Efficiency of molar distalization with the XBow appliance related to second molar eruption stage

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SUMMARY To quantitatively evaluate on lateral cephalograms horizontal, vertical, and angular changes in the position of the maxillary first molar based on the presence and absence of erupted maxillary second molars when it is distalized with the XBow appliance.

In this retrospective study, a total of 102 consecutively treated cases were assessed. Lateral cephalograms were obtained at the start and after completion of active treatment with the XBow appliance. In one group of patients, distal movement of the maxillary first molars was performed before the eruption of maxillary second molars; in the other group of patients, both first and second maxillary molars were simultaneously moved distally. All cephalograms were superimposed on palatal plane using the method of best-fit. In order to compare the mean horizontal, vertical, and angular changes in molar position between the treatment groups and gender, a multivariate analysis of covariance (MANCOVA) was performed with the pre-treatment class II severity used as a covariate. Regression analysis was also performed to further explore any possible relationships between the predictor variables and the quantity and quality of distalization.

A MANCOVA revealed that the eruption stage of the maxillary second molar did not have a significant effect on the change in position of the maxillary first molar after treatment with a XBow appliance.

When distalizing maxillary first molars with a XBow appliance, there is no difference in the amount of distalization in patients with erupted and unerupted maxillary second molars.

Introduction

A common orthodontic treatment objective is distalization of the maxillary molars. The question of how the second molar impacts distalization of the first molar is still a matter of controversy in the literature. The rate and efficiency of molar distalization has been reported to depend on two main factors: one being the type of movement (tipping versus bodily movement) and the other being the timing of treatment (before or after the eruption of the maxillary second molar; Gianelly et al., 1988). As early as 1955, it was argued that when the second molar has not yet erupted, distalization is by tipping rather than by bodily movement (Graber, 1955). Since that time, it has been theorized that the unerupted second molar acts as a fulcrum distal to the first molar, thereby increasing its tipping movement (Kinzinger et al., 2004). As it is distalized, the first molar is thus tipped over the germ of the second molar. According to this theory, as the second molar continues to erupt, the contact point between the molars shifts more coronally, and the tipping tendency is reduced (Kinzinger et al., 2004). Over the last number of years, several other authors have agreed with Graber stating that the eruption stage of the second molar had a basic qualitative and quantitative impact on the distalization of the first molars (Ten Hoeve, 1985; Gianelly et al., 1988; Jeckel and Rakosi, 1991; Hilgers, 1992; Bondemark et al., 1994; Gianelly, 1998; Kinzinger et al., 2004; Karlsson and Bondemark, 2006). Duration of therapeutic treatment has also been shown to increase if second molars have erupted and therefore distalization has been recommended before this stage has been reached (Gianelly et al., 1988). Contrary to this, there have also been many investigations that have concluded that when distalizing the first molar, the position of the second molar is of little consequence (Muse et al., 1993; Ghosh and Nanda, 1996; Byloff and Darendeliler, 1997; Bussick and McNamara, 2000; Joseph and Butchart, 2000). The authors of these studies found that there is no connection between second molar budding stage, magnitude of linear or angular molar distalization, and duration of therapy.

Over the years, various methods have been used to distalize maxillary molars. Popular appliances such as headgear, distal jet, and pendulum/pendex appliances have been well studied in the orthodontic literature. Since 2002, the CrossBow (or XBow) appliance has been gaining attention as a fixed Cass II corrector with the ability to distalize maxillary molars (Flores-Mir et al., 2009). Using Forsus FRD springs bilaterally to connect a maxillary hyrax expander and a mandibular labial and lingual bow, the XBow can
be used as a phase 1 appliance for class II malocclusion in the late-mixed to early permanent dentition. Dentally, one aspect of the class II correction in patients treated with a XBow has been shown to include maxillary molar distalization (Flores-Mir et al., 2009).

The aim of the present study is to investigate the efficiency (tooth movement quality) of maxillary molar distalization according to the stage of dental development of the second molar in patients treated with a XBow appliance. The null hypothesis was that no difference existed in the amount of tooth movement quality according to developmental stage of the second molars.

### Material and methods

Ethics permission was granted by the institutional board (University of Alberta Pro00013453 approved 9 June 2011). All patients were treated with a XBow appliance (Higgins, 2012) in the late-mixed to early permanent stage of dentition and their records were consecutively and retrospectively obtained from one joint private practice having both pre-treatment (T1—initial records) and post-treatment (T2—around 4 months after deactivated the XBow before any other appliance is inserted) lateral cephalograms taken between January 2005 and December 2010. Both clinicians had extensive experience using this appliance.

