Original Article

Radiographic technique and brackets affect measurements of proximal enamel thickness on mandibular incisors

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Summary

Objective: To investigate the influence of radiographic film and tube positioning, the presence and the size of brackets on in vitro measurements of proximal enamel thickness of mandibular incisors on periapical radiographs aimed to aid planning of interproximal enamel reduction procedures in orthodontics.

Materials and Methods: Eighty human mandibular incisors were assigned to sets of four and located in a customized base. Periapical radiographs were taken with the film positioned at three different angles (0°, 2°, and 5°) in relation to the frontal plane and the tube head positioned at five angles (0°, −2°, −5°, +2°, and +5°) in relation to the sagittal plane. The proximal enamel width was calculated by means of computerized image analysis and compared with measurements obtained at 0°. Statistical analysis was carried out to compare the enamel measurements on radiographs made with all angular combinations with and without the presence of brackets of different dimensions.

Results: A significant difference (P < 0.05) was found between the measurements of proximal enamel width obtained at the different angles in relation to the frontal and sagittal planes for all sets with or without brackets. The presence of brackets significantly affected the measured width only for the enamel side further away from the radiation source at the sagittal plane (P < 0.05).

Conclusion: Angular changes in taking periapical radiographs of mandibular incisors and the presence of brackets significantly affect interproximal enamel measurements made with image analysis software.

Introduction

Interproximal enamel reduction (IER) represents a valid treatment modality in contemporary orthodontics aimed to enhance tooth alignment, anterior aesthetics, and long-term stability of the treatment outcome (1–3). As a gold standard, 50% of interproximal enamel may be removed without harming the dental and periodontal tissues (4, 5). Sheridan claims that 1 mm (0.5 mm per proximal surface) can be removed from the contact points of the buccal section (6). Following the latest update, orthodontic interproximal reduction is limited to 0.5 mm per interproximal space in the anterior region, due to the thinner proximal walls (7–9).
However, individual differences with regard to enamel thickness should not be underestimated. Different factors such as tooth category and ethnic groups have been associated with differences in enamel width (10, 11). The orthodontist is generally advised to customize the stripping procedure according to each patient’s dental characteristics, tooth morphology, and restorations (4). Therefore, given the individual variations and irreversible effects of excessive removal of enamel, IER needs to be planned meticulously. Preoperative radiographic examination has been advocated by several authors to determine the amount of acceptable enamel reproximation (10–12). Placement of fixed appliances and correction of rotations are recommended prior stripping to increase visibility and mechanical access to the contact points (13). However, the impact of clinical aspects such as radiographic film positioning and direction of the central beam of the radiographic unit has not been so far subjected to investigation. Furthermore, the presence of brackets may distort measured enamel width as the film positioning deviates.

The objective of this study was to investigate the use of periapical radiographs and computer image analysis software to determine the proximal enamel width of human mandibular incisors for orthodontic purposes, and especially the influence of angular variations in radiographic film and tube positioning and the presence of brackets of different dimensions on such measurements.

Materials and Methods

Sample selection

Eighty recently extracted human permanent mandibular incisors were selected for the purposes of this study. The inclusion criteria were lack of caries, fractures, enamel defects, and restorations. At the time of collection, no information regarding the ethnicity of the donors was available. Immediately after extraction, all sample teeth were cleaned prior storage in a 3% thymol solution at 4°C.

Experimental setting

A custom designed standard base made of plastic was utilized to reproduce the positioning of radiographic film (Image plate plus size 2, VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany) at three different angles (0°, 2°, and 5°) in relation to the frontal plane at a fixed distance from the mandibular incisors (Figures 1 and 2). The standard base was placed on a three-dimensional positioning platform to enable acquisition of periapical radiographic images under five different angles (0°, −5°, −2°, +2°, and +5°) in relation to the sagittal plane (Figure 3).

All incisors were randomly divided into 20 sets of 4 teeth. Each set was positioned in the anterior curve of the oval mandibular arch-formed base in a socket filled with silicone putty material (Silicone Putty, Great Lakes Prosthodontics, Tonawanda, New York, USA). The tip of a periodontal probe 10 mm length was attached in front of the incisor segment as a reference ruler to facilitate real-life calculations (Figure 4). From each set, seven radiographic images were acquired. The base image showed the set under 0° in both the frontal and the sagittal planes. The other six images were made under either a deviating frontal angle or a deviating sagittal angle. After obtaining radiographic images without the brackets, the incisors were randomly reassigned to four groups of five sets each according to bracket type: groups I, II, and IV self-ligating brackets; group III, conventional bracket (Table 1). The brackets were bonded 2 mm from the incisal edge with Transbond™ XT (3M Unitek, Monrovia, California, USA) composite resin according to the manufacturers’ recommendation. Brackets were positioned with gentle pressure and excessive adhesive was removed with an explorer.

