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A retrospective study comparing the loss of anchorage following the extraction of maxillary first or second premolars during orthodontic treatment with fixed appliances in adolescent patients

S. Haque, P.J. Sandler, M.T. Cobourne, P. Bassett and A. T. DiBiase

ABSTRACT

Introduction: This retrospective study assessed the difference in anchorage loss using 3D superimposition of study models between cases treated with extraction of maxillary first premolars and maxillary second premolars carried out in orthodontic specialist practice.

Method: Sixty subjects who have undergone extractions of either maxillary first or second premolars as part of their orthodontic treatment were selected. Eligibility criteria included patients with a Class i, mild Class II or III malocclusions, mild-to-moderate crowding with no anchorage reinforcement. Pre- and post-treatment maxillary dental study cases were scanned using a surface laser scanner to produced 3D digital images which were superimposed using areas of stability on the anterior hard palate. Anchorage loss was measured by the mesial movement of the maxillary first permanent molar.

Results: The mean mesial movement for the maxillary first molars, when adjusted for confounding factors was 4.7 mm (SD 1.6) in the maxillary first premolar extraction group and 4.6 mm (SD 1.6) in the maxillary second premolar extraction group.

Conclusions: There is no difference in anchorage loss when comparing the extraction of the maxillary first premolars to the extraction maxillary second premolars.

Introduction

Space is required in orthodontic treatment to relieve crowding, camouflage a skeletal discrepancy or facilitate segmental osteotomies. To create space there are several options, which include enlargement of the arch form, reduction of tooth size or extractions (Travess et al. 2004). While there has been much controversy surrounding the use of extractions in orthodontics, this remains a predictable way to create space for orthodontic treatment. The most commonly extracted teeth are premolars because their position in the dental arch is ideal to relieve both labial and buccal crowding and allow retraction of the labial segments. In cases with anterior crowding the loss of first premolars can allow spontaneous alignment of mesially angulated canines (Crossman & Reed 1978; Travess et al. 2004). The first and second premolar teeth have a similar morphology and the loss of a premolar unit in a quadrant has little aesthetic impact on the smile (Meyer et al. 2014). Finally extraction of premolars can also be used as a means to camouflage a skeletal discrepancy and facilitate correct of a molar relationship.

The pattern of tooth extraction is judged on each individual malocclusion. A study reviewing orthodontic cases treated with extraction and non-extraction orthodontics found the amount of crowding reflected the decision to extract premolars (Saelens & De Smit 1998). In cases with severe crowding the four first premolars were removed, while in subjects with mild crowding the extraction of second premolars was prescribed on the assumption that the further back the extraction was in the dental arch, the less space would be available due to greater anchorage loss.

Anchorage loss is a multifactorial response to orthodontic treatment and is affected by the amount of crowding, the type of tooth movement (tipping or bodily), patient age, root angulation and length. Loss of anchorage following the extraction of premolar teeth can be assessed by the amount of mesial movement of the first permanent molars (Geron et al. 2003). Creekmore reviewed the available evidence and devised a ‘rule-of-thumb’ for premolar extractions (Creekmore 1997). According to this, if first premolars are
extracted the posterior teeth will move forward using one-third of the space available, the remaining two-thirds is used up with the relief of crowding and retraction of the incisors. When second premolars are extracted, he stated that half the space will be lost due to mesial movement of the molars, with the remaining space available for the relief of labial crowding and retraction of the incisors. However, there is a lack of evidence for these claims.

The aim of this study was to investigate differences in maxillary arch anchorage loss as measured by mesial movement of the first molar in cases treated with extraction of maxillary first or second premolars and fixed appliances. The null hypothesis was that there is no statistically significant difference in anchorage loss when comparing the extraction of maxillary first premolars to maxillary second premolars during orthodontic treatment with fixed appliances.