The inclusion criteria for all patients were the following:

1. The exclusive use of a XBow appliance in the late-mixed to early permanent stage of dentition and their records were consecutively and retrospectively obtained from one joint private practice having both pre-treatment (T1—initial records) and post-treatment (T2—around 4 months after deactivated the XBow before any other appliance is inserted) lateral cephalograms taken between January 2005 and December 2010. Both clinicians had extensive experience using this appliance.

2. A class II molar relationship defined by at least a molar end-to-end relationship.

3. No previous orthodontic treatment. No extractions were performed on any patients prior to or during this phase of treatment.

A total sample of 51 participants was required. This sample size calculation was based on:

- \(\alpha\) of 0.05 and a \(\beta\) of 0.10.
- \(S_1 = 1.64\) mm (standard deviation of horizontal distance of molar distalization, based on the average of 3 pilot trial measurements of 10 randomly selected patients for GR 1).
- \(S_2 = 1.45\) mm (standard deviation of horizontal distance of molar distalization, based on the average of 3 pilot trial measurements of 10 randomly selected patients for GR 2).
- \(\Delta = 1\) mm based on clinical significance of molar distalization.

Since the subjects available for the study exceeded the required number of patients for both GR 1 and GR 2, random selection was used to determine the final selection of the subjects studied. The statistician provided the random selection list based on a computer-generated allocation.

Subjects were divided into two groups. In group 1, treatment was performed before the eruption of second molars (GR 1); in group 2, both first and second maxillary molars were erupted at the beginning of treatment (GR 2).

Radiographs were taken with the same kind of equipment (Orthoceph OC100D, General Electric) and under equivalent conditions. All cephalograms were superimposed using best-fit superimposition on palatal plane registered at ANS. Similar to the methods of Nielsen (1989), the best-fit superimposition was made as the optimal fit of the hard palate with the nasal floors aligned and registered at ANS and the region between ANS and point A. All measurements were recorded in random order by one investigator at two different time points, with at least 4 weeks between the recordings. All measurements were estimated to the nearest 0.5 mm or 0.5 degrees. Any measurements taken from a bilateral image were bisected. Correction for linear enlargement was made (7 per cent) and therefore all recorded measurements were assumed based on true patient size. This enlargement factor was determined by calculating the linear difference between the nosepiece ruler on the cephalograms and a true ruler used to manually produce all measurements.

Changes in the measuring points were measured as differences between landmarks before and after treatment (Figure 1). The changes in position of the maxillary first molars were recorded for all patients in the horizontal, vertical, and angular direction. For the horizontal change in position of the maxillary first molar, the most mesial point on the crown of the tooth was used as a reference point; for the vertical change in position of the maxillary first molar, the most mesial point of the cementoenamel junction was used as the reference point; and for the angular change in position of the maxillary first molar, the angle formed by the long axis of the tooth (created by a line connecting the furcation area and the midpoint of the crown in a mesial-distal direction) and the palatal plane was used as a reference point.

The molar relationship of all patients, prior to treatment, was also recorded by measuring the horizontal millimeter distance from the mesial contact point of the maxillary and mandibular first molars at T1. A measurement of 0 indicated a molar end-to-end relationship and anything above 0 indicated a more severe class II relationship. These measurements were used as a way to control for the potential impact of the pre-treatment class II severity on the degree of molar distalization achieved.
MOLAR DISTALIZATION WITH THE XBOW

Figure 1 Cephalometric superimposition of patients treated with the XBow appliance to analyze the horizontal, vertical and angular changes in the position of the maxillary first molar. (All superimpositions were based on palatal plane: ANS-PNS.) (a) Diagrammatic representation of the calculation of the angular change in the maxillary first molar position (angle in degrees). The angle formed by the long axis of the tooth and the palatal plane was used as the measuring point. (b) Diagrammatic representation of the calculation of the vertical change in the maxillary first molar position (line mm distance). The cementoenamel junction was used as the measuring point. (c) Diagrammatic representation of the calculation of the horizontal change in the maxillary first molar position (line mm distance). The most mesial point on the crown of the tooth was used as the measuring point.

Method error

Intrarater reliability was assessed using intraclass correlation coefficients (ICC) from three repeated measures of the horizontal, vertical, and angular changes in the position of the maxillary first molar in 20 randomly selected subjects. Each of the three sets of measurements was taken at least 4 weeks apart. Error measurements were also evaluated by calculating the standard deviation of the three repeated measurements for each type of movement (horizontal, vertical, and angular) for 20 randomly selected subjects. For each plane of movement, the standard deviations of all 20 patients were then further averaged to get an approximation of the overall degree of landmarking error.

