Changes to Incisor Anteroposterior Angulation during Correction of Class II Malocclusion: Impact on Perceived Root Resorption as Analyzed from Conventional Radiography

by

Long Dao Tieu

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Abstract

Objectives:

1. Assess the prevalence of OIEARR over the course of treatment in a selected sample of patients treated with either the X-bow for Forsus?
2. Assess the severity of OIEARR over the course of treatment in a selected sample of patients treated with either X-bow for Forsus?
3. Assess if the incisor length measurements determined from panoramic radiographs accurate and reliable when maxillary and mandibular incisor angulations are modified in a custom made typodont?
4. Determine if several cephalometric variables are considered simulataneously over time, does sex and or treatment type affect the final outcome in a selected sample of patients treated with either X-bow or Forsus?

Methods:

Pre-treatment (T_1) and post-treatment (T_2) panoramic and cephalometric radiographs were taken on the same machine (Instrumentarium OP 100D) in the private practice of Dr. Robert Miller. All T_1 and T_2 radiographs were coded and transferred via a digital file to a blinded author for measurement. All panoramic radiographs were hand traced and measured to the incisal edge and root apex using a digital caliper and cephalometric radiographs were digitally traced using Dolphin Imaging software.

Two titanium were placed on a rapid prototyping model of the maxillary and mandibular incisors at the apical edge and incisal edge. The maxillary and mandibular arches were fit into a special holding device and maxillary and mandibular incisor segments of various angulations were fitted to their respective arches using a lock and key type of jig. The panoramic images were then hand traced and measured using a digital caliper.

Results/Conclusions:

1. What is the prevalence of OIEARR over the course of treatment in a selected sample of patients treated with either the X-bow for Forsus?
    a. Prevalence per tooth 65.3%
    b. Prevalence per patient 98.6%

2. What is the severity of OIEARR over the course of treatment in a selected sample of patients treated with either X-bow for Forsus?
    a. Per tooth – None (34.7%); Mild (45.2%); Moderate (9.3%); Severe (11%)
    b. Per patient – None (1.4%), Mild (32.9%); Moderate (30%); Severe (35.7%)

3. Are the incisor length measurements determined from panoramic radiographs accurate and reliable when maxillary and mandibular incisor angulations are modified in a custom made typodont?
    a. Under experimental conditions, Md incisors appear to respond as expected when compared to theoretical model (assumption – teeth within focal trough)
        i. 10 degrees – 1.4% shorter
        ii. 20 degrees – 6.3% shorter
        iii. 30 degrees – 13.4% shorter
        iv. 40 degrees – 23.7% shorter
        v. 50 degrees – 34.6% shorter

b. Mx Incisors are more difficult to say. At some angulations yes (80, 90), at others (50,60, 70, 100, 110) the answer isn't clear
c. Severe Resorption in clinical study was found in 11% of treated incisors and of the 25 patients with at least one tooth with severe RR, 20 of the cases were found on the Md arch

4. When several cephalometric variables are considered simulataneously over time, does sex and or treatment type affect the final outcome in a selected sample of patients treated with either X-bow or Forsus?

   a. No evidence of a Sex (p=0.840) difference in the overall pattern of cephalometric variables.
   b. No Evidence of a treatment type (p=0.395) difference in the overall pattern of cephalometric variables.
   c. Convincing evidence of a Time (p=0.006) difference in the overall pattern of cephalometric variables.
   d. Convincing evidence (p=0.019) that over the course of treatment OB was reduced by 1.79mm [1.66,1.92].
   e. Convincing evidence (p=0.015) that over the course of treatment Y-Axis increased 1.3° [1.24,1.33].

5. Additional Findings

   a. Shorter treatment length (p=0.037) with X-bow (24.18 months) compared to Forsus (30.17 months)
   b. Both compliance free Class II correction protocols (X-bow and Forsus) for the treatment of mild to moderate class II malocclusion appear to generate similar degrees of lower incisor proclination with similar variability.

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Chapter 1 - Introduction and Literature Review

1.1 Statement of Problem

Orthodontically induced external apical root resorption (OIEARR) is a relatively common iatrogenic problem that has challenged orthodontists for many years. OIEARR is a complex multifactorial process that results from a sterile inflammatory process that is conducent to external root resorption. Minor apical root blunting is commonly reported after orthodontic treatment, and often does not affect the long-term prognosis of the tooth. It has been suggested that root contact with the cortical plate is one of the most critical factors to generate root resorption (RR) in orthodontic treatment, with the associated risk of root resorption increasing twenty-fold[1]. This scenario is likely to occur when attempting to camouflage a skeletal problem, as seen in moderately Class II or III correction that will not be surgically treated. Additionally, while attempting to camouflage, the tipping and/or torqueing of the incisors make it much more difficult to accurately evaluate root resorption through conventional radiography.

There are a number of fixed Class II correctors available for clinicians to help in the correction of mild to moderate Class II malocclusions. The Fatigue Resistant Device, commonly referred to as Forsus (3M Unitek) is a fixed functional class II corrector usually used to correct the Class II malocclusion while the patient is simultaneously using full edgewise appliances. This appliance consists of a push rod and an inter-arch coil spring attached to the upper molar with either an L-pin module or an EZ module. An additional use of the Forsus is as a part of an Xbow appliance (pronounced crossbow). The later is another fixed functional class II corrector that attempts to correct the occlusion anteroposteriorly before the initiation of full edgewise appliance. This class II corrector typically consists of Forsus springs, a maxillary expander, and a modified lower holding arch.

The frequency of external root resorption has been reported to increase from 15% in incisors prior to treatment, to 73% following orthodontics[2]. External root resorption can be diagnosed histologically or radiographically. Clinicians often rely on radiographic imaging to help them identify and potentially modify treatment of teeth that show early signs of more advanced root resorption. This is done to try to improve the long-term prognosis of these teeth. Traditionally, orthodontic records consist of 2D radiographs using panoramic and/or lateral cephalometric radiographs. Clinicians often assess whether resorptive changes in teeth undergoing orthodontic treatment are occurring using these 2D radiographs. In cases of suspected root resorption further imaging using periapical radiographs may be prescribed to assess and evaluate the severity of resorption. Assessment of root resorption using 2D radiographs must be done with caution as the radiographic image is affected by distortion in root angulation[3] and magnification[4].

1.2 Significance of Study

When camouflaging Class II malocclusions, there are often changes to both the maxillary and mandibular incisor angulations that can lead to artificial elongation and/or foreshortening of the dental image. OIEARR is a common result of orthodontic treatment and given the inherent limitations of 2D radiography, it would be beneficial to better understand how changes of tooth angulation can alter the perceived root lengths. With this knowledge, clinicians may be better equipped at recognizing cases of true root resorption as opposed to cases where the appearance of root resorption on the radiograph is due to an imaging foreshortening. This information can help clinicians identify teeth that need further imaging (periapical) to confirm/assess severity of root resorption and will also allow clinicians to make modifications to their treatment in an attempt to minimize the progression of root resorption.

1.3 Research Question

1. What is the frequency of orthodontically induced root resorption over the course of an orthodontic treatment in a selected sample of Class II malocclusions using either Forsus or Xbow?
2. What is the severity of orthodontically induced root resorption over the course of an orthodontic treatment in a selected sample of a Class II malocclusion using either Forsus or Xbow?
3. Are incisor length measurements determined from panoramic radiographs accurate and reliable when upper and lower incisor angulations are modified in a custom made typodont?
4. When several cephalometric variables are considered simultaneously over time, does sex (M/F), and/or treatment type (Forsus/Xbow) affect the final class II correction significantly in a selected sample of a class II malocclusion using either Forsus or Xbow?

1.4 Null Hypothesis

H_{o1}: There is no difference in frequency and/or severity of orthodontically induced root resorption in a sample of Class II patients treated with either Forsus or Xbow.

H_{o2}: There is no difference in tooth length measurement from panoramic radiographs when angulation of tooth is changed in a custom made typodont.

H_{o3}: There is no difference in terms of sex (M/F) and/or treatment type (Forsus/X-bow) effect over time to correct class II malocclusion when overjet (OJ), overbite (OB), Skeletal Class II (ANB), Lower Incisor angle to Mandibular Plane (L1MP), Upper Incisor angle to Palate Plane (U1PP), Sella-Nasion-Articulare (SnAr), Growth Direction (Gnathion-Sella-Nasion) (YAxis) and Frankfort Mandibular Plane Angle (FMA) are considered simultaneously over time in a sample of Class II patients treated with either Forsus or Xbow.

1.5 Literature Review

1.5.1 Fixed Class II Correctors

Class II malocclusions affect approximately one-third of the population[5]. Currently there is no treatment gold standard for non-extraction correction of mild to moderate class II malocclusion. Ideally the lower incisor angulation should be approximately 90-95 degrees relative to the mandibular plane; however a common side effect of non-extraction camouflage correction of the class II malocclusion is an increase in lower incisor angulation, more commonly referred to as proclination, while trying try to obtain an adequate OJ relationship. The degree of acceptable incisor proclination often lies within a range that is dependent on the patient's individual biological tolerance.

The correction of class II malocclusions often relies on patient compliance (i.e., headgear, elastics, wearing a removable appliance), and in an attempt to minimize the need for patient cooperation and maximize the predictability of the result, clinicians sometimes opted for compliance-free fixed class II correctors. In many clinics, the use of compliance-free fixed class II correctors provide predictable results and thus, are used in all types of patients and are not limited to only the non-compliant patients.

There are numerous fixed class II correctors available on the market today. The available appliances can be classified into those that rely on their anchorage via an inter-maxillary appliance (Herbst, Jasper Jumper, Mandibular Anterior Repositioning Appliance (MARA), Forsus, Xbow), or intra-maxillary appliance (Pendulum, Distal Jet). Inter-maxillary appliances use the lower arch as anchorage, whereas the intra-maxillary appliances use the upper anterior teeth, premolars and palate for anchorage control.

A succinct revision of the available compliance-free fixed class II correctors:

1.5.2 Herbst

The Herbst appliance consists of bilateral telescopic mechanism attached to bands, crowns or acrylic splints which keeps the mandible in a protruded position[6] (Figure 1). The telescoping mechanism consists of a tube and plunger that fit together and are attached to the crown of maxillary molar and mandibular premolar by screws.

This appliance can have a restraining effect on maxillary growth while having a stimulating effect on mandibular growth[7]. Pancherz[8] reported that sagittal molar correction was attributed to 43% skeletal and 57% dentoalveolar. Dentoalveolar changes consisted of lower incisor proclination, maxillary molar distalization and intrusion.

1.5.3 Jasper Jumper

The Jasper Jumper consists of two vinyl coated auxiliary springs which are fitted to fully banded upper and lower fixed appliances and work to hold the mandible in a protruded position[7] (Figure 2). Cope et al.[9] reported that the majority of the class II correction was due to dental rather than skeletal changes. In the maxilla, the molars tended to tip distally whereas in the mandible, the molars moved forward via tipping and bodily movement, while the lower incisors proclined[9].

1.5.4 Mandibular Anterior Repositioning Appliance (MARA)

The MARA appliance is a Herbst variant that can be used with complete fixed appliance and works to hold the mandible in the forward position full time[5] (Figure 3). This tooth borne functional appliance consists of square wire attached to tubes on upper first molar bands or stainless steel crowns[7]. A lower molar crown has an arm projecting perpendicular to its buccal surface and is adjusted so when the patient closes, the upper first molar guides the lower first molar and repositions the mandible forward into a class I relationship[7]. Pangrazio-Kulbersh et al.[10] reported that the MARA produce 5.8mm of Class II molar correction with 47% of it due to skeletal and 53% due to dental.

1.5.5 Forsus

The Forsus appliance (Figure 4) is an intermaxillary push spring that is comprised of a push rod that inserts into a telescoping cylinder and can be used in conjunction with complete fixed orthodontic treatment. The Forsus is attached onto the maxillary first molar via the head-gear tube and onto the mandibular archwire distal to either the canine or first premolar. The distal end of the telescoping tube attach to the headgear tube from the distal using a L-pin or from the mesial using an EZ clip module. The push rods come in four different sizes and produces approximately 200 grams of force when compressed. When the patient bites down, the coil is compressed and the forces are transmitted to the sites of attachment to help correct the malocclusion[11]. Franchi et al. [12] reported both a dental and orthopedic effect for the Forsus appliance. The author noted a great skeletal effect on the maxilla by restraining the sagittal advancement of the maxilla. On the mandible, skeletally there was an increase in mandibular length, however the main effect on the mandible was dentoalveolar forward movement of the molars and incisors.

1.5.6 Xbow

The Xbow appliance (Figure 5) consists of three main components: 1. palatal expander attached to the maxillary 1st premolar and 1st molar by bands, 2. Mandibular labial and lingual arch, 3. Forsus springs attached to maxillary first molar via head-gear tube and to the mandibular labial bow with Gurin locks. This appliance is used in the late mixed dentition or in the early permanent dentition before edgewise appliances are bonded. Flores-Mir et al.[13] reported a favourable dental and skeletal effect using the Xbow appliance. Skeletally, the author reported a reduction of maxillary protrusion without mandibular advancement. Dentally, overjet reduction was corrected by distalization of the maxillary molars, mesialization of mandibular molars and protrusion of the mandibular incisors.

1.5.7 Pendulum

The Pendulum appliance was first described by Hilgers[14] and uses a Nance button on the palate for anchorage and TMA springs to distalize the maxillary molars by inserting into the lingual sheaths of the molar bands[7] (Figure 6). When the appliance is placed before the eruption of the second molars, two-thirds of the movement is molar distalization and one-third is mesial movement of premolars[14]. If this appliance is placed after eruption of the second molars, one-third of the movement was distalization of first molar and two-thirds mesial movement of premolars[14].

1.5.8 Distal Jet

The distal jet, uses bilateral tubes where a coil and screw clamp are slid onto the tube and is inserted into the lingual sheath of the molar band[7] (Figure 7). The tubes are attached to an acrylic Nance button which is also connected to a premolar band[7]. The appliance is activated by sliding the clamp closer to the molar and has been reported to overcome the disadvantage of other distalizing appliances by reducing the tendency for the teeth to tip[15].

1.6 Orthodontically Induced External Apical Root Resorption

RR of deciduous teeth is a normal, physiologic process that often is the first step in the eruption of the permanent successor tooth. OIEARR of the permanent teeth is a common complication of orthodontic treatment whose etiologic factors are complex and multifactorial with potential contribution from patient related and treatment related factors[16-18]. Examples of reported patient related risk factors include: previous history of RR[19], tooth-root morphology and length[20,21], and genetic influence[21]. Examples of treatment related factors include treatment duration[22,23], magnitude of applied force[24], and amount of apical displacement[25].

OIEARR can be defined as blunting or shortening of the root apex during the course of orthodontic treatment. Many general dentists regard root resorption as being avoidable and often hold orthodontists accountable[26] so it is important for orthodontists to identify risk factors that contribute to root resorption early so that the potential impact of this problem is reduced.

Andreasen[27] describes three types of OIEARR: surface resorption, inflammatory resorption and replacement resorption. Surface resorption is a self-limiting process where only the outer cementum layer is resorbed and repaired from the adjacent periodontal ligament[17,19]. Inflammatory resorption is where cementum and outer dentin are resorbed and is irreversible because only cementum is repaired[17,19]. Replacement resorption is where bone replaces the resorbed tooth material and results in ankylosis of the tooth[17,19].

When teeth are moved orthodontically, the periodontal ligament (PDL) is subjected to localized areas of compression and tension. If forces are heavy and persist for long enough, hyalinization of the PDL may occur. Root resorption is closely associated with the remodeling of the PDL[28-30]. In this scenario, macrophages often appear and are responsible for the initial resorption of the cementoid (unmineralized precementum) layer. This process may expose the underlying cementum which is more susceptible to attack by odontoclasts[31]. Histologically root resorption presents itself as microscopic areas of resorption on the root surfaces; however seventy-five percent of these areas completely repair with secondary cementum[32] thereafter. During treatment, an increase in duration and magnitude of force can increase the incidence of RR when resorption exceeds the reparative capacity of cementum[31].