Materials and methods

Participants, eligibility criteria and setting

This was a retrospective study reviewing the records of 60 subjects treated by two experienced orthodontic specialists (ATD and PF) within the same specialist orthodontic practice that provides comprehensive orthodontic treatment for children, adolescents and adults (Flanagan and Associates, Kent, UK) using the same appliances and mechanics. All treatments were provided within the United Kingdom National Health Service. As this study analysed existing patient records taken as part of routine clinical procedures that had been anonymised, on the advice of the NHS Research Authority no formal ethical approval was required. The selected patients fulfilled the following inclusion criteria: (1) adolescent patients under the age of 18 years; (2) presenting with a class I or mild class II/III skeletal base relationship; (3) extraction of maxillary first or second premolars; (4) mild to moderate anterior segment crowding (1–8 mm); (5) no anchorage reinforcement, with the exception of inter-maxillary elastics; (6) average Frankfort-Mandibular Plane Angle (27 ± 5°); (7) complete orthodontic records including pre- and post-treatment study models and start lateral cephalogram. The exclusion criteria consisted of: (1) any patients requiring surgical intervention or dentofacial orthopaedics; (2) treatment with a removable or functional appliance; (3) treatment with any form of anchorage reinforcement (headgear, trans-palatal arch or implants); (4) patients with missing teeth before the start of treatment (due to hypodontia or caries).

Interventions

All subjects were treated with pre-adjusted edgewise, labial fixed appliances using the same appliance system and treatment mechanics. The brackets used had MBT prescription with a 0.022-inch × 0.028-inch arch wire slots (3M Victory, APC, 3M Unitek, Monrovia, Calif) using en-masse retraction on 0.019-inch × 0.025-inch stainless steel arch wires. The use of inter-maxillary elastics was accepted.

Primary outcomes

Pre- and post-treatment plaster study models were scanned using the R700™ (3Shape, Copenhagen, Denmark 2009) 3D scanner. A single operator blinded to the extraction pattern and allocation scanned the models and undertook the analysis (SH). Crowding of the maxillary dentition and overjet were measured using 3Shape ‘OrthoAnalyzer™’ 2011 Version 1.2.2.2 software. Tooth movement was measured using Rapidform 2006 Version 1.0 software (3D Systems, Rock Hill, SC, USA); which allowed the superimposition of pre- and post-treatment maxillary study models (Thiruvenkatalachari et al. 2009). Each scan was manipulated independently and enlarged to allow for accurate identification of the rugae. Landmarks were selected on each model indicated by the coloured dots (Figure 1) once a sufficient number of points were identified the programme carried out initial superimposition of the two images.

The accuracy of superimposition was visualised on a histogram and the colour of the study models—blue indicates a ‘perfect fit’; whilst red displays a large discrepancy. The ‘average value’ of the discrepancy is calculated. Any superimposition with an average discrepancy of less than 0.8 mm was acceptable and any superimpositions above this were repeated until an acceptable level of discrepancy was achieved (Figure 2).

Once the initial superimposition was accepted a more accurate regional superimposition was performed. An area of known stability was highlighted, the medial ends of the first three major palatal rugae and the hard palate (Figure 3). A histogram indicated the degree of deviation from ideal and when the calculated average discrepancy was <0.8 mm the superimposition was considered acceptable. The crowns of the left and right first permanent molars were outlined to create ‘shells’. The shell of the molar to be measured on the start-of-treatment model was superimposed on to the shell of the end-of-treatment model using fine superimposition of tooth surface anatomy. This allowed the final molar shell to use the buccal and palatal outlines of the start
molar shell, removing any gingival distortions (overgrowth or hyperplasia) present on the end of treatment model, which would affect the Centre of Mass calculation of the crown.

The Centre of Mass for the first permanent molar was calculated. The physical distances between the Centre of Mass on these two sets of models represent the tooth movement that occurred during treatment. Movement of the molar tooth in a bucco-palatal direction is seen in the X-axis, movement in a vertical direction is seen in the Y-axis and the Z-axis shows mesio-distal movement (Figure 4). The last measurement was used to measure anchorage loss.