Statistical approach

Means and standard deviations were calculated for each outcome variable. In order to compare the mean horizontal, vertical, and angular changes in molar position between the treatment groups and gender, a multivariate analysis of covariance (MANCOVA) was performed with the pre-treatment class II severity used as a covariate. Regression analysis was also performed to further explore any possible relationships between the predictor variables and the quantity and quality of distalization. P values with a significance level of α = 0.05 were considered statistically significant.

Results

Intraclass correlation coefficient results are shown in Table 1. Errors of measurements for the outcome variables are shown in Table 2.

Table 1 Intraclass correlation coefficients for horizontal, vertical, and angular measurements of the change in position of the maxillary first molar in subjects treated with a XBow appliance.

<table>
<thead>
<tr>
<th></th>
<th>Intraclass correlation coefficient</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (mm)</td>
<td>0.832</td>
<td>(0.686, 0.923)</td>
</tr>
<tr>
<td>Vertical (mm)</td>
<td>0.448</td>
<td>(0.178, 0.700)</td>
</tr>
<tr>
<td>Angular (°)</td>
<td>0.842</td>
<td>(0.703, 0.928)</td>
</tr>
</tbody>
</table>

Table 3 shows basic summary statistics for each group prior to treatment. Pairwise comparisons were made to determine the actual differences in change in the position of the first molar between the two treatment groups for all three directions of movement (Table 4).

Treatment changes for each outcome variable are shown in Table 5. The average (both groups) time of treatment was 4.7 months and the mean time between radiographs was 13.5 months.

Results of the MANCOVA analysis showed that neither the treatment group nor the gender had a significant effect on the overall change in position of the maxillary first molar.

Table 2 Errors measurements for the horizontal, vertical, and angular changes in position of the maxillary first molar.

<table>
<thead>
<tr>
<th></th>
<th>Error measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.53 mm</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.41 mm</td>
</tr>
<tr>
<td>Angular</td>
<td>0.87°</td>
</tr>
</tbody>
</table>
Table 3  Summary statistics for GR 1 and GR 2, prior to treatment.

<table>
<thead>
<tr>
<th></th>
<th>GR 1</th>
<th>GR 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of female patients</td>
<td>34</td>
<td>26</td>
</tr>
<tr>
<td>Number of male patients</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>Mean class II severity*</td>
<td>1.4 mm</td>
<td>1.0 mm</td>
</tr>
</tbody>
</table>

*Molar end-to-end relationship and anything above 0 indicates a more severe class II malocclusion, in mm. Since initial class II severity was used as a covariate in our statistical analysis, any differences between the groups in this regard were statistically accounted for.

Table 4  Average horizontal, vertical, and angular changes in position of the maxillary first molar in patients treated with a XBow appliance.

<table>
<thead>
<tr>
<th></th>
<th>GR 1 (n = 51)</th>
<th>GR 2 (n = 51)</th>
<th>Mean difference*, P [CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average horizontal change (mm)</td>
<td>1.7 (1.1)</td>
<td>1.6 (0.9)</td>
<td>-0.030, P = 0.874 [-0.410, 0.349]</td>
</tr>
<tr>
<td>Average vertical change (mm)</td>
<td>0.8 (0.5)</td>
<td>0.9 (0.7)</td>
<td>-0.215, P = 0.074 [-0.021, 0.451]</td>
</tr>
<tr>
<td>Average angular change (°)</td>
<td>3.1 (2.7)</td>
<td>3.1 (2.3)</td>
<td>-0.133, P = 0.791 [-1.127, 0.861]</td>
</tr>
</tbody>
</table>

*One-way analysis of covariance results for effect of treatment group on first molar change in position, with initial class II severity as covariable.

Table 5  Mean and standard deviation for the change in horizontal, vertical, and angular positions of the maxillary first molar in patients treated with the XBow appliance.

<table>
<thead>
<tr>
<th></th>
<th>GR 1 Male (n = 17)</th>
<th>GR 1 Female (n = 34)</th>
<th>GR 2 Male (n = 25)</th>
<th>GR 2 Female (n = 26)</th>
<th>GR 1 Total (n = 51)</th>
<th>GR 2 Total (n = 51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal change (mm)*</td>
<td>1.8 (1.3)</td>
<td>1.7 (1.0)</td>
<td>1.6 (1.0)</td>
<td>1.7 (0.9)</td>
<td>1.7 (1.1)</td>
<td>1.6 (0.9)</td>
</tr>
<tr>
<td>Vertical change (mm)**</td>
<td>0.8 (0.5)</td>
<td>0.8 (0.5)</td>
<td>1.0 (0.8)</td>
<td>0.9 (0.5)</td>
<td>0.8 (0.5)</td>
<td>0.9 (0.7)</td>
</tr>
<tr>
<td>Angular change (°)</td>
<td>-0.215</td>
<td>-0.021</td>
<td>-0.215</td>
<td>-0.021</td>
<td>-0.133</td>
<td>-0.133</td>
</tr>
</tbody>
</table>

*All horizontal changes were in a distal direction.
**All vertical changes were in an intrusive direction.