Polymerization was carried out using light-emitting diode with light intensity of 1800 Mw/cm² for 10 seconds. Subsequently, the same seven radiographic images were acquired from the same sets with brackets. The X-ray tube head remained at a fixed position to maintain the distance and angles between the unit and the radiographic film with a focus-object distance of 34.5 cm (Figure 1). To imitate clinical conditions, every radiographic film was enclosed in a light protection cover (VistaScan, Dürr Dental, Bietigheim-Bissingen, Germany).

Enamel width measurements

The maximum mesiodistal enamel width was calculated using ImageJ, a public domain open source software (http://rsb.info.nih.gov/ij/index.html) programmed to calculate area, distance, and pixel value statistics of user-defined selections (ImageJ, version 1.48i for Windows, US National Institutes of Health, Bethesda, Maryland, USA). Each periapical radiograph taken by a standard radiographic unit (Prostyle Intra, Planmeca, Helsinki, Finland) was saved as JPEG format file and imported in ImageJ for image processing. The settings for the radiographic unit were 60 kV, 8 mA, 0.16 seconds for...
Figure 3. A schematic drawing of the panoramic view of the experimental setting (R, right side; L, left side): (a) standardization base, (b) radiographic film, (c) reference ruler, (d) position angles of the central beam of X-rays in relation to the sagittal plane, and (e) radiographic unit.

Figure 4. The frontal view of the experimental setting with the reference ruler in place.

each periapical radiograph, whereas the scanning resolution of the detector system was set at 2309 dpi.

The steps of the measuring procedure are illustrated in Figure 5. Images were first magnified up to 100% to enhance visibility. Before performing enamel measurements, we addressed any discrepancies in radiographic enlargement, by measuring the actual length of the segment of the periodontal probe, the scale was adjusted to pixels/mm for size accordance (Figure 5b). Subsequently, a 2 mm vertical white line was drawn from the incisal edge. A horizontal white line crossing all the set teeth on the image was made perpendicular to the vertical line to ensure that every enamel distance was measured at the same height (Figure 5c). A yellow line was drawn on top of the horizontal white line equally to the enamel width to obtain the measurements (Figure 5d). In total, eight measurements per image were made. All measurements were performed by two examiners individually. Measurements of five randomly selected sets were repeated two weeks after the initial series of measurements to determine intra- and inter-examiner reliability.

Statistical analysis

To establish examiner reliability, the intraclass correlation coefficient (ICC) was calculated. Differences in measurements with and without brackets obtained at 0°, 2°, and 5° on the frontal plane and at −5°, −2°, +2°, and +5° on the sagittal plane were determined using repeated measures analysis of variance (ANOVA). For the different angles in the sagittal plane, analyses were performed separately for negative/positive degrees and the left/right sides of the incisors. The underlying rationale was that as the angle in the sagittal plane increases, one would expect a different effect on the proximal enamel thickness for the left side than for the right side of the incisors. When an ANOVA test was significant, post hoc tests were used to further explore differences between angles and measurements with or without brackets. The ANOVA result was reported as an F-statistic and its associated degrees of freedom and P-value. When the assumption of sphericity was violated, the degrees of freedom were corrected using a Huynh–Feldt correction or a Greenhouse–Geisser correction (14), based on the extent of the violation. For the radiographic images with brackets, separate repeated measures ANOVA were performed to test for any differences between bracket types. Statistical significance was set at 5%. The statistical analysis was carried out with a statistical software package (SPSS 22.0, Armonk, New York, USA).

Results

Intra- and inter-examiner reliability

The measured ICC was 0.802 and 0.892 indicating excellent intra- and inter-examiner reliability, respectively.

Enamel width from radiographic films taken at three different angles (0°, 2°, and 5°) in relation to the frontal plane (Table 2)

The measurements of enamel width decreased significantly as the angle in the frontal plane increased (F_{1,241} = 8.88; P < 0.00). The presence of brackets did not affect the measured enamel width (F_{1,20} = 0.219; P = 0.64). Paired-samples t-tests were conducted to compare the mean enamel width under different angles. The decrease in measured enamel width from 0° to 2° (P = 0.00) and from 0° to 5° (P = 0.00) was significant, while the decrease in enamel width from 2° to 5° was insignificant (P = 0.06).