Intra-rater reliability was assessed by the repeated measurement of 20 pairs of 3D scans randomly selected by an online random number generator and the process of superimposition was repeated one week following the initial superimposition (33% of the data-set). This was undertaken to detect any intra-operator error and to ensure consistency in the methodology.
Sample size calculation
The sample size was calculated based on the basis of a clinically appreciable difference in anchorage loss between the two groups equal to 1.5 mm (Sandler et al. 2014). A power calculation was conducted using a standard deviation of 1.7 mm (Geron et al. 2003) investigating mesial movement of maxillary first molars during premolar extraction space closure. Using a nomogram with 90% power at the 5% significance level this would require an overall sample size of 54. A sample size of 30 in each group was therefore used (Altman 1980).

Statistical analysis
The repeatability of the primary outcome measurements was analysed using Bland–Altman limits of agreement (Bland & Altman 1986, 1999). Categorical variables were compared between groups using the Fishers’ exact test in the software package Stata (Version 12; StataCorp LLC, College Station, TX, USA). The continuous variables, which were found to be approximately normally distributed were compared between groups using the unpaired t-test. Linear regression was used to compare mesial movement between groups. An unadjusted analysis was performed, along with multiple linear regression adjusting firstly for age only, and then additionally for other factors found to vary between groups.

Results

Repeatability of the method
The repeatability of the method showed a −0.1 mm mean difference between original and repeated measurements (Table 1). The Bland–Altman limits of agreement were (−0.7 to 0.5) for the right maxillary first molar (UR6) and (−1.1 to 0.8) for the left maxillary first molar (UL6) (Figures 5 and 6). Clinically, this is an acceptable amount of variation between the two measurements as the range of molar movement was between 2 and 7 mm.

Baseline data
The demographic and baseline characteristics of the two groups – maxillary first premolars extractions (G1) and maxillary second premolars extractions (G2) were recorded and compared. The results are summarised in Table 2. The results suggested that there were significant differences between the two groups for overjet, incisal and skeletal base relationships. Thirty per cent of
patients in G2 presented with a class III incisal and skeletal base relationships compared to none in G1. In G1, the majority of subjects presented with a class II incisal relationship (57%) and 77% had a class II skeletal base. The mean overjet in G2 was also lower with a value of 3.1 mm (SD 2.2) compared to 5.1 mm (SD 2.0) in G1. There was a small difference in mean age between the two groups, but this difference was not statistically significant. The mean age of the subjects in G1 was 12.3 years (SD 1.7) compared to G2 with a mean age of 14.1 years (SD 1.9). There was no significant difference in the use of either class II or class III elastics between the two groups.

Due to the significant differences found between the baseline characteristics of the two groups, three sets of analysis were carried out. The first was conducted without accounting for any variables (unadjusted). For the second and third analyses Linear regression was used to adjust for potential confounders: age, incisal relationship, skeletal base and overjet. The second analysis was adjusted for potential confounders without accounting for the age of the subjects; whilst the third was adjusted for all confounding factors between groups (Table 3).

### Molar tooth movement

The results show no statically significant difference between the two groups for either UR6 or UL6 mesiodistal measurement in both the unadjusted and adjusted analysis. The mean mesial movement of the maxillary first molars in G1 when the confounding factors are adjusted was 4.7 mm (4.5 mm for UR6.
and 4.9 mm for UL6) with a 95% confidence interval (CI): 4.3–5.1. The mean mesial movement of the maxillary first molars in G2 was 4.6 mm (4.2 mm for UR6 and 5.0 mm for UL6) with a 95% CI: 4.2–5.0. This was not statistically significant supporting the null hypothesis that there is no significant difference in anchorage loss when comparing the extraction of maxillary first premolars to maxillary second premolars during orthodontic treatment with fixed appliances.
Both the mean and the marginal mean values are presented. The marginal mean are the values that would be obtained if the two groups were perfectly matched for the variables that are adjustment for in each analysis. Also reported are the means.