Root resorption usually does not present with a clinical sign or symptom. In order to diagnose RR, clinicians rely on either radiography or histology. Histologic studies report greater than 90% occurrence of OIEARR[33-35] whereas radiographic analysis often yielded significantly lower percentages[35]. Lupi et al.[2] used periapical radiographs to measure apical root resorption. They found that 15% of untreated maxillary and mandibular incisors in adults had root resorption prior to treatment and this value increased to 73% after at least 12 months of fixed treatment. It is difficult to compare frequencies of root resorption among different studies because each researcher has a different criteria to define OIEARR[36]. For example, Hemley[37] reported 3% of the teeth examined in his patients showed OIEARR whereas another study by Rudolph[38] found nearly 100% of his patients had OIEARR.

OIEARR is a common iatrogenic consequence of orthodontics and while most treated patients experience some resorption, the loss is often mild to moderate and usually does not increase the risk of tooth loss in the future[16,39-41]. Regardless of patient or treatment related factors, the maxillary incisors followed by the mandibular incisors have been regarded as the most susceptible to RR[35,42]. The majority of OIEARR is usually classified as mild or moderate[22,35,43-45], however in rare instances, 1-5% of treated teeth developed severe RR (>4mm or > 1/3 of original root length) [2,22,43,44,46]. In cases of severe resorption, the crown to root ratio may be compromised and as a result, splinting may be needed to help reduce mobility. The potential of encountering cases of severe root resorption is a realistic concern for all orthodontists, and because of this, clinicians heavily rely on radiographs as a diagnostic aid for assessing root resorption during treatment. In cases where OIEARR is noted on a radiograph, it has been suggested that active treatment should be discontinued for two to three months with patient in passive archwires[47], although this suggestion is not evidence-based.

1.7 Dental Imaging

A radiographic examination is an essential part of the diagnostic process in orthodontics and imaging is required before the start of orthodontic treatment to assess overall dental health, root form, presence of underlying disease/pathology and to show the position and number of developing teeth[48]. In orthodontics, a lateral cephalometric film and a panoramic film are routinely ordered as the primary pretreatment radiographs[49].

Although lateral cephalometric radiographs provides an image of the length of the incisors, superimposition of one side on the other and magnification of 5-12% make it not ideal for assessment of root resorption in orthodontics. To acquire a lateral cephalometric radiograph (Figure 8), the sagittal plane of the head is parallel to the film. The x-ray beam is horizontal and perpendicular to the sagittal plane and the film. The x-ray tube head and cephalotstat are in fixed positions so that the x-ray source to patients mid-sagittal plane is 5 feet and the distance from the mid-sagittal plane to the cassette can vary but be the same for any one patient every time[50].

A panoramic film produces in a single image, the maxillary, mandibular arches and supporting structures. The focus section, or focal trough is similar in shape to a dental arch and resembles a 3D horse-shoe shape[51]. The advantage of the panoramic film include: less radiation exposure, less patient chair time, less operator time, better patient cooperation compared to full mouth series[52]. The main disadvantages of panoramic images is the quality of image is dependent on correct patient positioning and the closeness of the desired anatomical structure to the set focal trough[52]. The correct position of patient requires that their heads be aligned so that the Frankfort plane is parallel to the floor[52], however important structures may end up being situated outside the plane of focus (focal trough), resulting in the structure being distorted or obscured in the radiographic image[53]. The focal trough (Figure 9) is often narrow in the incisor region and sometimes causes the apices and palatal structures to be out of focus or invisible[51]. In orthodontic camouflage of mild-moderate class II cases, mandibular incisors may become excessively proclined leading to an apparent foreshortening of the roots in the radiographic image[51] (Figure 10). This may explain why panoramic images have been reported to over-estimate the amount of tooth loss by 20% or more, and why the mandibular incisors were especially vulnerable to this distortion[54].

In addition to panoramic images, it is sometimes recommended that periapical views be taken to supplement areas that may be out of focus on the panoramic image. In order to best obtain an image that is geometrically accurate the following are required: 1. Tooth/teeth and film should be parallel to each other 2. X-ray tubehead should be positioned so that the beam meets the tooth and film at right angles in both the vertical and horizontal planes[51].

For periapical images, two techniques are used: paralleling and bisected angle technique. The paralleling technique places the film parallel to the tooth/teeth with the xray beam aimed at right angle to both the film and tooth (figure 11). In cases where the film cannot be placed parallel and close to the tooth/teeth, the bisecting technique is used[51]. This method places the film as close as possible to the tooth/teeth without bending the film. The angle between the film and tooth/teeth is bisected and the xray beam is aimed at right angles to this line through the apex of the tooth[51] (figure 12). When using the bisecting technique, it is important to remember that incorrect vertical tubehead positioning can also cause either foreshortening or elongation of the image and this can complicate the assessment of RR (Figure 13).

RR is a 3D problem, however most clinicians rely on 2D imaging to assess it. Cone-beam computed tomography (CBCT) is a radiographic method that offers 3D imaging of dental structures[55]. CBCT provides a highly detailed 3D image with only 1 x-ray exposure and can be obtained at any angle, thus offering optimum viewing and eliminating superimposition[56]. Da Silveira et al.[57] assessed the diagnostic ability of

CBCT to detect simulated RR and reported that this imaging technique showed high sensitivity and excellent specificity. Comparing panoramic radiographs to CBCT imaging, examiners noted 69% of orthodontically treated teeth had some level of RR, whereas only 44% of teeth were identified in panoramic radiographs[56]. Currently there is no gold-standard imaging technique to assess RR. There are several studies that show CBCT scans provide more accurate diagnosis of RR than 2D imaging[56,58]. CBCT is becoming more widely used in orthodontics, however there are only still very limited situations where enough data exists to support its wide use in orthodontics. While CBCT is capable of providing a highly detailed 3D image, concerns of higher radiation dosage for the patient have sparked strong debates amongst clinicians. Increased radiation dosage from CBCT may be justifiable if it can provide additional diagnostic information that a 2D radiograph cannot provide which results in a change in treatment approach. As technology continues to improve the quality of CBCT image and reduce the radiation dosage there maybe a significant reduction in the resistance of this technology amongst many clinicians. For the moment, although there is great potential in this technology, it is evident that CBCT has not yet replaced 2D imaging as the majority of clinicians still rely on this technology for the diagnosis and case management.

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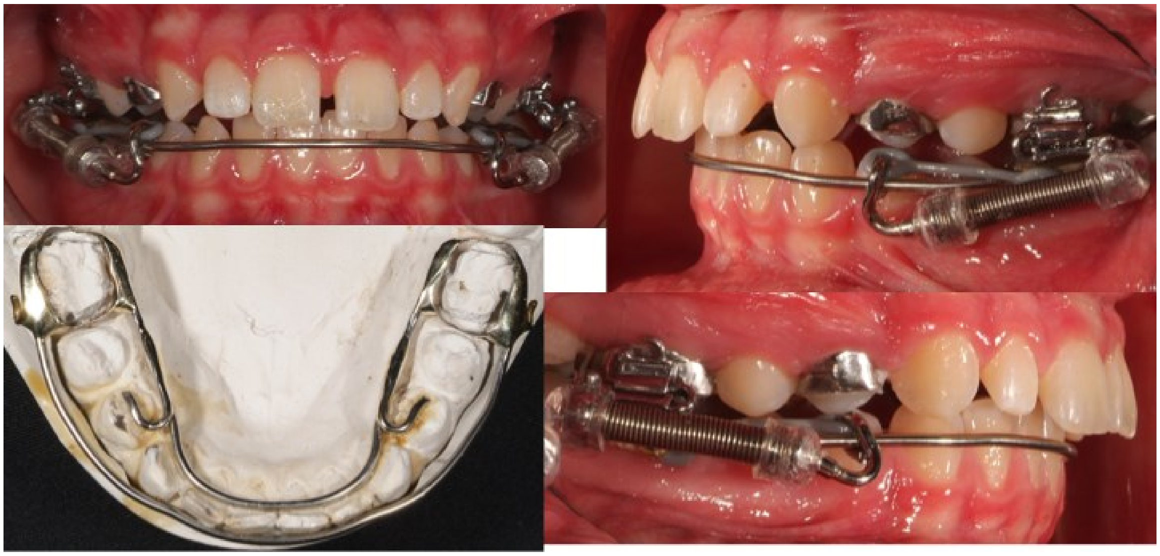

Figure 1 - Herbst Appliance (image courtesy of Dr. Carlos Flores-Mir). This appliance uses a pin and tube apparatus to hold the mandible in an advanced position.

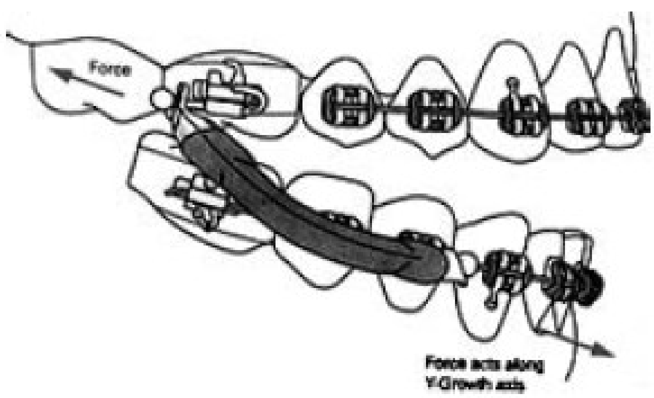

Figure 2 - Jasper Jumper (image from Kucukkeles et al.[59])

Figure 3 - MARA Appliance (image from Proffit[5])

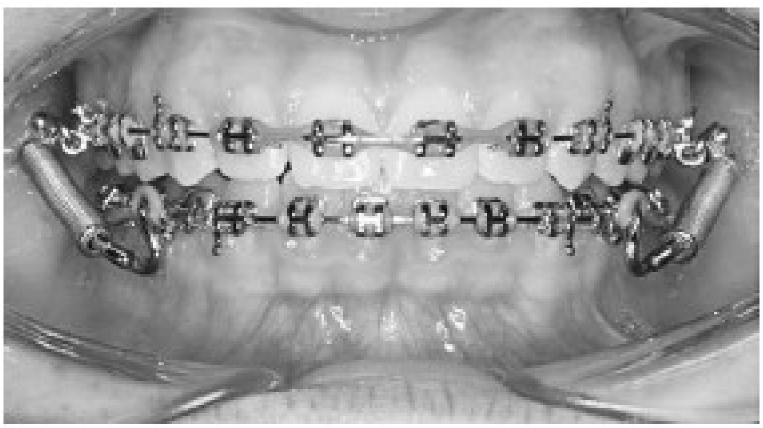

Figure 4 - Forsus (image from Miller et al.[60])

Figure 5 - Xbow (image obtain from www.crossboworthodontics.com/xbow.htm).

Figure 6 - Pendulum (image from Proffit[5])

Figure 7 - Distal Jet (image from http://www.ortho-concept.com/distal-jet,orthodontie_en,2,23)

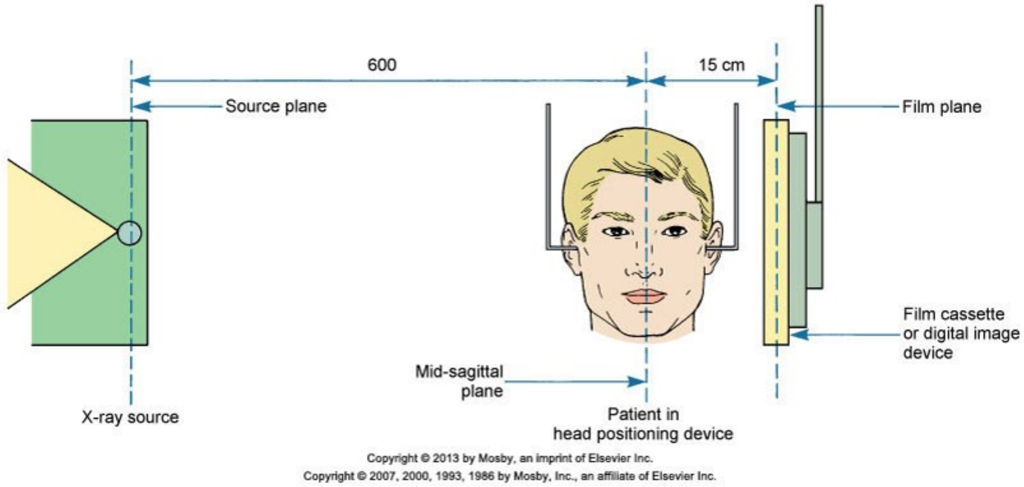

Figure 8 - Adapted from Proffit et al.[50] Lateral Cephalometic Arrangement

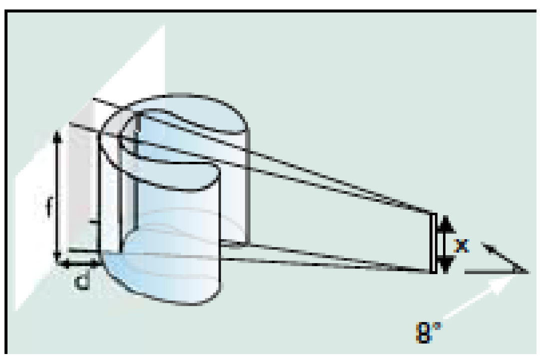

Figure 9 - Adapted from Leach et al.[51] Diagram showing horseshoe-shaped focal trough with x-ray beam aimed upwards at 8 degrees.

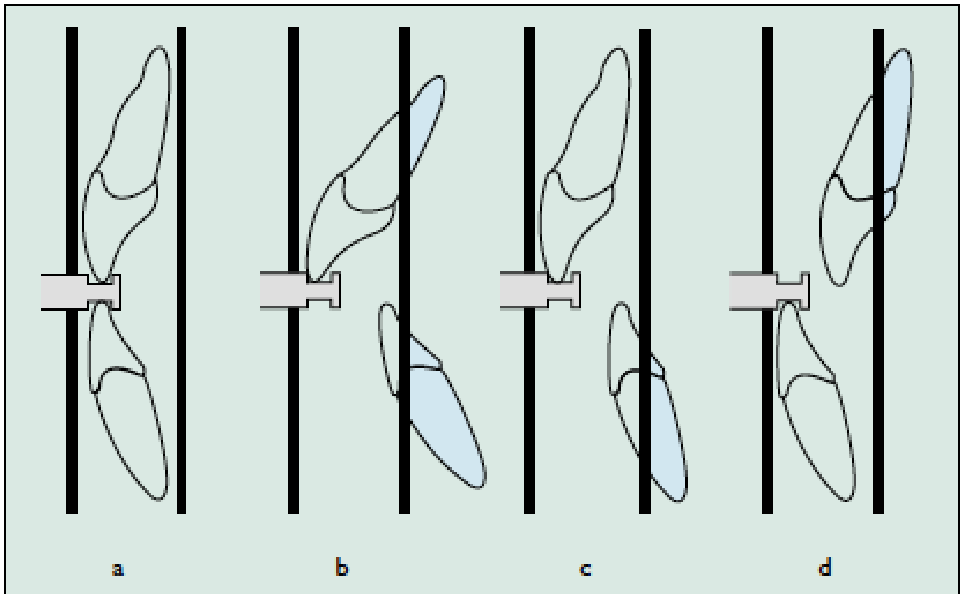

Figure 10 - Adapted from Leach et al.[51] Diagram showing the vertical walls of the focal trough in the incisor region and the relative positions of teeth with different underlying dental or skeletal abnormalities. A. Class I skeletal B Class II Division I malocclusion C. Class II Skeletal D. Class III Skeletal. (blue parts are parts of teeth outside focal trough will be blurred and out of focus on film).