Enamel width from radiographic films taken at five different angles (−5°, −2°, 0°, +2°, and +5°) in relation to the sagittal plane (Table 3)

The repeated measures ANOVA comparing enamel width of the left side of the incisors under angles of 0°, −2°, and −5° in the sagittal plane showed differences between the angles (F_{1,7,135.5} = 7.11; P < 0.00) regardless of the presence of brackets. The presence of brackets had no effect (F_{1,20} = 0.24; P = 0.63) on measurements from the same angles. Paired-samples t-tests showed that the observed average enamel width decreased significantly as the angle changed from 0° to −2° (P = 0.01) and from 0° to −5° (P = 0.00). The measurements taken at 0°, +2°, and +5° showed a significant interaction between the angles and the presence of brackets (P < 0.00). The observed enamel width decreased significantly as the angle increased from 0° to +5° (P = 0.00) and from +2° to +5° (P = 0.00). The presence of brackets affected the measured enamel width only at +2° and +5° (P < 0.00).

Comparison of enamel width of the right side under angles of 0°, −2°, and −5° yielded a significant interaction between the angles and the presence of brackets (F_{1,4,312.2} = 46.5; P < 0.00). Whereas
less enamel width was measured with brackets of large dimensions (groups I and II) than with brackets of the smallest dimension group IV \((P < 0.05)\), however, only at the left side of the teeth.

**Discussion**

Measurement of enamel thickness has been carried out by previous radiographic studies on periapical \((10, 15)\), bitewings \((1)\), and lateral radiographs \((16)\), with the latter radiograph type being the least accurate. Furthermore, periapical radiographs have been presented as reliable means for longitudinal and linear distance measurements \((17)\). In view of the fact that improper film positioning has been identified as the most frequent error in dental students making intraoral radiographs \((18)\) and the common involvement of more dental team members in a standard practice setting, it would be interesting to examine the effect of angular radiographic variables on enamel width measurements. The proposed method combined the use of periapical incisor images and ImageJ, a validated image processing tool formerly employed by orthodontic research to determine contact point displacement \((19)\) and area of white spot enamel lesions \((20)\). This image processing program facilitates the data transfer to a database for documentation, the communication between clinicians, and outperforms manual data recording \((19)\).

Our *in vitro* study found a significant difference between the enamel width measurements obtained at three different angles in relation to the frontal plane and at five different angles in relation to the sagittal plane for all sets regardless of the presence of brackets. The influence of the presence of brackets was only significant for the enamel side further away from the X-ray tube head at the sagittal plane. Under all circumstances, the enamel width measurements decreased at the presence of brackets when the X-ray tube head deviated from 0°, resulting in an underestimation of the actual enamel width. Furthermore, the results might be of great importance in determining the available amount of interproximal enamel to be removed since overreduction of enamel width may cause exposure of dentin and hypersensitivity \((4)\). In this sense, differences of 0.3 mm in measuring enamel width on radiographs obtained at 5° in relation to the sagittal plane could be clinically undesirable or even detrimental to the enamel’s integrity. On the contrary, in strict clinical terms, the maximum potential benefits in gaining space may be confined by underestimation of the actual enamel dimensions.

A recent histological study confirmed no significant differences between distal and mesial enamel thicknesses in mandibular central and lateral incisors ranging from 0.60 mm to 0.64 mm, respectively \((21)\). Likewise, our investigation found thinner enamel on the left incisor side compared to the right side, without reaching statistical significance \((0.57 \text{ mm versus } 0.59 \text{ mm})\). On the other hand, previous assessment of enamel thickness in human mandibular incisors \((10)\) concluded significantly greater enamel thickness on the distal tooth surfaces. Discrepancies in study results may be attributed to the observed enamel width of the incisors slightly increased without the presence of brackets, it decreased as the angle increased in the presence of brackets both at \(-2^\circ (P = 0.04)\) and at \(-5^\circ (P < 0.00)\). Measurements of enamel width under different angles decreased significantly, regardless of the presence of brackets, as the angle increased from \(0^\circ\) to \(+5^\circ\) and from \(+2^\circ\) to \(+5^\circ\) \((P < 0.05)\).