Table 2. Comparison of variables in G1 (maxillary first premolar extraction group) and G2 (maxillary second premolar extraction group).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>G1</th>
<th>G2</th>
<th>P. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisal relationship</td>
<td>Class I</td>
<td>13 (43%)</td>
<td>9 (30%)</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Class II</td>
<td>17 (57%)</td>
<td>12 (40%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class III</td>
<td>0 (0%)</td>
<td>9 (30%)</td>
<td></td>
</tr>
<tr>
<td>Skeletal base</td>
<td>Class I</td>
<td>7 (23%)</td>
<td>9 (30%)</td>
<td>0.003</td>
</tr>
<tr>
<td>relationship</td>
<td>Class II</td>
<td>23 (77%)</td>
<td>17 (57%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class III</td>
<td>0 (0%)</td>
<td>9 (30%)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td>21 (70%)</td>
<td>14 (47%)</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>9 (30%)</td>
<td>16 (53%)</td>
<td></td>
</tr>
<tr>
<td>Maxillary mandibular</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plane angle</td>
<td>–</td>
<td>28.7 (3.2)</td>
<td>28.2 (4.6)</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Discussion

Main findings in the context of existing evidence and interpretation

The results of this study fail to reject the null hypothesis that there is no difference in anchorage loss as measured by mesial movement of the maxillary first molar in adolescents treated with either extraction of first or second maxillary premolars.

Clinical attitudes concerning extractions have varied over the years due to practitioner beliefs and treatment techniques available. The decision to extract the maxillary first premolar over the second premolar is often made on the assessment of how much space is required to correct crowding and the antero-posterior position of the labial segment, on the assumption that the first maxillary premolars have a greater anchorage value. The intent of this study was to evaluate if any clinically significant difference in anchorage loss could be identified in a sample of adolescents treated with extraction of either maxillary first or second premolar teeth and fixed appliances.

The results obtained would refute this and imply that there is no statistical or clinical difference between extracting first or second maxillary premolars in the absence of adjunct procedures to reinforce anchorage, with a 0.1 mm difference between two groups. This agrees with the findings of previous studies (Schoppe 1964; Crossman & Reed, 1978; Ong & Woods 2001; Geron et al. 2003). The results of these studies show slightly greater, but insignificant anchorage loss when maxillary second premolars are extracted, with results ranging from 1.6 to 5.3 mm due to the varying anchorage demands of the subjects. According to the study by Geron et al. there was only a 0.5 mm difference in anchorage loss when comparing the maxillary first to second premolar extractions (Geron et al. 2003). This study looked at multiple factors affecting anchorage loss and found that the extraction pattern was a secondary factor with crowding and mechanics having a greater influence.

Most of these studies assessed anchorage loss following the extraction of teeth using serial superimposition of lateral cephalograms and measurements on study models. However, the use of cephalometrics does not allow the evaluation of three dimensional tooth movement or volumetric changes and superimposition of bilateral landmarks can lead to interpretation errors (Ghafari et al. 1998). The use of study models to assess growth and the effects of orthodontic treatment has not been popular, due to the difficulty in establishing stable reference planes for superimposition and achieving accurate measurements (Cha et al. 2007). Previous studies have shown the medial two-thirds of the third rugae and regional palatal vault dorsal to it is a stable region to register 3D digital models in adult subjects (Peavy & Kendrick 1967; Bailey et al. 1996; Chen et al. 2011). In growing subjects, vertical growth in the third palatal region is negligible (Christou & Kiliaridis 2008). There is an increase in length and distance between rugae; however, these changes are minimal in subjects monitored for over four years, which is greater than the average course of orthodontic treatment (Kim et al. 2012).

Digital models have been found to be as accurate as analogue plaster models (Bell et al. 2003; Sousa et al. 2012; Saleh et al. 2015). A recent systematic review has investigated the diagnostic accuracy and sensitivity of measurements on digital study models for orthodontics.

Table 3. Results showing mean mesial movement for G1 (maxillary first premolar extraction group) and G2 (maxillary second premolar extraction group).