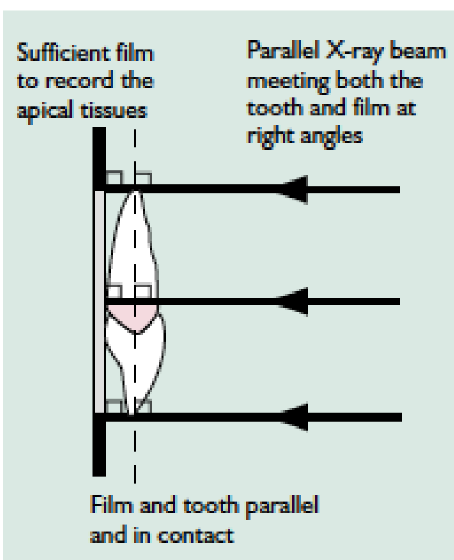

Figure 11 - Adapted from Leach et al.[51] Parallel Technique.

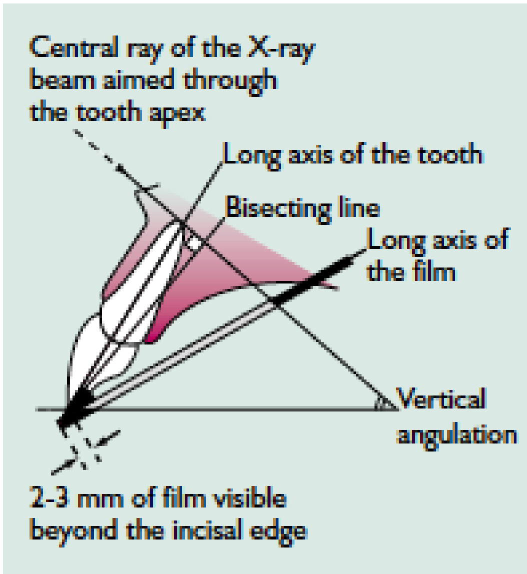

Figure 12 - Adapted from Leach et al.[51] Bisected Angle Technique

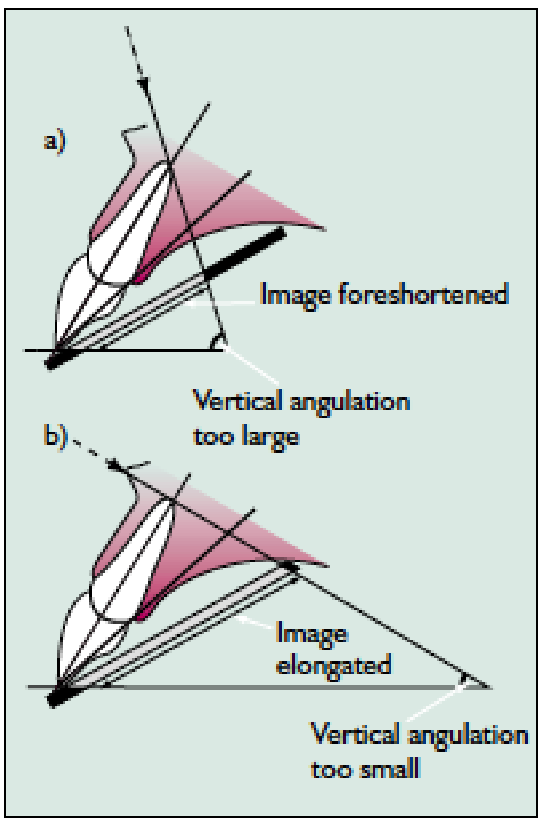

Figure 13 - Adapted from Leach et al.[51] Diagram showing the effects of incorrect vertical tubehead positioning. A. Foreshortening of image B. Elongation of image.

Chapter 2 –Radiographically Determined Root Resorption in Non-Surgical Orthodontic Treatment of Class II Malocclusion: A Systematic Review

2.1 ABSTRACT

Purpose: To critically evaluate incisor external apical root resorption (EARR) in patients undergoing orthodontic treatment of mild to moderate Class II Division I malocclusion by a systematic review of the published data.

Methods: An electronic search of two databases was performed; the bibliographies of relevant articles were also reviewed. Studies were included if they examined the amount of incisor EARR produced during orthodontic treatment of individuals with mild to moderate Class II Division I malocclusion in the permanent dentition. Individuals had no previous history of EARR, syndromes, pathologies, or general diseases. Study selections, risk of bias assessment and data extraction were performed in duplicate.

Results: Eight studies of moderate methodological quality were finally included. An increased prevalence (65.6-98.1%) and mild-moderate severity of orthodontically induced EARR (<4mm and <1/3 original root) was reported. No sex difference in root resorption was found. For the maxillary incisors, there was no evidence that either the central or lateral incisor was more susceptible to EARR. A weak to moderate positive correlation between treatment duration and root resorption, and anteroposterior apical displacement and root resorption was found.

Conclusions: Current evidence suggests that comprehensive orthodontic treatment to correct Class II malocclusions causes increased prevalence and severity of root resorption compared to pretreatment. However, given the methodological limitations identified in the selected studies, our findings should be considered with caution. Future studies would benefit from using CBCT to assess root resorption.

Key Words: Root Resorption, Systematic Review, Class II Malocclusion

2.2 INTRODUCTION

External apical root resorption (EARR), as a result of orthodontic treatment, is a relatively common iatrogenic problem that has challenged orthodontists for many years. Histologic studies have reported greater than 90% occurrence of orthodontically induced external apical root resorption (OIEARR)[1-4], whereas radiographic evaluation studies reported between 48-66% occurrence[5-8]. OIEARR is usually less than 2.5mm[9-12] when assessed by panoramic or periapical radiographs and is typically classified as mild-moderate with minor clinical significance. On rare occasions, severe resorption exceeding 4mm, often classified as loss of more than a third of the original root length, has been reported in 1-10% of treated teeth[5,7,13-16].

The etiology of EARR is unclear with various studies reporting 7-15% of untreated patients present with EARR prior to orthodontic treatment [5,17]. Individuals vary in their susceptibility to OIEARR with various factors such as tooth root morphology[10], length[10], genetics[18] and chronological age[19]. There are also a number of reported orthodontic treatment related risk factors suggested in the literature such as treatment duration[13,20], magnitude of applied force[4], and amount of apical movement[20].

There have been a number of previous literature reviews[21-24], a systematic review[25] and a meta-analysis[26] reporting root resorption and OIEARR. While these reports looked at OIEARR, they did not specifically address root resorption of maxillary and mandibular incisors in non-extraction or extraction treatment of Class II malocclusions. Class II malocclusions affect approximately one-third of the North American population[27]. There are reports of a twenty-fold increase in risk of severe root resorption of maxillary incisors if their roots were forced against the cortical plate during treatment[28]. This is likely to occur when attempting to camouflage a skeletal problem, as seen in moderately Class II correction that has not been surgically treated. Since root resorption risk varies from individual to individual, it is important to critically assess the different treatment techniques in order identify the presence of specific factors that may be identified to help reduce the incidence of this problem.

As such, the purpose of this systematic review is to critically analyze the available scientific literature regarding OIEARR to maxillary and mandibular incisors during orthodontic treatment (extraction and non-extraction) in mild to moderate Class II Division I malocclusions.

2.3 MATERIALS AND METHODS

Reporting of this systematic review was performed in accordance with the PRISMA statement for reporting systematic reviews of health sciences interventions[29].

2.3.1 Data Sources and Searches

Comprehensive searches up to July 20th, 2013 were conducted using the following electronic bibliographic databases: PubMed (1966 to July 2013, week 3) and MEDLINE (OvidSP) (1980 to 2013, week 28). The terms used for this literature search were 'root resorption', 'root shortening', 'malocclusion', 'Class II', and 'orthodontics'. The initial search strategy was designed for PubMed (Appendix 1) and later adapted to Medline. From the selected articles, hand searches were subsequently performed on the reference lists. No restrictions were applied regarding publication year or language. When additional information was needed, efforts were made to contact the authors.

2.3.2 Study Selection

Appropriate studies to be selected met the following pre-defined inclusion-exclusion criteria:

- *Population:* Individuals with mild to moderate Class II Division I malocclusion. Individuals should have no history of root resorption, syndromes, pathologies or general diseases. Only human studies were eligible with no restrictions applied regarding sex.

- *Intervention:* A non-surgical orthodontic treatment of Class II malocclusion: either extraction treatment (bicuspids extraction on the upper and/or lower arch) or non-extraction treatment (e.g., functional therapy by removable or fixed appliances with Class II elastics).
- *Comparison:* Before and after treatment, or extraction versus non-extraction treatment or another equivalent intervention (non-treated control).
- *Outcome:* Root resorption evaluated by the root lengths of maxillary and mandibular teeth assessed using radiographic imaging (e.g., periapical, cone-beam computer tomography images).
- *Study Design:* Prospective and retrospective clinical studies were included in this study.

In the first step of the review process, two reviewers (LT, HS) independently reviewed the list of titles and abstracts for inclusion. Once potentially adequate abstracts were selected, full articles were retrieved in a second final selection process. If the abstract was judged to contain insufficient information for a decision of inclusion or exclusion, the full article was obtained and reviewed before a final decision was made. In the second phase of selection, eligibility criteria were applied to the full articles. Any discrepancies in inclusion of articles between reviewers were addressed through discussion until consensus was reached.

2.3.3 Risk of Bias

Two reviewers evaluated the methodological and reporting quality of the finally selected reports; discrepancies were resolved by discussion until consensus was reached. The following quality items were used to assess the methodological quality and risk of bias in the studies[30,31]: eligibility criteria, adequacy of sample size, reporting of randomization, reporting of blinding, avoiding selective reporting, description of intervention details, description of outcome measures, description of adverse effects, and adequacy of data analysis.

2.3.4 Data Extraction

Data was extracted for each of the selected studies based on the following outcomes: study design, sample size, and age at start of treatment, whether there were extractions, and method of Class II treatment. Study demographics including publication year and country where study was conducted were also collected. Data extraction was done by two investigators (LT and HS). Any discrepancies were resolved by discussion until an agreement was reached.

2.3.5 Data Synthesis

Data was planned to be pooled in order to provide an estimate of the effectiveness of the interventions planned for the studies reporting the same outcome measures. Evaluation of clinical heterogeneity was planned to be performed by examining various characteristics of the finally selected reports, such as the dis-similarity between the different types of interventions, outcomes, and patients. A qualitative synthesis was planned for any intervention where there was an insufficient clinically homogeneous trial.

2.4 RESULTS

2.4.1 Study Selection

The search yielded 1831 potential studies for inclusion from different electronic databases (Appendices 1 to 3). Full texts of 22 journal articles were retrieved for further evaluation. Ultimately, nine papers fulfilled the inclusion-exclusion criteria, however eight[32-39] studies were included since one author had two[37,40] different publications using the same sample group. No additional studies were identified through the reference list search and an update search revealed no additional studies. A flow diagram of the data search can be seen in Figure 1. The excluded studies and the reasons for their exclusion can be found in Table 1.

2.4.2 Study Characteristics

A summary of the methodological data and study results can be found in Tables 2 and 3. Seven of the studies were retrospective studies and one was prospective. Seven studies were written in English and one was written in German.

Prevalence and Severity

Prevalence of incisor root resorption ranged between 65.6% and 98.1%, depending on whether it was calculated per patient or per tooth. When calculating per patient, resorption ranged between 65.6 and 98.1%[32,35] whereas on a per tooth basis, resorption ranged between 72.9 and 94.2%[32,33,37,40].

In this review, mild-moderate root resorption is considered to be anything less than 1/3 of the original root length. Three studies reported little resorption (1.7-27.1%) following treatment[32,33,39]. One study[39] reported 6.25% of treated maxillary incisors resulted in severe root resorption where greater than 1/3 of the original root length was lost. Another study[34] reported 17.2% (5/29) of treated patients experience resorption of greater than 4mm in at least one maxillary incisors. Each study classified root resorption differently; however all reported that the majority of teeth experienced mild-moderate resorption following treatment.

Sex and Age

The majority of studies had both male and female patients, however, only one[32] reported no difference in root resorption between the sexes. Five studies[32,33,35,36,39] examined patients in their teenage years (age ranged from 12.4 to 13.6 years) whereas there was one research[38] that examined an adult sample (age, 25.4 years).

Treatment Time

Six studies[32,34-36,38,39] reported treatment duration ranging from 22 to 38 months. One study[32] reported a weak to moderate positive correlation when duration of treatment in months was compared to apical root resorption ($r=0.434$, $\boldsymbol{\alpha}=0.01$).

Treatment Mechanics

Different treatment mechanics were used to correct the Class II malocclusion. DeShields[32] corrected the Class II malocclusion without extractions and relied on the use of headgear and/or Class II elastics. Studies by Hollender[33] and Liou[38] both relied on extraction of upper first premolars and applying en-masse retraction of the anterior segment using coils with or without miniscrews. In the study by Reukers[35] treatment ranged from non-extraction to extraction of 2, 3 or 4 premolars. Another study by Mavragani[40] compared straight wire to standard edgewise using extraction of premolars. Similarly, Taner[36] and Martins[39] studies corrected the malocclusion with extraction of 4 first premolars and using headgear and/or Class II elastics.

Risk of Bias Assessment

Of the eight selected reports, seven were retrospective studies[32-34,36.-39] and one was a prospective study[35]. The methodological quality assessment tool showed low to moderate methodological quality with variance of 38.46 to 69.23% of the total scores (Table 4).

Synthesis of results

Data pooling of the selected reports was not suitable because of methodological and clinical heterogeneity across studies[31].

2.5 DISCUSSION

This systematic review examined OIEARR of maxillary and mandibular incisors in extraction/non-extraction Class II treatments. Eight studies were considered eligible. Six of the eight studies treated patients with edgewise appliance only, whereas two of the eight studies compared edgewise to straight wire. The studies included in this systematic review made measurements of root resorption using radiographs (periapical or lateral cephalometric).

2.5.1 Prevalence and Severity

The prevalence of root resorption in our review ranged between 65.6 to 98.1%. The maxillary incisors are often regarded as being most susceptible to root resorption[7,10,25] due to blunted or bottle shaped root form[9,13]. Similarly, this review noted one study where resorption was reported in 72.9% of maxillary incisors compared to 34.7% of the remaining maxillary teeth[33]. When assessing if the central or lateral is more susceptible to resorption, studies by Mavragani[37] and DeShields[32] showed closer frequency of root resorption between the central and lateral incisors.

While root resorption of incisors from Class II treatment appears to be quite prevalent, overall resorption appears to be mild to moderate. The studies included in this review reported mild-moderate resorption of root with one study[39] reporting severe root resorption in 6.25% (7/112) of the teeth. A literature review by Weltman[25] found that with panoramic or periapical radiographs, OIERR is usually less than 2.5mm, with severe resorption (>4mm or >1/3 original root length) being seen in only 1 to 5% of the teeth. Another study [34] reported 17.2% (5/29) of treated patients experienced resorption of greater than 4mm in at least one maxillary incisor. There is a possibility that the reported percentage of severe root resorption might be over-estimated, and thus care should be taken when interpreting this value. Based on the information available in the current studies, severe root resorption in terms of percentage of teeth affected in treatment of Class II malocclusions appears consistent with what is currently published in the literature for orthodontic treatment in general.

2.5.2 Sex and Age

Sex has been reported to be a potential individual risk factor for root resorption. In our systematic review, only one study[32] reported no difference in root resorption between sexes. The other studies did not explicitly mention a difference in root resorption between sexes; this may suggest that no difference was found. This finding is in agreement with a number of other large-scale studies in the literature[9,10,28], suggesting that sex is an unlikely risk factor for root resorption.

It is often wondered if adults experience more root resorption than adolescents undergoing orthodontic treatment. From this review, it appears that treatment of younger patients produced a mild to moderate amount of root resorption. When looking at the adult population, similar mild to moderate resorption in terms of percentage of root resorption compared to original root and absolute amount of resorption was also reported. However, no study directly compared root changes between younger and older patient.

The study by Mavragani et al.[37] reported mild to moderate overall root resorption, however, the authors did report that roots that were incompletely developed before orthodontic treatment reached a greater length than those that were fully developed at the start of treatment. The authors hypothesized that there might be a mechanism whereby the immature teeth with open apexes protects the younger roots against resorption during orthodontic treatment and allows them to reach the normal root length when compared to untreated controls. One proposed concept suggested that teeth with open apex experience less severe pulp changes, thereby allowing for greater biological tolerance during treatment.