**Enamel width from radiographic films at the presence of brackets of different dimensions (Table 4)**

As expected, the presence of brackets, regardless of the dimensions, had no effect on the measured enamel width from radiographic films taken at different angles in relation to the frontal plane \((P > 0.05)\). At the sagittal plane, the measurements of enamel width were not significantly different among the four brackets for either side of the teeth when comparing angles of \(0^\circ\), \(-2^\circ\), and \(-5^\circ \(P > 0.05\)). However, comparing angles of \(0^\circ\), \(+2^\circ\), and \(+5^\circ\), a significant interaction was observed between angle and bracket type \((P < 0.05)\). Less enamel width was measured with brackets of large dimensions (groups I and II) than with brackets of the smallest dimension group IV \((P < 0.05)\), however, only at the left side of the teeth.

**Table 1. The types of brackets used in the study.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Type</th>
<th>Product name</th>
<th>Dimensions in mm (width x height x depth)</th>
<th>Manufacturer company</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Self-ligating active clip</td>
<td>0.22” In-Ovation®</td>
<td>2.5 × 3.2 × 2.8</td>
<td>GAC International, Central Islip, New York, USA</td>
</tr>
<tr>
<td>II</td>
<td>Self-ligating passive clip</td>
<td>0.22” BioQuick LP®</td>
<td>2.5 × 3.2 × 2.7</td>
<td>Forestadent, Pforzheim, Germany</td>
</tr>
<tr>
<td>III</td>
<td>Conventional twin bracket</td>
<td>0.22” Omni-arch®</td>
<td>2.5 × 3.2 × 2.1</td>
<td>Dentsply, GAC International Inc, Islandia New York, USA</td>
</tr>
<tr>
<td>IV</td>
<td>Self-ligating active clip</td>
<td>0.22” Speed®</td>
<td>2.2 × 3.0 × 2.3</td>
<td>Strite Industries, Cambridge, Ontario, Canada</td>
</tr>
</tbody>
</table>

**Table 2. Means and standard deviations of the enamel width measurements at three different angles in relation to the frontal plane in millimetres.**

<table>
<thead>
<tr>
<th>Angle</th>
<th>0°</th>
<th>2°</th>
<th>5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>No bracket</td>
<td>0.578 ± 0.10</td>
<td>0.571 ± 0.10</td>
<td>0.568 ± 0.10</td>
</tr>
<tr>
<td>Bracket</td>
<td>0.578 ± 0.09</td>
<td>0.573 ± 0.10</td>
<td>0.563 ± 0.11</td>
</tr>
<tr>
<td>Average</td>
<td>0.578 ± 0.10</td>
<td>0.572 ± 0.10*</td>
<td>0.566 ± 0.10*</td>
</tr>
</tbody>
</table>

*Statistically significant from the measurements at 0° \((P < 0.05)\).*

the observed enamel width of the incisors slightly increased without the presence of brackets, it decreased as the angle increased in the presence of brackets both at \(-2^\circ (P = 0.04)\) and at \(-5^\circ (P < 0.00)\). Measurements of enamel width under different angles decreased significantly, regardless of the presence of brackets, as the angle increased from \(0^\circ\) to \(+5^\circ\) and from \(+2^\circ\) to \(+5^\circ\) \((P < 0.05)\).
Table 3. Means and standard deviations for enamel width at five different angles in relation to the sagittal plane for the left side in millimetres.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Left side</th>
<th>Right side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No bracket</td>
<td>Bracket</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>−5°</td>
<td>0.559 ± 0.10</td>
<td>0.567 ± 0.10</td>
</tr>
<tr>
<td>−2°</td>
<td>0.563 ± 0.10</td>
<td>0.579 ± 0.11</td>
</tr>
<tr>
<td>0°</td>
<td>0.572 ± 0.10</td>
<td>0.584 ± 0.11</td>
</tr>
<tr>
<td>+2°</td>
<td>0.580 ± 0.11</td>
<td>0.588 ± 0.11</td>
</tr>
<tr>
<td>+5°</td>
<td>0.562 ± 0.17</td>
<td>0.554 ± 0.17</td>
</tr>
</tbody>
</table>

*Statistically significant from the measurements at 0° (*P < 0.05).

Table 4. Means and standard deviations for enamel width at five different angles in relation to the sagittal plane for the left (L) and right (R) side in millimetres.