Table 6  Multivariate analysis of covariance (MANCOVA) results for the overall change in position of the maxillary first molar after treatment with a XBow appliance.

<table>
<thead>
<tr>
<th></th>
<th>Wilk’s lambda</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment group</td>
<td>0.956</td>
<td>1.442</td>
<td>0.236</td>
</tr>
<tr>
<td>Gender</td>
<td>0.992</td>
<td>0.238</td>
<td>0.870</td>
</tr>
<tr>
<td>Initial class II severity (mm)</td>
<td>0.810</td>
<td>7.361</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Interaction between treatment group and gender</td>
<td>0.931</td>
<td>2.315</td>
<td>0.081</td>
</tr>
</tbody>
</table>

GR 1 indicates patients with unerupted second molars at the start of treatment and GR 2 indicates patients with erupted second molars at start of treatment. The values in parentheses indicate standard deviation.

Table 4 indicates that the eruption stage of the second molar did not have a significant effect on the horizontal distalization of the maxillary first molar (P = 0.155). The interaction between the class II severity and the eruption stage did, however, show a generalized trend (P = 0.069) that as the class II severity initially increased beyond a molar end-to-end relationship, the subjects with erupted second molars had greater horizontal distalization than subjects with unerupted second molars (Figure 2). This effect continued up to the point that the class II was approximately 2 mm beyond a molar end-to-end relationship at which point the trend reversed and the subjects with unerupted second molars showed a greater
Table 7  Multivariate analysis of covariance (MANCOVA) results for the change in position of the maxillary first molar after treatment with a XBow appliance with ‘gender’ removed from the model.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Wilk’s lambda</th>
<th>F</th>
<th>P-value</th>
<th>Partial eta squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment group (GR 1 versus GR 2)</td>
<td>0.965</td>
<td>1.16</td>
<td>0.328</td>
<td>0.035</td>
</tr>
<tr>
<td>Initial class II severity (mm)</td>
<td>0.812</td>
<td>7.4</td>
<td>&lt;0.001*</td>
<td>0.188</td>
</tr>
</tbody>
</table>

GR 1 indicates patients with unerupted second molars at the start of treatment and GR 2 indicates patients with erupted second molars at start of treatment.

*Statistically significant at $P < 0.05$ significance.

amount of distalization. Approximately 20 per cent of the variation in the horizontal distalization of the first molar can be explained by this regression model ($R^2 = 0.198$).

For the vertical change in the position of the first molar it appeared that the subjects with erupted second molars consistently had more intrusion (approximately 0.2 mm) than subjects with unerupted second molars (Figure 3). This effect was not statistically significant ($P = 0.174$) and was below the measured 0.41 mm of measurement error. Approximately 8 per cent of the variation in the vertical movement of the first molar can be explained by this regression model ($R^2 = 0.08$).

Figure 3  Vertical change (intrusion) in the position of the maxillary first molar as a function of pre-treatment class II severity, in patients with erupted and unerupted second molars.

No difference was present between subjects with erupted and unerupted second molars with respect to the angular change in position of the first molar (Figure 4).

Discussion
A quantitative evaluation on lateral cephalograms of horizontal, vertical, and angular changes in the position of the first molar when it is distalized with the XBow appliance was made. These changes were analyzed and compared in the presence and absence of erupted maxillary second molars. The main findings of this study were that the presence of erupted versus unerupted second molars and the gender of the patients did not have an effect on the amount or direction of distalization of the maxillary first molar. It can be suggested that there is no optimal time to treat patients in the mid-mixed to early permanent stage of dentition with a XBow appliance when distalization is the main treatment objective.