Collectively the included studies suggest that chronological age at the start of treatment may not be a primary indicator of root resorption, however it is possible that these patients although different in terms of chronological age, are identical in terms of degree of root formation. The study by Mavragani et al.[37], found the age was significantly higher among patients showing root resorption (12.8 to 12.9 years) of the maxillary lateral incisors during treatment than among those showing root elongation (11.5 to 11.6 years).

2.5.3 Treatment Time

Six studies[32,35-39] reported treatment duration ranging from 21.6±4.8 months to 38±20 months and all reported mild-moderate root resorption. A study by Segal et al.[26] concluded that one of the treatment-related causes of root resorption was treatment duration.

It is unclear in the literature whether treatment time is related to root resorption. Only one study[32] in this review compared root resorption to treatment time, which reported a weak to moderate positive correlation between duration of treatment and apical root resorption. This finding[32] support the notion that treatment time is related to root resorption as suggested by McFadden et al.[41], however it contradicts other studies which suggest that the two factors are unrelated[42,43].

It would have been interesting to determine how long patients were in active treatment as suggested by Segal et al.[26], since treatment duration could be inflated, despite limited times of activation if patients were missing appointments, or if the clinicians preferred longer times between appointments. Unfortunately, this information was not available from the selected studies so such assessments were not done.

2.5.4 Root Displacement

The study by DeShields et al.[32] reported weak to moderate correlation between anteroposterior apical displacement and root resorption. In addition, Liou and Chang[38] noted apical displacement (retraction 3.0mm/intrusion 2.7mm with miniscrews; retraction 1.3mm/intrusion 2.5mm without miniscrews) when using en-masse retraction of the anterior maxillary teeth using coils. In camouflage orthodontic treatment, it is conceivable that the incisors are subjected to large apical displacements that may lead to OIEARR. Clinicians should always be careful whenever displacing root apexes and should be aware that this type of movement might result in mild-moderate resorption.

2.5.5 Class II Division I Treatment Mechanics

Treatment mechanics involved any of the following: extractions, non-extraction, straight wire, edgewise, Class II elastics, headgear, functional appliances, and mini screws to correct the malocclusion. Given the diverse range in techniques used to correct the malocclusion, what was interesting to note was that all these studies[32-39] consistently reported mild to moderate root resorption following treatment. It seems that treatment of Class II malocclusions with any of the treatment strategies generally produces similar root resorption and the amount is similar to what is reported for orthodontic treatment of other types of malocclusions. The etiology of root resorption appears to be complex, so it is important for clinicians to recognize that there are many potential patient and treatment risk factors that may contribute to root resorption.

2.5.6 Measurement of root resorption

Assessment of root shape and length is an essential component of the initial diagnosis stage in orthodontics. Root resorption occurs tri-dimensionally (3D), however most of the reported information in the literature relies on the use of a bi-dimensional radiographic image (2D). Ideally, a 3D image would provide the most accurate information. Collectively the available studies have provided important insight into root resorption, however the varying degree of magnification and the limitations of 2D imaging make the quantitative value of these radiographs questionable[25]. When attempting to evaluate apical root resorption using 2D imaging techniques (periapical, panoramic, ceph), the image shows superimposition of all the root structures, thus complicating the measure of root resorption[44]. In addition, the angulation between incisor and radiographic film as well as the amount of magnification can affect the images obtained, thus potentially impacting on the clinician's ability to properly diagnose the case[44].

The studies included in this review relied on 2D imaging to determine the amount of root resorption. One study[36] measured root resorption using cephalometric radiographs. Incisor root lengths can be quite distorted and obscured with this imaging technique given the number of overlapping structures. Any root resorption information should be taken with caution. For completeness, this systematic review included a study[36] assessing root resorption using cephalometric radiographs, given its inherent limitations. Interestingly, root resorption reported using this technique reported similar severity as reported for periapical radiographs. Periapical images can be taken with either the parallel or bisecting technique. The parallel technique tends to be accurate and produces little magnification whereas the bisecting technique has more potential for image distortion. One study[35] reported using a non-standardized bisecting technique to obtain the image whereas the other studies did not specify which technique was used. Given the inherent potential for image distortion, it was surprising that only two studies[38,40] reported using a correction factor for distortion in their calculation of root resorption. While the data from this systematic review will provide some beneficial information, it is important to recognize that the available data has some inherent limitations.

Future studies would benefit from using CBCT to assess root resorption. This 3D imaging technique allows for slices of the root and eliminates superimposition of structures. Using this imaging technique, clinicians are better able to visualize and assess root resorption on any surface of the root. Future studies using this imaging technique may provide more accurate insight into the severity and prevalence of root resorption of maxillary incisors while also providing information for mandibular incisors since there is currently no data available.

2.6 CONCLUSIONS

Current evidence suggests that comprehensive orthodontic treatment to correct Class II malocclusions causes increased prevalence and severity of root resorption compared to pretreatment. Root resorption appears to be a complex process with a number of potential risk factors. These findings highlight the importance for proper informed consent of the potential risk and impact of OIEARR. Although a few studies were identified in our review, they did not provide meaningful evidence to adequately support clinically useful conclusions. As such, the reported findings should be considered with caution. Future studies would benefit from using CBCT to assess root resorption.

List of abbreviations

EARR, incisor external apical root resorption; OIEARR, orthodontically induced external apical root resorption

Figure Legend

Figure 1. Flow Diagram of Data Search According to PRISMA[29]

Ethics approval

Not required.

Competing Interests

The authors declare no conflicts of interests.

Authors' Contributions

LT HS collected and analyzed the data, and assessed risk of bias of included studies; LT drafted the manuscript and integrated critical feedback from the other authors. All of the authors were involved in interpretation of the data. All of the authors provided feedback on the revisions to the manuscript.

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Article	Reason for Exclusion
Goldson and Henrikson. 1975 [45]	1
Lee et al. 1999 [46]	1
McNab et al. 2000 [47]	1
Alwali et al. 2000 [48]	4
Brin et al. 2003 [49]	3
Segal et al. 2004 [50]	2
Nasiopoulos et al. 2006 [51]	4
Janson et al. 2007 [52]	1
Huang et al. 2010 [53]	1
Weltman et al. 2010 [54]	2
Sunku et al. 2011 [55]	1
Kinzinger et al. 2011 [56]	4
Wahab et al. 2013 [57]	4

1. Mixed data (Class II malocclusion data mixed with other malocclusion) 2. Review (literature or systematic review) 3. Mixed trauma data 4. Unrelated data

Table 1 - Articles not selected from the initial abstract selection list and reason for exclusion

Article	Study Design	Country	Sample Size	Age at T1 (Years)	Extraction	Class II Treatment
DeShields.1969 [32]	RS	USA	52 (24M:28F)	M: 12.6/F: 12.2 Group: 12.4±0.9Y	No	Headgear or Class II Elastics
Hollender et al. 1980 [33]	RS	Sweden	12 (3M:9F)	Group 13Y3M	Yes Upper 14/24	Edgewise
Eisel et al. 1994 [34]	RS	Germany	44	Group 14.7 (7.1)	Yes 64% No 36%	48% Edgewise 9% only Functional 43% combined
Reukers et al. 1998 [35]	PS	Holland	Started 149 (64M:85F) Finished: 61 Excluded 2 – moved 7- early debond 79 – poor Radiographs	Group 12Y4M±1Y2M	Yes and No If extractions were done could be 2, 3 or 4 premolars extracted	29 Edgewise 32 Straight wire Class II elastics
Taner et al. 1999 [36]	RS	Turkey	27	G 13.6±2.5Y	Yes 4 bicuspid	Edgewise
Mavragani et al. 2000 [40] **Mavragani et al. 2002** [37]	RS	Norway	80 Edgewise (22M:18F) Straight wire (20M:20F)	Edgewise 13.8±0.7Y Straight wire 13.1±0.7Y	Yes At least 14/24 or Upper bicuspid with lower 4's or Upper bicuspid with lower 5's	40 Edgewise 40 Straight wire
Liou and Chang 2010 [38]	RS	Taiwan	50 Group I (0M:30F) Group II (4M:16F)	Group I: 26.5±5.5Y Group II: 22.5±1.6Y	Yes Mx 14/24	I-30 Minscrew + FFA II- 20 FFA
Martins et al. 2012 [39]	RS	Brazil	28 I: (16M:12F) II:N/A Mixed Data	I: 13.4±2.4Y	Yes (2 Mx PM or 4PM)	Edgewise Headgear and Class II Elastics (if necessary)
*RS- Retrospective Study, PS- Prospective Study, RCT- Random Controlled Trial						

Table 2 - Description of Selected Studies

Article	Treatment Duration	X-ray	Root Resorption (RR)	RR -Specific Tooth & Severity	Additional Information
DeShields.1969 [32]	M: 20.5M F: 22.5M G: 21.6±5.2M	PA	51/52 cases had resorption in at least 1 Mx incisor <u>Severity</u>[1] Grade 0 – 12/208 Grade 1- 24/208 Grade 2 – 82/208 Grade 3- 79/208 Grade 4- 11/208 Grade 5- 0/208 <u>Gender-Severity</u>[1] 4M -Grade 2 17M- Grade 3 3M- Grade 4 1F- Grade 1 7M- Grade 2 17F- Grade 3 3F- Grade 4	<u>Tooth 12</u> [1] Grade 0 – 1/52 Grade 1- 4/52 Grade 2 – 23/52 Grade 3- 21/52 Grade 4- 3/52 <u>Tooth 11</u>[1] Grade 0- 4/52 Grade 1- 7/52 Grade 2- 19/52 Grade 3- 17/52 Grade 4- 5/52 <u>Tooth 21</u>[1] Grade 0- 3/52 Grade 1- 5/52 Grade 2- 26/52 Grade 3- 17/52 Grade 4- 1/52 <u>Tooth 22</u>[1] Grade 0- 4/52 Grade 1- 8/52 Grade 2- 14/52 Grade 3- 24/52 Grade 4- 2/52	Treatment Time Edgewise (Months) Male: 11.6M Female: 10.1M Mean: 10.8±5.7M Headgear Time (if used) (Months) Male: 16.5M Female: 17.0M Mean: 16.8±7.6M Class II Elastics (if used) (Months) Male: 7.5M Female: 5.2M Mean: 6.3±5.6M
Hollender et al. 1980 [33]	Mean 18M	PA	<u>Grade I or II RR</u>[2] 60/120 Teeth	<u>Tooth (Grade 1 or 2 RR)</u>[2] 16 – 3/12 15- 3/12	Mx Anterior Teeth most affected 48/60

			Severity Grade 1- 53/60 Grade 2- 7/60	13- 5/12 12- 11/12 11- 7/12 21- 6/12 22- 11/12 23- 8/12 25- 3/12 26- 3/12	Lateral Incisor 22/24 No Grade 3 resorption
Eisel et al. 1994 [34]	38±20M (total sample)	PA	Mean four upper incisors: Up to 1mm 21 individuals Between 1 and 2 mm 6 individuals Between 2 and 3mm 1 individuals More than 3mm 1 individuals Maximum for either upper incisor: Up to 1mm 12 individuals Between 1 and 2 mm 6 individuals Between 2 and 3mm 6 individuals More than 4mm 5 individuals	Not described.	Only 29 patients had periapicals to quantify RR. No explanation why only these ones. RR dx through Linge & Linge method (AJODO 1991)
Reukers et al. 1998 [35]	Overall 20.4±6.0M Straight wire 21.6±4.8M Edgewise 19.2±6.0M	PA	Mean Degree of Resorption Overall – 7.8% ±6..9 Straight wire – 8.2%±6.4 Edgewise- 7.5%±7.6 Overall Prevalence Overall – (40/61)- 65.6% Straight wire – (24/32) 75% Edgewise – (16/29) 55%		Statistical test showed no difference in root resorption between straight wire and edgewise Study only focused on root resorption of Mx Central Incisors
Taner et al. 1999 [36]	28.1±9.0M	Ceph	Mean RR 2.1 ±1.6mm	N/A	N/A

Mavragani et al. 2000 [40]	N/A	PA	Same Data as 2002	Same Data as 2002	Same Data as 2002
Mavragani et al. 2002 [37]	N/A	PA	Tooth/Median Control 12- 17.03mm 11- 16.79mm 21- 16.69mm 22- 17.48mm Shortened 12- 14.55mm 11- 15.32mm 21- 15.30mm 22- 13.77mm Elongated 12- 17.36mm 11- 17.56mm 21- 15.52mm 22- 16.85mm	Mean RR 12 – 1.86±0.26mm 11- 1.82±0.26mm 21- 1.93±0.25mm 22- 1.78±0.33mm Shortened Roots 12- 59/72 teeth 11- 60/72 teeth 21- 58/67 teeth 22- 53/69 teeth Elongated Roots 12- 13/72 teeth 11- 12/72 teeth 21- 9/67 teeth 22- 16/69 teeth	Root elongation was noted for 50/280 teeth Age at T_1 was significantly higher among patients showing root shortening of lateral incisors than those showing root elongation ($p<0.05$) Roots that were incompletely developed before treatment reached a significantly greater length than those that were fully developed at the T_1
Liou and Chang 2010 [38]	En-Masse (Group I) 28.3±7.3 FFA (Group II) 22.7±5.0	PA	Group 1 16-20% (2.5-2.8mm) Group 2 13.4-14.4% (2.1-2.3mm)	Group I 12- 20.0±7.3% (2.7±1.0mm) 11- 19.6±6.6% (2.8±1.0mm) 21- 16.8±8.8% (2.5±1.4mm) 22- 16.0±9.2% (2.5±1.5mm) Group II 12- 14.4±7.3% (2.1±1.4mm) 11- 14.4±8.5% (2.3±1.7mm) 21- 13.6±7.6%	Group I (ANB 7.1°±1.9°) Group II (ANB 3.2°±2.9°) Apical RR of Mx Central Incisor was significantly correlated to the duration of treatment (P=0.026) but not to the amount of en-masse retraction, intrusion, or palatal tipping of Mx Incisors Mx lateral incisors was significantly greater in Group I than in Group 2

				(2.1±1.5mm) 22- 13.4±7.3% (2.1±1.3mm)
Martins et al. 2012 [39]	28.0±9.4M	PA	RR Severity[3] 0- 0/112 (0%) 1- 19/112 (16.96%) 2- 39/112 (34.83%) 3- 47/112 (41.96%) 4- 7/112 (6.25%)	

1. **Grade 0 – No resorption, Grade 1- Possible resorption (Some indistinctness to apical outline), Grade 2- Definite Resorption (Apical outline was definitely irregular, but the root was not shortened or blunted), Grade 3- Mild apical blunting (<3mm), Grade 4- Moderate apical blunting (>3mm but <1/3 root length, Grade 5- Severe blunting (>1/3 of the root length loss).**
2. **0- No visible resorption, 1- Apical resorption ≤ 2mm, 2- Apical resorption > 2mm ≤1/3 of the root length, 3- > 1/3 of the root length**
3. **0- no root resorption, 1- mild resorption, normal length and only displaying irregular contour, 2- moderate resorption, small area of root loss with the apex exhibiting an almost straight contour, 3- accentuated resorption, loss of almost 1/3 root length, 4- extreme resorption, loss of more than 1/3 of root length**

Table 3 - Descriptive Statistics of Selected Studies

Article	X-ray	Validity	Precession	Extraction	Class II Treatment Mechanics and additional treatment information
DeShields.1969 [32]	PA	✓	✓	No	All Class II Division 1 Malocclusion Edgewise appliance Headgear (HP, M, L) or Class II Elastics RR assessed using PA AP and vertical root movement assessed using Ceph Compared to similar untreated pts
Hollender et al. 1980 [33]	PA	✓	✓	Yes Upper 14/24	All Class II Division 1 Malocclusion Edgewise appliance RR assessed using PA
Eisel et al. 1994 [34]	PA	✓	✓	Yes 64% No 36%	48% Edgewise 9% only Functional 43% combined
Reukers et al. 1998 [35]	PA	✓	✓	Yes and No If extractions were done could be 2, 3 or 4 premolar extracted	Class II Malocclusion (Division 1, 2 and subdivisions) Edgewise vs Straight wire Edgewise – Sliding Straight wire - Loops Class II elastics 0.022 inch Standard Edgewise Slot 0.018 inch Straight Wire Edgewise Slot Roth Prescription Not clear how many cases were treated with extractions/non-extraction RR assessed using PA
Taner et al. 1999 [36]	Ceph	×	×	Yes 4 1st premolar	Class II Division 1 Malocclusion 0.018 inch Edgewise slot RR, AP and vertical root movement assessed using Ceph OJ corrected with controlled tipping of Upper incisors
Mavragani et al. 2000 [40] **Mavragani et al. 2002 [37]**	PA	✓	✓	Yes At least 14/24 or Upper bicuspid with lower 4's or Upper bicuspid with lower 5's	Class II Division I Malocclusion 0.018 inch Standard or Straight Wire Edgewise slot Edgewise vs Straight wire RR assessed using PA Compared to similar untreated pts