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Adjustments</th>
<th>Group</th>
<th>Mean (SD)</th>
<th>Difference (95% CI)</th>
<th>P. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UR6</td>
<td>Unadjusted</td>
<td>G1</td>
<td>4.7 (1.6)</td>
<td>0 (0.1)</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>4.1 (1.5)</td>
<td>-0.6 (-1.4, 0.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age only</td>
<td>G1</td>
<td>4.7</td>
<td>0</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>4.1</td>
<td>-0.5 (-1.4, 0.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All factors</td>
<td>G1</td>
<td>4.5</td>
<td>0</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>4.2</td>
<td>-0.3 (-1.2, 0.7)</td>
<td></td>
</tr>
<tr>
<td>UL6</td>
<td>Unadjusted</td>
<td>G1</td>
<td>5.2 (1.5)</td>
<td>0</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>4.6 (1.7)</td>
<td>-0.6 (-1.4, 0.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age only</td>
<td>G1</td>
<td>5.2</td>
<td>0</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>4.7</td>
<td>-0.4 (-1.3, 0.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>All factors</td>
<td>G1</td>
<td>4.9</td>
<td>0</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G2</td>
<td>5.0</td>
<td>0.1 (-0.9, 1.0)</td>
<td></td>
</tr>
</tbody>
</table>

Both the mean and the marginal mean values are presented. The marginal mean are the values that would be obtained if the two groups were perfectly matched for the variables that are adjustment for in each analysis. Also reported are the means.

Marginal mean presented for adjusted analyses.

Adjustments for age, incisal relationship, skeletal base and overjet.

Discussion

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The results of this study fail to reject the null hypothesis that there is no difference in anchorage loss as measured by mesial movement of the maxillary first molar in adolescents treated with either extraction of first or second maxillary premolars.

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Digital models have been found to be as accurate as analogue plaster models (Bell et al. 2003; Sousa et al. 2012; Saleh et al. 2015). A recent systematic review has investigated the diagnostic accuracy and sensitivity of measurements on digital study models for orthodontics.
This review found high reproducibility and no clinically significant differences between digital and plaster models (Rossini et al. 2016). A study compared the superimposition of digital study models (generated by the indirect method) to cephalometric superimposition of subject treated with a fixed orthodontic appliance following extractions of permanent teeth. They found no statistically significant difference in mean incisal and molar movement between 3D models and cephalometric superimpositions (Cha et al. 2007).

The method used in this study was developed as an accurate method to superimpose digital models for the assessment of 3D tooth movement (Thiruvenkatachari et al. 2009). The laser scanner was found to be accurate to 0.0235 mm for antero-posterior measurements for every 0.5 mm of movement. It was concluded that 3D laser scanning and superimposition is accurate for orthodontic investigations and is an alternative to cephalometric analysis for tooth movement.

**Limitations**

The current study was limited because it was a retrospective analysis; although the subjects were best-matched from reviewing clinical records, there were significant variables between the groups, particularly in relation to the type of malocclusion and the extraction pattern. There was a greater proportion of class II malocclusions in the first premolar extraction group and a greater number of class III malocclusions in the second premolar extraction group. This is relevant because it would have influenced the mechanics used during treatment, with a tendency for greater potential for planned anchorage loss in class III malocclusions than class II. While both operators used the same treatment appliances and mechanics (sliding mechanics and en-masse retraction) this was not fully controlled between patients, as timing of appointments and arch wire changes were not matched. Breakages were not recorded, or the exact strength and duration of inter-maxillary traction; these may all have affected treatment outcomes and anchorage demand.

One could speculate the operator may have intentionally ‘burnt-up’ space in certain cases and maintained/ held the molars when the anchorage demands were higher. This may have influenced the degree of mesial movement of the molar. The inclination of the incisors may also have affected management of the extraction space and the use of additional torque placed in the wire in the upper labial segment. However, as the difference in anchorage loss between the two groups was minimal it is unlikely that any of these factors had any great influence on the outcome.

**Generalizability**

The cases selected were treated in a specialist orthodontic practice that offers comprehensive treatment for adolescents. They represent a wide range of malocclusions routinely seen and should therefore represent a fairly typical caseload, making the results applicable to the wider orthodontic community.

**Conclusions**

In this study there was no significant difference in loss of anchorage when measured from the mesial movement of the maxillary first molar during treatment with pre-adjusted edgewise fixed appliances in adolescents when extracting maxillary second premolars compared to first premolars.

**Acknowledgements**

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**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**