<table>
<thead>
<tr>
<th>Group</th>
<th>Side</th>
<th>−5°</th>
<th>−2°</th>
<th>0°</th>
<th>+2°</th>
<th>+5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>I In-Ovation®</td>
<td>L</td>
<td>0.591 ± 0.12</td>
<td>0.597 ± 0.11</td>
<td>0.588 ± 0.10</td>
<td>0.463 ± 0.29</td>
<td>0.179 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.382 ± 0.34</td>
<td>0.549 ± 0.21</td>
<td>0.596 ± 0.10</td>
<td>0.597 ± 0.09</td>
<td>0.502 ± 0.23</td>
</tr>
<tr>
<td>II BioQuick LP®</td>
<td>L</td>
<td>0.543 ± 0.09</td>
<td>0.560 ± 0.10</td>
<td>0.574 ± 0.12</td>
<td>0.399 ± 0.28</td>
<td>0.207 ± 0.30</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.304 ± 0.29</td>
<td>0.536 ± 0.14</td>
<td>0.588 ± 0.09</td>
<td>0.588 ± 0.10</td>
<td>0.468 ± 0.25</td>
</tr>
<tr>
<td>III Omni-arch®</td>
<td>L</td>
<td>0.549 ± 0.10</td>
<td>0.555 ± 0.11</td>
<td>0.555 ± 0.11</td>
<td>0.546 ± 0.17</td>
<td>0.420 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.332 ± 0.30</td>
<td>0.542 ± 0.16</td>
<td>0.579 ± 0.10</td>
<td>0.570 ± 0.11</td>
<td>0.575 ± 0.10</td>
</tr>
<tr>
<td>IV Speed®</td>
<td>L</td>
<td>0.561 ± 0.08</td>
<td>0.555 ± 0.08</td>
<td>0.567 ± 0.09</td>
<td>0.517 ± 0.19</td>
<td>0.461 ± 0.25</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>0.368 ± 0.29</td>
<td>0.553 ± 0.16</td>
<td>0.577 ± 0.09</td>
<td>0.591 ± 0.09</td>
<td>0.591 ± 0.09</td>
</tr>
</tbody>
</table>

*Statistically significant from group III on the left side (*P < 0.05).

methodological differences; Sarig et al. (21) measured directly proximal contact areas on histological specimens, whereas dental cast measurements were matched with computer-analyzed periapical images to determine enamel thickness from the contact points to the shortest distance from the dentinoenamel junction in the study of Hall et al. (10).

As a consequence, an equal amount of enamel should be removed from adjacent proximal walls when performing interproximal enamel reduction. Moreover, given the safe zone of 50% enamel removal, the findings of our study strengthen the suggestion to keep the existing guideline of maximal 0.50 mm reduction per two adjacent teeth in the mandibular anterior region.

The observed difference in enamel width between different types of brackets can be explained by the bracket design. Only a significant difference was found for the group with an overall smaller dimension, in mesiodistal dimension, in comparison with the two groups with larger dimensions. Although the brackets from group III are smaller in depth, surprisingly it was not significantly different from the other groups. This effect might be caused by the width being equal to groups I and II. Interestingly, significant differences were only observed of measurements of the left side of teeth bonded with brackets and taken at different angles of the sagittal plane. Hypothetically, consistent inaccuracy in bracket placement and the positioning of the mandibular incisor in the socket in rotation might have interfered with the significantly different observations on the left side.

This study presents certain limitations. Firstly, the actual width of interproximal enamel width remained unknown. Instead, the measured width at 0° was taken as the reference for the comparison of the study measurements. In future studies, this shortcoming may be addressed by application of micro-computed tomography imaging technology (22). Secondly, the loose fit of a light protection cover might have an influence on standardization of the specific film positioning angles. Nonetheless, such likelihood holds also true for real-life practice conditions and should be considered accordingly when interpreting the results of the study. Thirdly, the age and ethnicity of the donors of the sample teeth were unknown, which have introduced more enamel width variation in our sample. For example, a decrease in enamel thickness has been reported to occur after the 50 years of age (21, 23). Regarding the ethnic background, thicker enamel has been demonstrated in black subjects (10).

Given the limitations of the in vitro study design, further research is needed to elucidate the potential application of the radiographic assessment of enamel width using computer image analysis in the clinical setting. However, on the basis of our experimental results, it can be recommended that the amount of enamel to be removed by stripping procedures can be determined on standard periapical radiographs obtained at 0° in relation to the frontal and sagittal planes with the presence of brackets.

**Conclusion**

Angular changes in the periapical radiographic technique and the presence of brackets on mandibular incisors significantly affect interproximal enamel measurements made with image analysis software. The measurements of enamel width decreased on radiographs obtained from angles deviated from 0° in relation to the frontal and sagittal planes, resulting in an underestimation of the actual enamel width.

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References