Liou and Chang 2010 [38]	PA	✓	✓	Yes Mx 14/24	Class II Division I Malocclusion Edgewise appliance En-Masse Mx anterior retraction and FFA vs. FFA Anterior retraction using NiTi coils RR assessed using PA
Martins et al. 2012 [39]	PA	✓	✓	Yes (2 Mx PM or 4PM)	Class II Malocclusion 0.022 inch Edgewise slot HG and Class II Elastics (if necessary) RR assessed using PA

Table 4 - Descriptive Statistics of Selected Studies

Methodological Quality Criteria	DeShield. 1969	Hollender et al. 1980	Eisel et al. 1994	Taner et al. 1999	Mavragani et al. 2000 and 2002	Liou and Chang. 2010	Martins et al. 2012
Eligibility criteria—clearly described (✓), adequate (✓)	✓≠	≠≠	××	✓≠	✓≠	✓≠	✓≠
Sample size—calculated (✓), adequate (✓)	×✓	××	××	×✓	×✓	×✓	×✓
Randomization/Consecutive selection—stated (✓)	×	×	✓	×	×	×	×
Blinding of assessor—stated (✓)	×	×	×	×	×	×	×
Intervention details—clearly described (✓)	≠	≠	×	✓	✓	✓	✓
Outcome measures—clearly described (✓)	✓	✓	✓	✓	✓	✓	✓
Selective reporting—avoided (✓)	×	✓	✓	✓	✓	✓	✓
Adverse effects—described (✓)	×	×	✓	×	≠	×	×
Data analysis—appropriate (✓)	≠	✓	✓	✓	✓	✓	✓
Point estimates and variability —exact *P* value (✓), variability measures, SD/CI (✓)	×≠	×✓	×≠	×✓	✓✓	✓✓	✓✓
Quality score (% of total)	38.46%	42.30%	42.30%	57.69%	69.23%	65.38%	65.38%

Maximum number of ✓s = 13
(✓) Fulfilled satisfactorily the methodological criteria (1 check point); (≠) Fulfilled partially the methodological criteria (0.5 check point); (x) Did not fulfill the methodological criteria (0 check point).

Table 5 - Methodological Score of Selected Studies

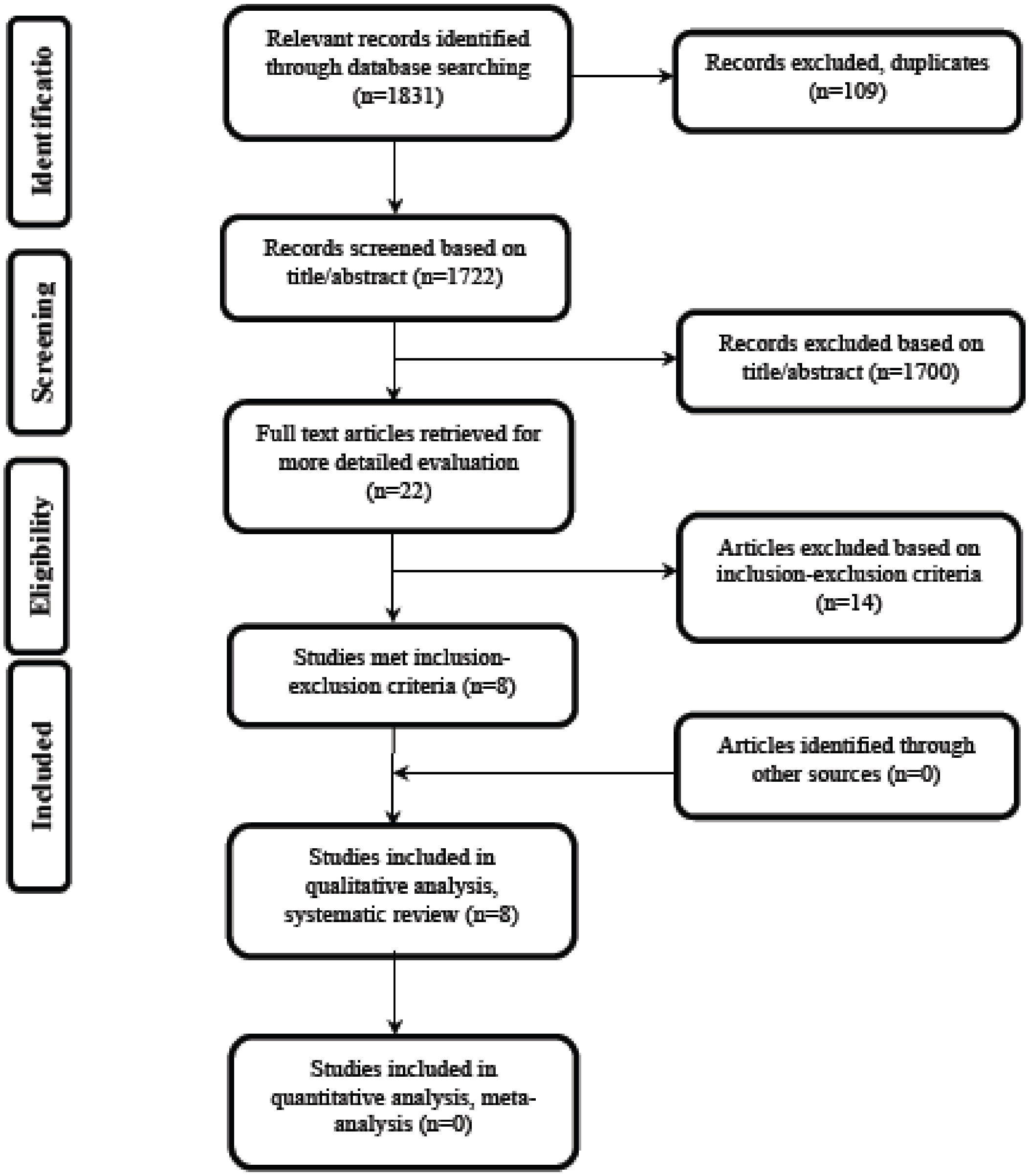

Figure- 1 – Flow Diagram of Data Search According to PRISMA[29].

Appendix 1 – Search Strategies and Results from Different Electronic Databases

Database	*Keywords*	*Results*
PubMed 1966 to July 2013, week 2	(Root* Resorption OR Root* Shortening) AND (Orthodontic* OR Class II OR Malocclusion*)	302
Ovid MEDLINE(R) 1946 to July Week 2 2013	((Resorption.ab or resorption.in or resorption.kf or resorption.kw or resorption.nm or resorption.ot or resorption.ti) OR (Shortening.ab or shortening.in or shortening.kf or shortening.kw or shortening.ot or shortening.ti)) AND ((Exp Orthodontic brackets or orthodontic*.mp or exp Orthodontic appliances or exp orthodontic extrusion or exp orthodontics space closure or exp orthodontic appliance design or exp Orthodontic retainers or exp Orthodontic Appliance, functional or exp orthodontic anchorage procedures or exp "index of orthodontic treatment need" or exp orthodontic wire or exp orthodontics appliances, removable) OR (Malocclusion*.mp or exp Malocclusion or exp Malocclusion Angle Class II))	1529
Total electronic databases searches		1831
Duplicates		109
Final		1722

Appendix 2 – PubMed Selection

Search #	Search	Items Found
1	Root* Resorption	4502
2	Root * Shortening	453
3	Orthodontic*	49955
4	Class II	79607
5	Malocclusion*	27701
6	#1 OR #2	4920
7	#3 OR #4 OR #5	135322
8	#6 AND #7	302

Appendix 3 – Medline Selection

Search #	Search	Items Found
1	Resorption.ab or resorption.in or resorption.kf or resorption.kw or resorption.nm or resorption.ot or resorption.ti	37091
2	Shortening.ab or shortening.in or shortening.kf or shortening.kw or shortening.ot or shortening.ti	41579
3	Exp Orthodontic brackets or orthodontic*.mp or exp Orthodontic appliances or exp orthodontic extrusion or exp orthodontics space closure or exp orthodontic appliance design or exp Orthodontic retainers or exp Orthodontic Appliance, functional or exp orthodontic anchorage procedures or exp “index of orthodontic treatment need” or exp orthodontic wire or exp orthodontics appliances, removable	44406
4	Malocclusion*.mp or exp Malocclusion or exp Malocclusion Angle Class II	30472
5	#1 OR #2	78546
6	#3 OR #4	58589
7	#5 AND #6	1529

Duplicates- 109
Search # overall – duplicates = 1722

Chapter 3 – Measured Root Resorption of Patients treated with Forsus or Xbow to Correct a Mild to Moderate Class II Malocclusion

3.1 Introduction

External apical root resorption (EARR), as a result of orthodontic treatment, is a relatively common iatrogenic problem that has challenged orthodontists for many years. Histologic studies have reported greater than 90% occurrence of orthodontically induced external apical root resorption (OIEARR) [1-4], whereas radiographic evaluation studies reported between 48-66% occurrence[5-8]. OIEARR is usually less than 2.5mm when assessed by panoramic or periapical radiographs and is typically classified as mild-moderate (less than 4mm) with a concomitant minimal clinical significance. On rare occasions, severe resorption (exceeding 4mm), often classified as loss of more than a third of the original root length, has been reported in 1-10% of treated teeth.

The etiology of EARR is unclear with various studies reporting 7-15% of untreated patients present with EARR prior to orthodontic treatment[5,9]. Individuals vary in their susceptibility to OIEARR with various factors such as tooth root morphology, length[10], genetics and chronological age. There are also a number of reported orthodontic treatment related risk factors suggested in the literature such as treatment duration[11,12] magnitude of applied force[4], and amount of apical movement[12].

It has been suggested that root contact with the cortical plate is one of the most critical factors for root resorption in orthodontic treatment, with the risk of root resorption increasing twenty-fold. This scenario is more likely to occur when attempting to camouflage a skeletal problem, as seen in moderately Class II or III correction that has not been surgically treated. Additionally, while attempting to camouflage, the tipping and/or torqueing of the incisors make it much more difficult to accurately evaluate root resorption by conventional radiographic means. With these limitations in mind, the objectives of this study is to evaluate the frequency and severity of root resorption of the maxillary and mandibular incisors following non-extraction treatment to correct mild to moderate class II malocclusions with either the Forsus or Xbow appliance.

3.2 Materials and Methods

The Human Ethics Research Office at the University of Alberta granted authorization (Pro00023805) for this study. The sample was obtained from a private practice of Dr. Robert Miller (Culpepper, VA) and consisted of a total of 40 consecutively treated patients using either the Forsus (Figure 1) or Xbow (Figure 2) (Mean ANB of Study Group 4.64, Standard Deviation 1.923, Range 0-8). A total of ten patients (8 Forsus, 2 Xbow) were later excluded due to poor Panoramic image at T_1, T_2 or both T_1 & T_2, reducing the sample size of this study to seventy (32 Forsus: 38 X-Bow). The breakdown of the seventy patients in this study was as follows: 17 male Forsus, 15 female Forsus, 13 male Xbow, 25 female Xbow. The treatment methodology consisted of using the Xbow followed by full edgewise appliance or Forsus used in combination with full edgewise appliance for the non-extraction treatment of mild to moderate class II malocclusions. Both groups had the same brackets (0.022 inch slot, -6° torque in the lower incisors) and in patients treated with the Forsus appliance, the clinician inserted first a 0.019x0.025 inch stainless steel archwire before inserting the Forsus appliance. Once 2-3mm of class III overcorrection was obtained, the Forsus were removed and intraoral elastics were used when needed. For the Xbow patients, the class II malocclusion was over corrected into a class III occlusion. Forsus springs were later removed and the patient was followed over a course of 2-4 month period to let relapse express itself. During this time, no active class II mechanics were used. Following the relapse potential period, full edgewise appliances were used and intra-oral elastics were used if needed. Both groups were finished with the same occlusal finishing and esthetic objectives.

Pre-treatment (T_1) and post-treatment (T_2) panoramic radiographs were taken on the same machine (Instrumentarium OP 100D) in the private practice of Dr. Robert Miller. All T_1 and T_2 panoramic radiographs were coded and transferred via a digital file to a blinded author for measurement. All panoramic radiographs were hand traced and measured to the incisal edge and root apex using a digital caliper.

3.3 Results

3.3.1 Reliability

Reliability results (Table 1) (intraclass Correlation Coefficient) were generally fair-good, however when assessing tooth 22 (right permanent maxillary lateral incisor), and 3.1 (left permanent mandibular central incisor) a lower confidence interval resulted in poorer reliability.

3.3.2 Clinical Data

When assessing resorption on a per patient basis (Appendix 1) (patients were categorized as none, mild, moderate or severe based the incisor with the most severe root resorption), only one patient (1.4%, 1 Xbow) had no resorption. Approximately 33% of patients (32.9%, 10 Forsus, 13 Xbow) experience mild resorption and approximately 30% (12 Forsus, 9 Xbow) experienced moderate root resorption. Finally 35.7% (10 Forsus, 15 Xbow) of patients experienced severe root resorption. Of the 25 cases where the patient had at least once incisor with severe resorption, 80% of those cases involved the mandibular arch, whereas the maxillary arch was affected in 40% of the cases.

When assessing resorption on a per tooth basis (Table 2, Appendix 2), 34.5% experienced no resorption, while 45.2% experienced mild resorption (3mm or less), 9.3% experienced moderate resorption (>3mm to 4mm) and 11% of teeth experienced severe resorption (>4mm). In cases with severe root resorption, the mandibular incisors appeared to be more affected (62.3%) than the maxillary incisors (37.7%).

When comparing root resorption between Forsus and Xbow, of the teeth that experienced no resorption 43.8% were treated with Forsus whereas 56.2% were treated with Xbow. In teeth that experience mild resorption, 41.7% were treated with Forsus and 58.3% were treated with Xbow. In teeth that experienced moderate resorption, 67.3% were treated with Forsus, and 32.7% were treated with Xbow. Finally, of the severely resorbed teeth, 42.9% were treated with Forsus and 50.8% were treated with Xbow. Ultimately, using the statistical test, multiple analysis of variance (MANOVA) there was no difference noted in terms of root resorption for patients treated with either the forsus or Xbow (p=0.412).

3.4 Discussion

3.4.1 Reliability

Generally, reliability results (Table 1) using ICC were generally fair-good, however when assessing tooth 22 (right permanent maxillary lateral incisor), and 3.1 (left permanent mandibular central incisor) a lower confidence interval resulted in poorer reliability. It is interesting that measurements of 2 teeth on the left side of the face produced poorer reliability. It is possible that this error is due to natural wiring of the brain. Normally, the right brain hemisphere is responsible for processing visual imagery and the left side for logic, language and exact computations.

3.4.2 Clinical Data

Prevalence of incisor root resorption can be reported per patient or per tooth. Based on the literature available (Systematic Review – Chapter 2), when calculating root resorption per patient, resorption ranged between 65.6 and 98.1% whereas on a per tooth basis, resorption ranged between 72.9 and 94.2%. In this study, the results are similar with the prevalence of root resorption ranging between 65.3% (per tooth) and 98.6% (per patient) for patients treated via non-extraction therapy using either the forsus or Xbow. Furthermore, there was no difference in the severity of root resorption for patients treated with either the Forsus or Xbow (p=0.412).

