time; however, the logistic regression analysis showed no significant relationship between these variables and relapse status. Other studies have demonstrated that, whereas relapse continues to progress with time, the rate of relapse decreases with time and rapidly decelerates after the late teen years.29,30

The relapse group also had significantly higher T1 II and T2 II. The finding of a significant difference in T2 II was surprising. T2 was chosen for the volumetric comparison because this would be the time point when all subjects had equally well-aligned incisors, thus allowing for even distribution of alveolar bone. When included in the logistic regression analysis, T2 II was found to be a significant predictor of future relapse (odds ratio, 7.960). T1 II was not a significant predictor in this study; this is in contrast to prior studies showing that T1 II is one of the few reliable predictors of future incisor relapse.3,5,7,30 Thus, regardless of the extent of T1 II, our results indicate that the degree of incisor alignment after treatment (T2 II) is the significant predictor of relapse. Because the difference between the means in T2 II was about 1 mm, a value that is hard to detect clinically and not large enough to significantly impact AV, the logistic regression analysis was also conducted without T2 II as a variable. The result of this test was that AV remained a nonpredictor of relapse, and T1 II was the only significant predictor of relapse (odds ratio, 1.405), a finding that agreed with the previous studies.

It is possible that some limitations affected this study. First, the use of study models for the volumetric analysis has many limitations. The location of the arbitrary line used for the inferior border of each sample was determined by the extension of the model. Although it would have been ideal to go farther than 7 mm below the most inferior incisor gingival margin, this was not possible for each model, and the limitation was accepted to maximize the number of both relapse and stable subjects. Second, the treatment records were not accessible by the examiner (J.B.C), and the full scope of treatment was unknown. The use of adjunctive procedures to enhance stability, such as interproximal reduction or

---

**Fig 7.** Scattergrams depicting the correlations between CBCT images of dental models and in-vivo CBCT scans for V, AV, and TV.
circumferential fiberotomy, and poor compliance with removable retainers during the retention phase, was possible.\textsuperscript{31,32} Third, the nature of the case-control study design eliminates patients with T3 II between the extremes. The relationships observed in this sample apply to those with significant relapse or significant stability, not to the broad spectrum of all patients. Finally, the significant difference in T2 II can lead to the argument that mandibular incisors were not equally well aligned in each group during treatment. Future studies that additionally screen the subjects to obtain a statistically equal T2 II will help to further establish the relationship between bone volume and relapse.

The purpose of this study was to investigate whether the relationship of TV and AV was related to postretention orthodontic relapse. It was hypothesized that, for a given volume of alveolar bone, subjects with greater TV would be at greater risk for relapse. These results do not confirm that hypothesis; in fact, the findings point to the opposite. The relapse group had a smaller TV:AV ratio and a significantly larger AV. Although prior research suggested that increased MCT results in increased stability, a finding confirmed in this study, it does not appear that this stability has a relationship to increased bone volume in the mandibular incisor region.\textsuperscript{16}

CONCLUSIONS

Based on the sample investigated and the methods used, the following conclusions can be made.

1. Subjects with postretention relapse had significantly greater V and AV and thinner MCT.
2. MCT is not significantly correlated with AV.
3. Increased T2 II was a significant risk factor for postretention relapse.
4. V and AV measured on CBCT scans of dental casts were highly correlated with the same measurements on true patient CBCT scans.

REFERENCES