Intrarater reliability was moderate to strong for both horizontal and angular changes in the position of the maxillary first molar; the measured change in the vertical position of the maxillary first molar showed poor intrarater reliability. Given these results, a second method to measure the vertical displacement of the first molar was attempted to improve the reliability of the measurements. Specifically, the change in the distance from the occlusal surface of the molar to the palatal plane was measured for each patient. Unfortunately,
Muse et al. (1993) that continuous downward modeling of the nasal floor. In addition to this bony modeling, continued eruption of teeth also occurred throughout dental development (Cook et al., 1994). Therefore, as the alveolar processes were positioned more downward and forward it is possible that the amount of intrusion in this study was actually underestimated. Similarly, some mesial migration of the dentition may have occurred between the time that the T1 cephalogram was actually taken and the time that the XBow was actually inserted and activated. Group 1, where the second molars had not yet erupted, may have experienced more mesial migration of the maxillary first molar than group 2. This would especially be true if the maxillary second premolar had not yet erupted. In this way, the actual amount of distalization may have also been underestimated—especially for the patients in group 1.

The findings of this current study are similar to the findings from previous authors (Muse et al., 1993; Ghosh and Nanda, 1996; Byloff and Darendeliler, 1997; Bussick and McNamara, 2000; Joseph and Butchart, 2000) that concluded that the position of the second molar when distalizing the first molar is of little significance. Based on these results, the idea that the unerupted second molar acts as a fulcrum and causes more distal tipping of the distalizing first molar is not supported.

All patients in this study were consecutively treated with a XBow appliance (Higgins, 2012), but no other class II treatment option was usually offered. Therefore, results from this study should be taken as accurate only for patients treated with the XBow appliance.

Overcorrection was consistently sought. The goal was to get class III molar relationship to account for dental relapse. No method of retention was used between deactivating the XBow and taking the post-treatment radiographs. For the post-appliance radiograph it was taken a few months after the XBow was deactivated because of a relapse period that it is suggested for the appliance so that any physiological relapse occurs.

There were several limitations in this study. As previously stated, all data collected were done so retrospectively. Ideally, a randomized controlled clinic trail is the preferred method to accurately assess the efficiency of molar distalization between the two groups. Designing a study in this way would, however, require randomly designating certain patients to wait until their second molars were erupted before starting treatment—this experimental design could, therefore, have ethical considerations. As the later group (those waiting for second molar eruption) would have to wait sometime before treatment, there is a risk that new malocclusions could develop and therefore the two treatment groups would not be comparable prior to all treatment.

The timeframe between initial records and appliance insertion was usually only a few weeks. Although in theory second molar should be erupting in that timeframe, the...
magnitude of such eruption is unlikely to change the way this study classify eruption stage at T1.

All patients were in the late-mixed to early permanent stage of dentition and therefore no attempt was made to compare the efficiency of distalization among adult patients. Also, based on the fact that the selection of the patients (who were recruited from a specific Orthodontic Clinic) and the allocation of the patients to a particular group (who were allocated to a group based on the eruption of their teeth) were not random in nature, no causal inference or inference to the general population can be made from this study.

Pre-treatment class II severity, which was used as a covariate in our statistical analysis, was measured on cephalograms. Ideally, any future study based on this topic should also access patient models pre- and post-treatment to potentially allow more accurate measurements of molar classification. These records would also allow an assessment of potential rotations of the first molar during treatment.

Recent advances in the application of three-dimensional analysis have made more accurate assessment of tooth positional changes a reality (Kuroda et al., 1996). Three-dimensional cast analysis has been associated with significantly less variation and error than cephalometric assessment (Mavropoulos et al., 2005). Future studies that take advantage of these and other three-dimensional analyses could potentially provide more insight into this topic and reduce the significant error associated with measuring small linear distances on conventional two-dimensional radiographs and cast models.

This study did not measure mandibular plane angle prior to treatment. Future studies that investigate the effects of the eruption stage of the second molars on distalization efficiency could measure pre- and post-treatment mandibular plane angle to assess any potential differences in face height based on eruption stage.

Changes in the incisor position while on XBow treatment were not quantified in this study. Previous studies (Flores-Mir et al., 2009; Aziz et al., 2012) drawn from a similar sample origin have reported incisal changes. Although a number of studies have been published over the years reporting on maxillary molar distalization, some controversy still exists regarding upper molar distalization with respect to second molar eruption stage. Clinically, practitioners may tend to perceive that distalization is a more valid treatment option in younger patients before the second molars have erupted. More recently, however, this theory seems to be more anecdotal than evidence based. More studies are required to help confirm the idea that there may be no optimal time to treat when molar distalization is a treatment objective.

**Conclusions**

When distalizing maxillary first molars with a XBow appliance, there is no difference in the quantity or quality of distalization in patients with erupted and unerupted maxillary second molars.

**Funding**

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**References**


Higgins D W 2012 www.crossboworthodontic.com (29 October 2012, date last accessed)