In a recent systematic review of root resorption in treated patients with Class II Division I malocclusion (Chapter 2), the majority of treated incisors experienced mild-moderate resorption. In this study, 34.7% of incisors experienced no root resorption, while the majority (54.5%) of the incisors experienced mild-moderate resorption while undergoing correction of their malocclusion with either the Forsus or Xbow appliance. Severe resorption exceeding 4mm, often classified as loss of more than a third of the original root length, has been reported in the literature to range between 1-10% of treated teeth[5,7,11,13-15]. In this study, 11% of treated incisors were reported to have a root shortening of greater than 4mm. Of the 25 patients who experienced at least 1 tooth with severe root resorption, 80% of them involved the mandibular incisor. Furthermore, of the 61 reported teeth with severe root resorption following treatment, 62.3% of the affected teeth were reported for the mandibular incisors.

Orthodontic camouflage of a Class II Division I malocclusion often requires proclination (increased angulation) of the mandibular incisors. It is speculated that there is a relationship between increased angulation of the incisor in relation to a shorter tooth length being measured on a panoramic radiograph (Figure 3). In this study, over the course of camouflaging the malocclusion it is thought that the increase in reported root resorption with mandibular incisors may be due increase in mandibular incisor angulation. It is also important to note that assessment of RR using panoramic imaging has been reported to be overestimated 20% or more. To date there has been no study that has specifically assessed the relationship between incisor angulation and perceived root resorption.

3.5 Conclusions

1. No resorption was reported for 34.7% of treated incisors
2. Mild resorption was reported in 45.2% of treated incisors
3. Moderate resorption was reported in 9.3% of treated incisors
4. Severe resorption was reported in 11% of treated incisors
5. Of the 25 Severe Cases (20/25 Found in Md Arch) = 80%
6. Severe Resorption - 62.3% of incisors was reported in Md

3.6 References

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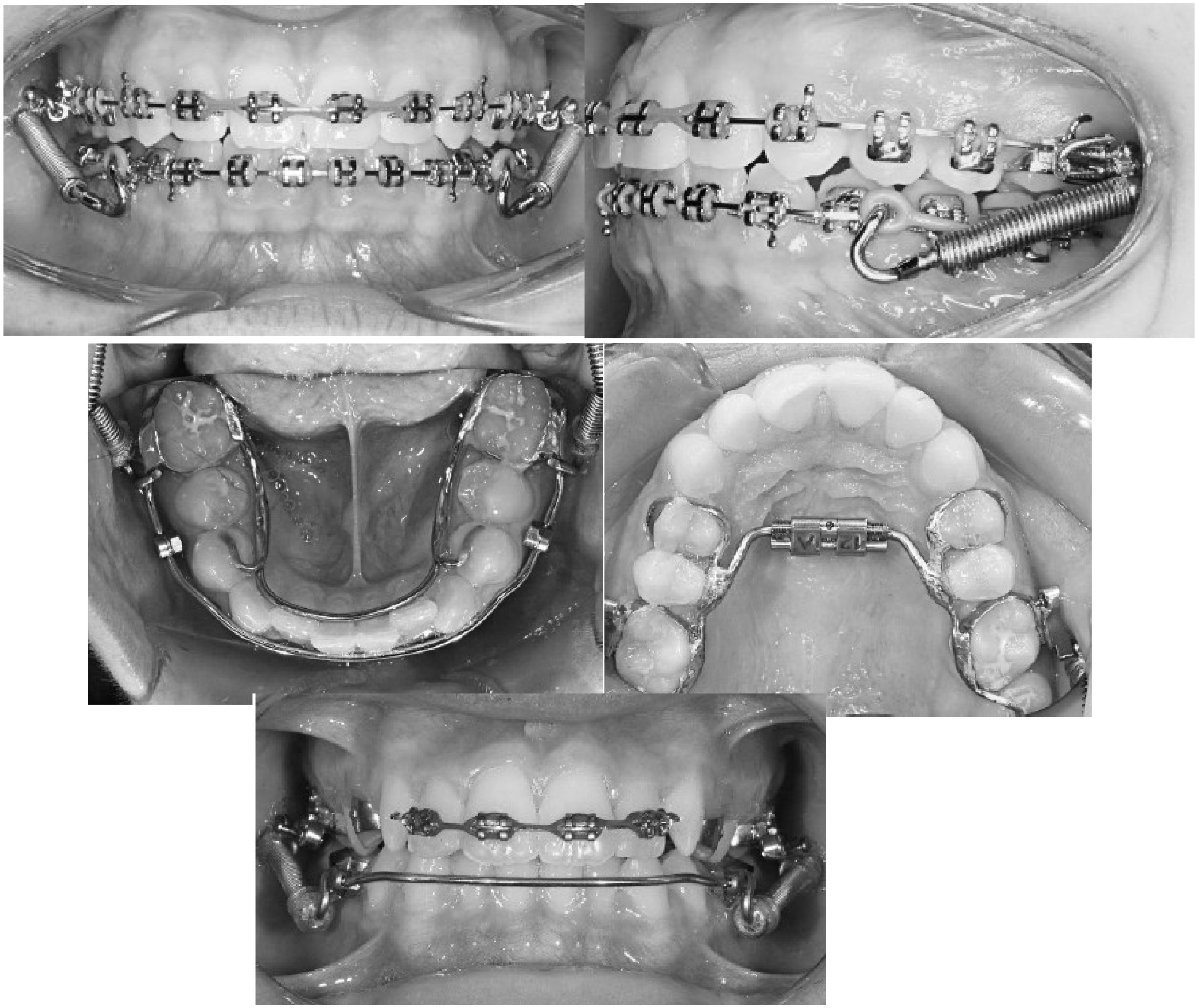

Figure - 1 - Left side: Forsus connected to the archwire (lateral view). Right side: Forsus connected to the archwire (frontal view).

Figure - 2 - Upper Left: Xbow mandibular occlusal view of a lingual arch and labial rail to support the pushrod and the forsus spring. Upper left: Xbow maxillary occlusal with rapid palatal expander connected to the headgear tube. Bottom: Xbow with brackets on maxillary anterior teeth to decompensate incisors during class II correction.

Tooth	ICC [95% CI]	Reliability
12	**0.847 [0.625-0.955]**	**Fair-Good**
11	**0.828 [0.588-0.949]**	**Fair-Good**
21	**0.888 [0.712-0.968]**	**Fair-Good**
22	**0.606 [0.235-0.868]**	**Poor**
32	**0.862 [0.657-0.960]**	**Fair-Good**
31	**0.704 [0.373-0.907]**	**Poor**
41	**0.754 [0.453-0.925]**	**Fair-Good**
42	**0.807 [0.548-0.943]**	**Fair-Good**

Table. 1 - Intra-Class Correlation Coefficient measuring root lengths from Panoramic Radiograph (Model: Two-Way Mixed, Type: Consistency)

Root Resorption Severity	# of Teeth	Tx Type	Mx Central Incisor	Mx Lateral Incisor	Md Central Incisor	Md Lateral Incisor
None	**192/557 (34.5%)**	**Forsus (43.75%) 84/192**	**25**	**30**	**14**	**15**
		X-Bow (56.25%) 108/192	**31**	**25**	**28**	**24**
Mild (3mm or less)	**252/557 (45.2%)**	**Forsus (41.7%) 105/252**	**28**	**21**	**29**	**27**
		X-Bow (58.3%) 147/252	**32**	**42**	**34**	**39**
Moderate (>3mm to 4mm)	**52/557 (9.3%)**	**Forsus (67.3%) 35/52**	**6**	**8**	**13**	**8**
		X-Bow (32.7%) 17/52	**4**	**3**	**5**	**5**
Severe (>4mm)	**61/557 (11%)**	**Forsus (49.2%) 30/61**	**5**	**3**	**8**	**14**
		X-Bow (50.8%) 31/61	**9**	**6**	**9**	**7**
Total	**557**		**140/557 25.1%**	**138/557 24.8%**	**140/557 25.1%**	**139/557 25.0%**

Table. 2 - Resorption (per tooth basis)

Appendix 1. Resorption (on per patient basis) (at least one Incisor with resorption)

1. None - 1/70 (1.4%); (1 X-Bow)
2. Mild (3 or less mm resorption) – 23/70 (32.9%); (10 Forsus: 13 X-Bow)
3. Moderate (>3mm and less than 4mm) – 21/70 (30%); (12 Forsus: 9 X-Bow)
4. Severe (>4mm) – 25/70 (35.7%)- (10 Forsus: 15 X-Bow)
5. Of the 25 Severe Cases (20/25 Found in Md Arch) = 80%
6. Of the 25 Severe Cases (10/25 Found in Mx Arch) = 40%

Appendix 2 – Root resorption (per tooth)

1. No Resorption (192/557) was reported in 34.7% of treated incisors
    a. 111/192 (57.8%) was reported in Mx Incisors
    b. 81/192 (42.2%) was reported in Md Incisors
2. Mild Resorption (252/557) was reported in 45.2% of treated Incisors
    a. 123/252 (48.8%) was reported in Mx Incisors
    b. 129/252 (51.2%) was reported in Md Incisors
3. Moderate Resorption (52/557) was reported in 9.3% of treated Incisors
    a. 21/52 (40.4%) was reported in Mx Incisors
    b. 31/52 (59.6%) was reported in Md Incisors
4. Severe Resorption (61/557) was reported in 11% of treated Incisors
    a. 23/61 (37.7%) was reported in Mx Incisors
    b. 38/61 (62.3%) was reported in Md Incisors

Chapter 4 – Root Changes to Incisor Anteroposterior Angulation during Correction of Class II Malocclusion: Impact on Perceived Root Resorption as Analyzed from Conventional Panoramic Radiograph

4.1 Introduction

Traditionally, orthodontic records consist of 2D radiographs using panoramic and/or cephalometric radiographs for diagnosis and treatment planning[1]. Clinicians often assess whether resorptive changes in teeth undergoing orthodontic treatment are occurring using these 2D radiographs. Panoramic radiographs are not likely able to accurately differentiate between early resorption and normal root length, so in cases of suspected root resorption, one may expect the degree of resorption to be more advanced and as a result, further imaging using periapical radiographs may be prescribed to better evaluate the severity of resorption. Assessment of root resorption using 2D radiographs must be done with caution as the radiographic image is often affected by distortion in root angulation[2] and magnification[3].

A thorough radiographic examination is part of the diagnostic process in orthodontics. In orthodontics, a lateral cephalometric film and panoramic film are routinely ordered as the primary pretreatment radiographs[4]. In past cases of trauma, periapical imaging may also be taken for pre-treatment assessment.

A lateral cephalometric radiograph provides an image of the length of the incisors and its angulation, however superimposition of one side on the other and magnification of 5-12% make it not ideal for assessment of root resorption in orthodontics. A panoramic film effectively displays, both the maxillary and mandibular arches as well as supporting structures in one convenient image. The quality of the generated image on a panoramic radiograph, relies on a focus section, or focal trough that is similar in shape to a dental arch and resembles a 3D horseshoe shape[5]. In order to obtain the best image on the panoramic image, the important structures need to be within the focal trough. Consequently, it is recommended that the patient be aligned so that the Frankfort plane is parallel to the floor[6]. Inevitably, important structures such as maxillary and mandibular incisors may end up being situated outside the plane of focus (focal trough), resulting in the structure being distorted or obscured in the radiographic image[7]. The focal trough (Figure 1) is often narrow in the incisor region and sometimes causes the apices and palatal structures to be out of focus or invisible[5]. In orthodontic camouflage of mild-moderate class II cases, mandibular incisors may become excessively proclined leading to foreshortening of the roots in the radiographic image[5] (Figure 2). In addition, it also possible that if the teeth are positioned outside of the focal trough this may also lead to foreshortening and can results in a distorted image of the incisors. By developing an appreciation for the amount of foreshortening that may occur due to incisor angulation, clinicians may be better able to recognize cases of true root resorption vs. cases of foreshortening.

Given the inherent limitations of panoramic films, supplemental periapical imaging maybe taken to better assess questionable teeth. Many general dentists regard root resorption as being avoidable and often hold orthodontists accountable[8] so it is important for orthodontists to identify risk factors that contribute to root resorption early so that the potential impact of this problem is reduced.

The objectives of this study are to measure the effects of angular changes of incisors on a rapid prototyping (RP) tooth model and the resulting length of tooth produced on the panoramic image.

4.2 Materials and Methods

Two titanium beads (Abbott Ball Company, West Hartford, CT) were placed on a rapid prototyping model of the maxillary and mandibular incisors at the apical edge and incisal edge. The maxillary and mandibular arches were fit into a special holding device and maxillary and mandibular incisor segments of various angulations were fitted to their respective arches using a lock and key type of jig (Figure 3). Panoramic imaging (Sirona Orthophos XG) (Figure 4) was acquired using the same machine (from the University of Alberta) and the image was stored in Dolphin Imaging™ (Chatsworth, CA). The panoramic images were then hand traced and measured using a digital caliper. The length was measured from the mid-point of the bead on the incisal edge to the mid-point of the bead on the apical edge. This value was compared to the known length, measured from incisal bead to apical bead on the rapid prototyping model minus the diameter of one bead. Using a length of wire of known size, this value was compared in all images to correct for image magnification. To account for magnification, the length of the tooth was calculated as followed: (Actual Length of calibration wire / Measured Length of calibration wire on radiograph) * Length of tooth on radiograph).

4.3 Results

In this study, as the mandibular incisor angulation changed from ideal, it was noted that the perceived length of the tooth appeared shorter. As the angulation of the maxillary and mandibular incisors was changed from approximately 90°, it was expected that the perceived tooth lengths on the panoramic radiograph would appear shorter (figure 5). The amount of apparent root resorption for the mandibular incisors coincided with the theoretical model for predicting the change in perceived tooth length due to the calculated change in angulation (Table 1).

On the other hand, the data for the maxillary incisors were not as easy to interpret (Table 1). When the maxillary incisors were positioned approximately 50°, 60° and 70°, the measured tooth length appeared larger than what was expected when compared to the theoretical model. When the maxillary incisors were approximately 80° and 90° the length was roughly similar to the theoretical model. Interestingly, when the maxillary incisors were angulated at approximately 100° and 110°, the tooth length appears shorter than expected when compared to the theoretical model.

4.4 Discussion

Ideally in order to obtain a dimensionally accurate radiographic image of the maxillary and mandibular incisors, the teeth and receptor film should be parallel and in contact with the x-ray beam meeting perpendicular to this. In reality, this ideal is unattainable, and thus dimensional accuracy of panoramic radiography is often impossible. With this in mind, magnification has been reported to range between 14-26%[9,10], however, in this study, magnification ranged between 27.5-29.3%.

The perceived tooth length appears to be the longest when the actual tooth is as close to parallel to the receptor film as possible. In this study, the tooth appeared the longest when the maxillary central incisor and lateral incisor were at 89.8° and 92.3° degrees relative to the true horizontal that was parallel to the floor. On the mandibular arch, the central and lateral incisors were the longest when it was situated 90.5° and 90.2° relative to the horizontal that was parallel to the floor. As the angulation of the maxillary and mandibular incisors was changed from the above mentioned angles for each specific tooth, it was expected that the perceived tooth lengths on the panoramic radiograph would appear shorter (figure 5).

In this experimental study, as the mandibular incisor angulation changed from ideal, the resulting panoramic radiograph showed a shortening of the mandibular incisors even though in reality, the length of the incisors did not change. The amount of 'apparent' root resorption coincided with the theoretical model for predicting the change in tooth length due to the change in the tooth's angulation. The fact that the measured length was similar to the predicted length using the angular projection model, suggests that although the lower incisors procline over the course of treatment, the tooth appears to stay within the focal trough during radiographic imaging. This finding reinforces to clinicians that incisor angulation can alter the panoramic image perceived root length and in the camouflage of Class II malocclusions, the mandibular incisors may appear shorter than they really are.

Unfortunately, the data for the maxillary incisor was not easy to interpret. When the incisors were significantly under torqued (50°, 60° and 70°), the teeth appeared larger than expected on the panoramic radiograph. When the maxillary incisors were approximately 80° and 90° the length was roughly similar to the theoretical model. When the maxillary incisors were angulated approximately 100° and 110°, the tooth length appeared shorter than expected length based on the theoretical model. It is speculated that the differences observed with the maxillary incisors and mandibular incisors may be due to the fact that the changes in angulation have a greater impact on the object to receptor film distance on the larger maxillary teeth than the smaller mandibular incisor teeth (Figure 6). When the maxillary incisors are more upright, it is speculated that the tooth film distance is increased thus resulting in the magnification observed. When the maxillary incisors are 80-90°, it is speculated that the tooth film distance is ideal, and as a result, there is no magnification and the image produced is similar to the theoretical model. When the maxillary incisors are angulated approximately 100° and 110°, the tooth length appeared shorter. It is speculated that at this angle, the tooth may be out of the focal trough, resulting in a foreshortening of the incisors that is greater than what was predicted based on angular changes. Interestingly, the mandibular incisors were not affected by this. It is quite possible that the mandibular incisors were situated within the focal trough for this experiment and thus did not experience what was observed for the maxillary incisors. Furthermore, it might also be possible that since the lower incisors are smaller teeth, large changes to the tooth in a buccolingual direction does not affect its position within the focal trough, whereas larger sized teeth like the maxillary incisors are more likely to move out of the focal trough even though the movements are minor.

Following non-extraction treatment of mild to moderate class II malocclusions, it is expected that the lower incisors will procline in order to camouflage the malocclusion. In this study (Chapter 3), approximately 36% of patients or 11% of incisors developed severe root resorption following camouflage treatment. The majority of these cases were found on the lower arch affecting the mandibular incisors. This study using RP models to evaluate proclination and 'apparent' root resorption provides weak evidence to support the idea that the increased number of severe root resorption of mandibular incisors may be due to proclination rather than true RR. As the lower incisors are proclined 10° above the ideal, the lower incisors will appear roughly 1.4% shorter (Table 2). As the lower incisors are proclined 20°, 30°, 40° and 50° above ideal, the lower incisors will appear roughly 6.3%, 13.4%, 23.7% and 34.6% shorter due to increased angulation (Table 4). While proclination can lead to foreshortening of the roots, in reality, the lower incisors will procline less than 20° following treatment. Proclination at this angle explains at most a 6.3% reduction in root length.

4.5 Limitations

This study attempted to account for magnification by placing a calibration wire of known length onto the RP model. Future studies may be better off designing grooves onto the RP model where the titanium beads can be affixed onto its surface with a known fixed distance on both the Mx and Md components. This may eliminate problems of the wire debonding from the model and minimizes potential errors caused by the wire bending. In addition, this can better account for imaging differences between arches given the narrow focal trough in the anterior. Finally, the grooves on the apical and incisal edges of the models should be made larger to better accommodate the titanium beads and to minimize errors in affixing this onto the model.

4.6 Conclusions

1. Changes to mandibular incisor angulation results in an increase of "apparent" root resorption on a panoramic radiograph
    a. As the lower incisors are proclined 10° above the ideal, the lower incisors will appear roughly 1.4% shorter.
    b. As the lower incisors are proclined 20° above the ideal, the lower incisors will appear roughly 6.3% shorter.
    c. As the lower incisors are proclined 30° above the ideal, the lower incisors will appear roughly 13.4% shorter.
    d. As the lower incisors are proclined 40° above the ideal, the lower incisors will appear roughly 23.7% shorter.
    e. As the lower incisors are proclined 50° above the ideal, the lower incisors will appear roughly 34.6% shorter.

4.7 References

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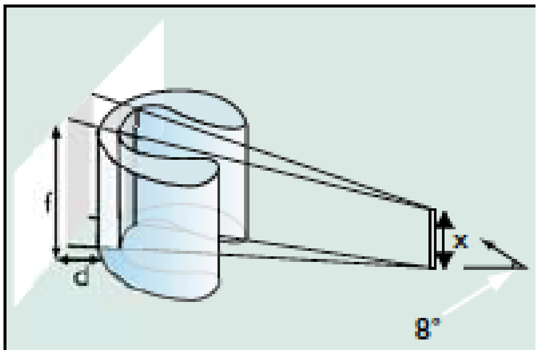

Figure. 1 - Adapted from Leach et al.[51] Diagram showing horseshoe-shaped focal trough with x-ray beam aimed upwards at 8 degrees.

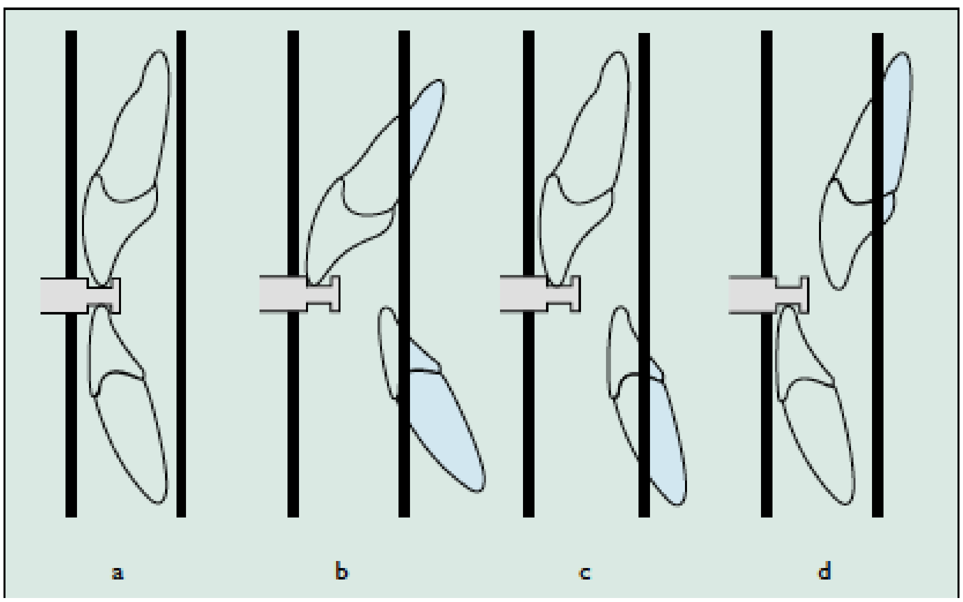

Figure. 2 - Adapted from Leach et al.[51] Diagram showing the vertical walls of the focal trough in the incisor region and the relative positions of teeth with different underlying dental or skeletal abnormalities. A. Class I skeletal B Class II Division I malocclusion C. Class II Skeletal D. Class III Skeletal. (blue parts are parts of teeth outside focal trough will be blurred and out of focus on film).

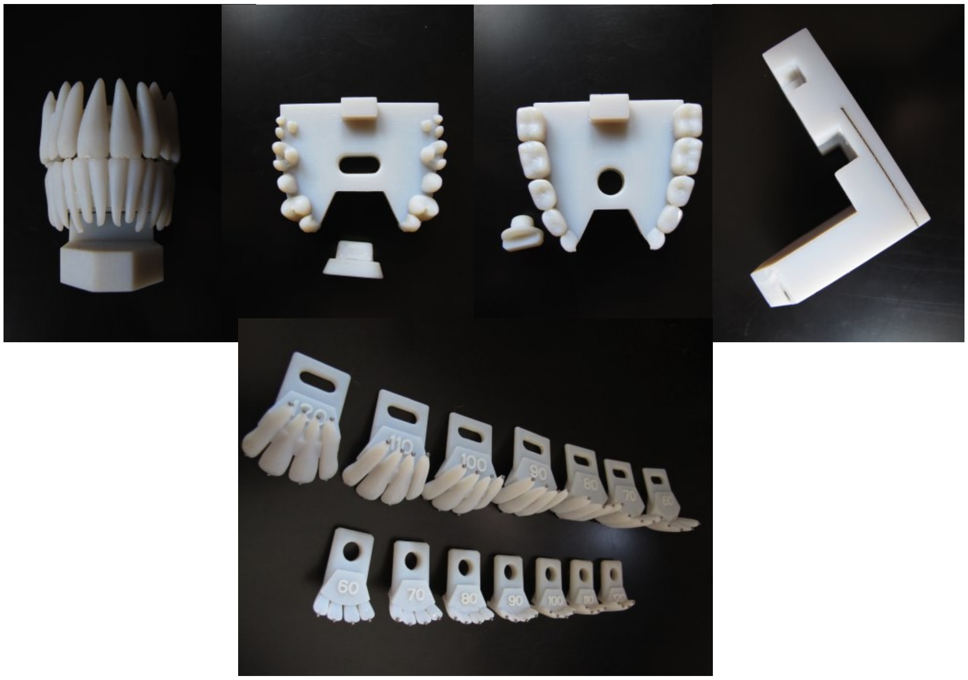

Figure. 3 - Rapid prototyping Model. (top left to right). First image – RP model with Mx and Md jigs attached. Second image – Mx jig. Third image – Md jig. Fourth Image – Base where Mx and Md jigs attach with guide wire for reference. Bottom Image – Inserts of Mx and Md incisors at different angulations.

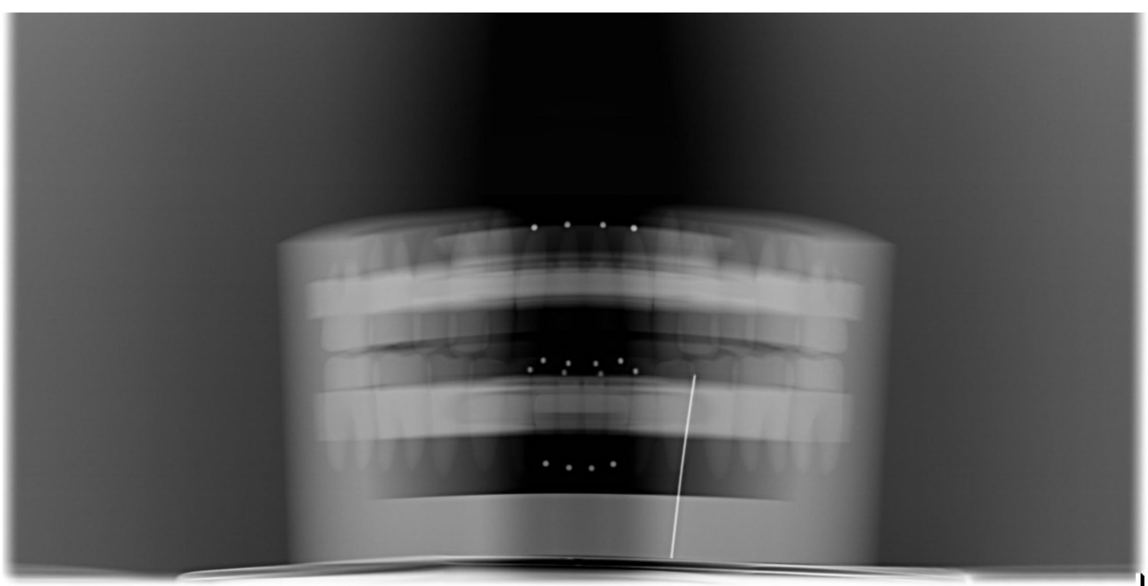

Figure. 4 - Panoramic image of RP model with Mx and Md jigs in place.

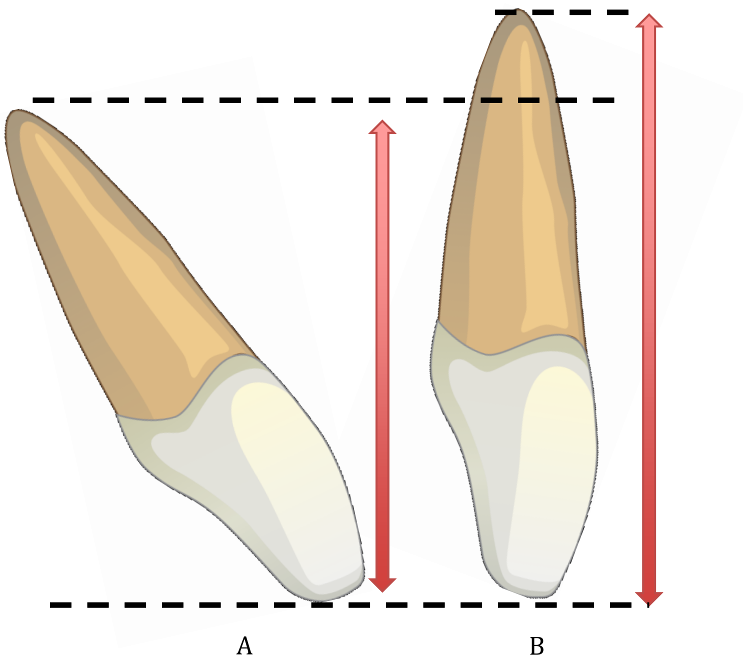

Figure. 5 - Projected Tooth Length. Teeth A and B are the same length, however the projected tooth size (red arrow) for A and B are different due to tooth's angulation.

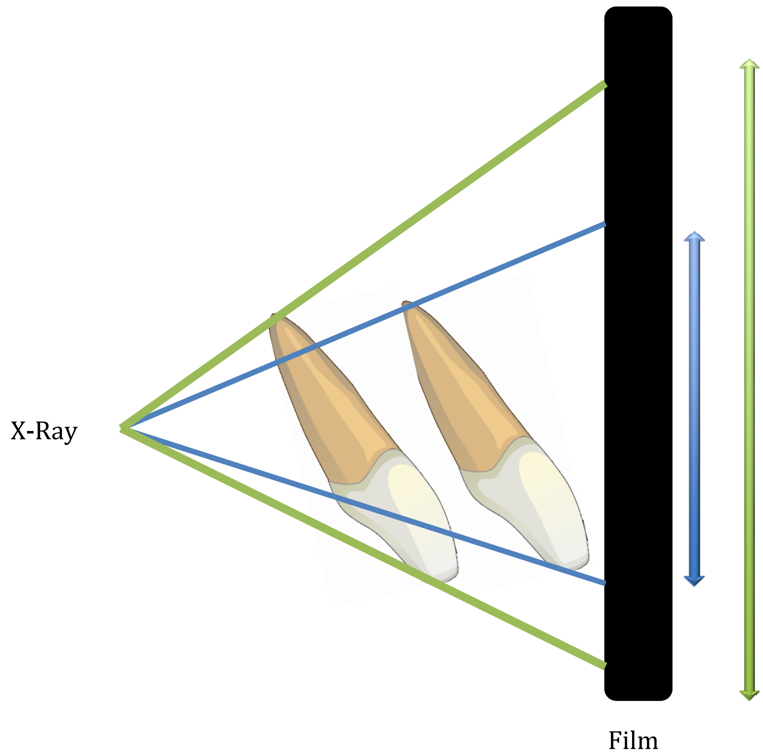

Figure. 6 - Object-Film Distance and Impact on Tooth Size. Both teeth are the same length, however the tooth with the shorter tooth-film distance is less magnified (blue arrow) than the tooth with increased tooth-film distance (green arrow).

Mx CI Angulation	Mx LI Angulation	**12 (mm)**	**11 (mm)**	**21 (mm)**	**22 (mm)**
49.8	52.3	2.94	4.28	4.82	2.97
59.8	62.3	2.11	3.30	2.99	1.81
69.8	72.3	0.90	1.41	1.33	0.91
79.8	82.3	0.43	0.44	0.60	0.40
89.8	92.3	-0.41	-0.59	-0.50	-0.11
99.8	102.3	-1.03	-1.55	-1.49	-0.80
109.8	112.3	-1.36	-3.02	-3.10	-2.07
Md CI Angulation	Md LI Angulation	42 (mm)	41 (mm)	31 (mm)	32 (mm)
140.5	140.2	-0.73	-0.07	-0.74	0.10
130.5	130.2	0.23	0.37	0.03	0.26
120.5	120.2	0.70	0.06	0.49	0.16
110.5	110.2	0.08	-0.05	0.04	0.04
100.5	100.2	0.25	0.05	-0.16	0.40
90.5	90.2	0.88	0.26	0.70	0.08
80.5	80.2	0.48	0.47	0.50	0.052

Table - 1 - Measured Compared to Theoretical Lengths of Teeth from Rapid Prototype Models after Adjusting for Magnification (Corrected Tooth Length – Theoretical)

Mx CI Angulation	Mx LI Angulation	**12 (mm)**	**11 (mm)**	**21 (mm)**	**22 (mm)**
49.8	52.3	20.70	20.97	20.94	20.92
59.8	62.3	22.94	23.58	23.70	23.17
69.8	72.3	25.26	26.12	25.73	24.96
79.8	82.3	26.04	27.52	27.15	26.10
89.8	92.3	26.37	27.54	27.53	26.22
99.8	102.3	26.07	27.41	27.41	25.78
109.8	112.3	24.31	25.95	25.80	24.60
Md CI Angulation	Md LI Angulation	42 (mm)	41 (mm)	31 (mm)	32 (mm)
140.5	140.2	12.99	12.99	13.07	13.03
130.5	130.2	15.17	15.57	15.44	15.36
120.5	120.2	17.20	17.59	17.36	17.35
110.5	110.2	18.61	19.01	18.99	18.73
100.5	100.2	19.60	19.80	19.97	19.59
90.5	90.2	19.87	20.50	20.19	20.03
80.5	80.2	19.74	19.94	20.39	19.59

Table - 2 - Theoretical Lengths of Teeth from RP Models after Adjusting for Magnification

Chapter 5 - Comparison of Two Compliance-Free Class II Correction Protocols for the Non-Extraction Treatment of Mild to Moderate Class II Malocclusion

5.1 Abstract

Objective: To compare the efficiency of two compliance-free class II correction protocols for the treatment of mild to moderate class II malocclusions.

Materials and Methods: A total of 72 consecutively treated class II malocclusion patients were analyzed. From them 38 patients were treated with an Xbow appliance followed by full edgewise brackets, whereas 34 patients were treated with a Forsus appliance connected to the archwire while in full edgewise brackets. Evaluated cephalometric variables were Overjet, Overbite, Skeletal Class II (ANB), Lower Incisor Angulation (L1MP), Upper Incisor Angulation (U1PP), and growth direction (Y-Axis). Additional factors that were also considered included: sex, treatment type, months in active class II treatment. Statistically, independent t-test, intra-rater correlation coefficient, and repeated measures multiple analysis of variance (MANOVA) was used.

Results: Treatment time with Xbow was approximately 6 months shorter than with Forsus (p=0.037). No difference in incisor angulation was identified. No differences was found in terms of sex and treatment type in the overall pattern of cephalometric variables. There was convincing evidence of a significant difference in overbite (1.79mm, p=0.019), growth direction (Y-Axis, increased 1.3 degrees, p=0.015) when measured over time. There was also suggestive, but inconclusive evidence of an improvement in skeletal class II over time (ANB, increased 1.41 degrees, p=0.063).

Conclusions: Both compliance free Class II correction protocols for the non-extraction treatment of mild to moderate class II malocclusions appear to produce

the same clinical results and thus the decision between the Forsus or Xbow appliance may be a practice management decision.

Key Words: Forsus, Xbow, Class II Correction

5.2 Introduction

Class II malocclusions affects approximately one-third of the North American population[1]. The etiology of this malocclusion often is multifactorial with dental, skeletal and/or neuromuscular components. There is no clear evidence of a treatment gold standard for non-extraction correction of this type of class II malocclusion and as a result there are numerous treatment methods suggested in the literature. Class II correctors are appliances made to improve the occlusion by a combination of skeletal and dental effects. Skeletal changes often include maxillary restriction and/or mandibular repositioning. Dental changes can include maxillary molar distalization and/or lower incisor proclination. Clinicians must be aware that the degree of incisor proclination should lie within the range that is dependent on the patient's individual biological tolerance. There is controversy concerning the amount of lower incisor proclination consistently produced by non-extraction treatment in mild to moderate class II malocclusions. Some authors [2-4] report that gingival/periodontal conditions worsen in patients who undergo incisor proclination, whereas other authors[5,6] report no association between class II mechanics and gingival recession or bone loss. Two systematic reviews[7,8] evaluated orthodontic therapy and gingival recession and it was hypothesized that a combination of thin attached gingiva, poor oral hygiene coupled with inflammation facilitates gingival recession while teeth are moved buccally.

The correction of class II malocclusions often relies on patient compliance (i.e., headgear, elastics, wearing a removable appliance), and in an attempt to minimize the need for patient cooperation and maximize the predictability of the results, many clinicians opt for compliance-free fixed class II correctors. In many clinics, the use of compliance-free fixed class II correctors provide predictable results and thus, are used in all types of patients and are not limited to only the non-compliant patients. A systematic review[9] assessing changes from Herbst therapy, found that dental changes were more significant than skeletal changes in the final treatment results. There are many appliance systems available that are used to correct a non-extraction Class II malocclusion using dental anchorage, however the resulting side effect reported is often lower incisor proclination.

The Fatigue Resistant Device, commonly referred to by its trade name, 'Forsus', is developed by 3M Unitek (3M Unitek, Monrovia, California). This fixed functional class II corrector is used to correct the malocclusion while the patient is using full edgewise appliances. This appliance consists of a push rod and an inter-arch coil spring attached to the upper molar with either an L-pin module or an EZ module (Figure 1). When fully compressed, the spring force is approximately 200g.

An additional use of the Forsus is as a part of an Xbow appliance (figure 2) (pronounced 'crossbow'). The Xbow typically consists of a maxillary expander (hyrax type), mandibular (lingual and labial arches) rigid frame, connected together using the Forsus springs. This appliance is a fixed functional class II corrector that is used in the late mixed or early permanent dentition to correct the malocclusion before the initiation of full edgewise appliance.

The objective of this study was to compare both compliance-free class II correction appliances (Forsus and Xbow), for the treatment of mild to moderate class II malocclusions and assess if treatment length and the amount of lower incisor proclination following treatment differed. In addition, this study also assessed eight cephalometric variables (overjet, overbite, ANB, L1MP, U1PP, SnAr, YAxis and FMA) of interest considered simultaneously over time and see if sex (M/F), and/or treatment type (Forsus/X-bow) differed significantly.

The hypothesis of this study was that there is no difference in terms of sex (M/F) and/or treatment type (Forsus/X-bow) over time to correct class II malocclusion when eight cephalometric variables (overjet, overbite, ANB, L1MP, U1PP, SnAr, YAxis and FMA) are considered simultaneously over time. In addition, no difference is expected in terms of treatment length between the two treatment types and the overall amount of lower incisor proclination.

5.3 Materials and Methods

The Human Ethics Research Office at the University of Alberta granted authorization (Pro00023805) for this retrospective study. The sample was obtained from a private practice of Dr. Robert Miller (Culpepper, VA), and consisted of 40 consecutively treated patients using either the Forsus or Xbow protocol (FO or XB respectively) (Skeletal Class II: Mean ANB of Study Group 4.64, Standard Deviation 1.923, Range 0-8). A total of 6 patients were excluded due to incomplete records (4 from FO, 2 from XB) and 2 due to poor records (2 Forsus), reducing the total sample size in this study to 72 (34 FO, 38 XB).

The treatment protocol consisted of using the Xbow followed by full edgewise appliance or a Forsus used in combination with full edgewise appliance for the non-extraction treatment of mild to moderate Class II malocclusions. Both groups used the same brackets (0.022 inch slot, -6° torque in the lower incisors) and in patients treated with the Forsus appliance, the clinician inserted in 0.019x0.025 inch stainless steel archwire before inserting the Forsus appliance. Once 2-3mm of class III overcorrection at the molar level was obtained, the Forsus was removed and intraoral elastics were used as needed. For the Xbow patients, the class II malocclusion was over corrected into a full molar class III occlusion. Forsus springs were then removed and the patient was followed over a course of 2-4 months to allow relapse to occur. During this time, there was no active class II mechanics used. Following the relapse period, full edgewise appliance was used and intra-oral elastics were used as needed. Both groups were finished with the same occlusal finishing and esthetic objectives as determined by the treating orthodontist.

Pre-treatment (T_1; taken prior to appliance placement) and post-treatment (T_2; 6-8 weeks after removal of fixed appliance) lateral cephalometric radiographs were taken on the same cephalometric machine (Instrumentarium OP 100D). All T_1 and T_2 cephalometric radiographs were coded and transferred via a digital file to a blinded author for measurement. All cephalometric radiographs were digitally traced using Dolphin Imaging™ (Chatsworth, CA) with a customized analysis measuring the eight variables (overjet, overbite, ANB, L1MP, U1PP, SnAr, YAxis and FMA).

5.3.1 Statistics

A reliability study was done whereby a randomly selected sample of 10 radiographs was traced three times with a week between tracings. An independent Student's t-test was used to determine if treatment length (number of months in orthodontic treatment) were different based on treatment group.

Repeated measure multiple analysis of covariance (rMANCOVA) was used to assess the differences over time with the within subject cephalometric variables (OB, OJ, ANB, L1MP, U1PP, SnAr, YAxis, FMA), the between subject (sex, treatment type) and the covariates (Months in Forsus or Xbow, Months with class II elastics, Months in total class II correction). Before starting with the rMANCOVA, model assumptions of independence, sphericity, multivariate normality, homogeneity of variance, and homogeneity of covariance matrices were assessed. Assumptions were met for independence (independent samples), sphericity (assumption didn't apply since there were only 2 time point measurements) and multivariate normality. Looking at the bivariate plots, there was no obvious curved relationship which suggested normal distribution. Looking at the 3D scatter plot, the data groups appear to have an ellipsoid-like distribution also suggesting multivariate normal distribution. Assumption was not met for homogeneity of variance and covariance matrices, however since the sample sizes of the 4 categories (Female Xbow (24); Female Forsus (17), Male Xbow (14), Male Forsus (17)) are large and appear roughly equal, these tests were considered robust against departures. Univariate analysis was done to follow up any significant rMANCOVA finding.

5.4 Results

Reliability results (Intraclass Correlation Coefficient - ICC) were excellent, as all were higher than 0.928 (Table 1).

Using the Independent t-test to assess treatment length between the Xbow and Forsus treatment groups, the treatment time was approximately 6 months shorter with the XB group than the FO group (p=0.037; Table 2; based on difference between records). Interestingly, when assessing treatment time (not accounting for relapse period for XB) with fixed edgewise appliance, the average difference was more than 10 months between the FO and XB groups (26.75 months FO vs. 16.68 months in the XB).

As expected the lower incisors proclined in both treatment groups, without the change being statistically significant between the two groups (Table 3). The lower incisors proclined approximately the same degree (FO 3.4° vs. XB 4.8°) with similar variability (standard deviation approximately 8°).

Regarding the rMANCOVA no interaction between Time*Sex*Treatment type (p=0.506) (Table 4) was found. To account for this finding, rMANCOVA was redone (Table 5) without the Time*Sex*Treatment type interaction term and was then used to assess the interactions between Sex*Treatment time (p=0.628), Time*Sex (p=0.399), and Time*Treatment Type (p=0.821). This test found no interactions, and so the rMANCOVA was redone again (Table 6) this time with no interaction terms, but was used to assess Time, Sex and Treatment Type effects. Following this test, no significant difference was noted for sex (p=0.840) or treatment type (p=0.395), however a significant difference with time (p=0.006) was reported. A follow up univariate analysis was done to further assess which specific cephalometric measurement over time showed a significant difference (Table 7). No significant differences were reported for OJ (p=0.17), L1MP (p=0.825), U1PP (p=0.188), SNAr (p=0.135) and FMA (p=0.954). Overbite was found to have reduced by 1.79mm (p=0.019) over treatment and Y-axis was found to increase by 1.3 degrees (p=0.015) over treatment.

5.5 Discussion

There are numerous appliances that are currently available for clinicians to use when attempting to correct a non-extraction Class II malocclusion. In this study, non-extraction treatment of the mild-to-moderate class II malocclusion was corrected using inter-maxillary anchorage with either a Forsus or an Xbow appliance. All patients in this study were treated by one clinician, (Dr. Robert Miller), and all cephalometric radiographs were taken with the same machine.

The Forsus appliance is an intermaxillary push spring that consists of a push rod inserting into a telescopic cylinder that is placed near the end of treatment while the patient is undergoing comprehensive fixed orthodontic treatment. In this study, patients underwent full edgewise appliance therapy where the doctor worked up to a 0.019x0.025 inch stainless steel archwire before inserting the Forsus appliance. The appliance was kept in the mouth until 2-3mm overcorrection was obtained. Following this, the appliance was removed and patient used intraoral elastics if needed. The Forsus appliance is used while the patient is in full edgewise treatment, whereas the X-bow appliance attempts to correct the occlusion anteroposteriorly before initiation of full edgewise therapy. This appliance consists of a palatal expander, mandibular labial and lingual arch and Forsus springs.

In this study, treatment times were shorter for the XB patients, on average of 6 or 10 months. When looking at overall active treatment time, Xbow patients were in treatment 6 months less than the FO patients, however when assessing time in full edgewise brackets, XB patients were in treatment 10 months less than the FO group. The potential benefit reduce treatment time as seen in the XB patient group could be reduced patient burn out, reduced risk for white spot lesion and reduced risk of root resorption. None of these outcomes was assessed in this study.

Interestingly, although treatment with the XB was shorter compared to the FO, the lower incisor proclination after treatment was approximately the same (FO 3.4° vs. XB 4.8°) with similar variability (standard deviation approximately 8°). The amount of proclination observed in this study is similar to other published reports[8,10,11] that found an increase of 3-5° of the lower incisor following treatment with Forsus or class II elastics.

Collectively there was no evidence of a sex ($p=0.840$) or treatment type ($p=0.395$) difference in the overall pattern of cephalometric variables. When the incisor angulation was re-evaluated with rMANCOVA statistical test using the following covariates: Months in forsus or Xbow, Months in class II elastics and Months in class

II correction, it was also noted that there was no difference in the amount of incisor proclination between the two treatment options (p=0.825).

Using the same statistical analysis, it was found that over the course of treating patients with either FO or XB, there was a significant difference in overbite and direction of growth. Overbite was reduced on average by 1.79mm (p= 0.019) and the Y-Axis was found to increase by 1.3 degrees (p=0.015). Following treatment, patients in this study experienced a reduction in overbite possibly due to lower incisor intrusion and eruption of lower molars with a concomitant mandibular plane clockwise rotation. In addition, there was also suggestive but inconclusive evidence of a favourable change in ANB over time. It seems that over the course of treatment, there was some mandibular growth in these patients of approximately 1mm as previously reported by Miller et al.[12]. The amount of growth observed in this study using either FO or XB is consistent with the findings reported in a systematic review[9] assessing Herbst therapy.

Clinicians have many options when attempting to correct a mild to moderate Class II malocclusion with non-extraction. Problems with compliance or a clinician's desire for more predictable results have resulted in development and popularity of fixed class II correctors. In this study, a comparison between forsus and Xbow was made to assess either treatment modality produced different clinical results. It appears that the choice of whether to use a FO or XB does not differ in terms lower incisor proclination and ultimately this decision may depend on clinician's personal preference of correcting the class II malocclusion prior to starting full edgewise appliance or towards of the end of full edgewise treatment. The fact that treatment times were shorter for the XB patients by an average of 6-10 months depending on how time is calculated, may help reduce patient burn out, risk for white spot lesion and risk of root resorption.

5.6 Conclusions

1. Shorter Treatment Length ($p=0.037$) with Xbow (24.18 months) compared to Forsus (30.17 months) treatment protocol.

2. Both compliance-free Class II correction protocols for the treatment of mild to moderate class II malocclusion appear to generate similar degree of lower incisor proclination with large variability.

3. No evidence of a Sex ($p=0.840$) difference in the overall pattern of cephalometric variables.

4. No Evidence of a treatment type ($p=0.395$) difference in the overall pattern of cephalometric variables.

5. Convincing evidence of a Time ($p=0.006$) difference in the overall pattern of cephalometric variables.

6. Convincing evidence ($p=0.019$) that over the course of treatment OB was reduced by 1.79mm [1.66,1.92].

7. Convincing evidence ($p=0.015$) that over the course of treatment Y-Axis increased 1.3° [1.24,1.33].

5.7 References

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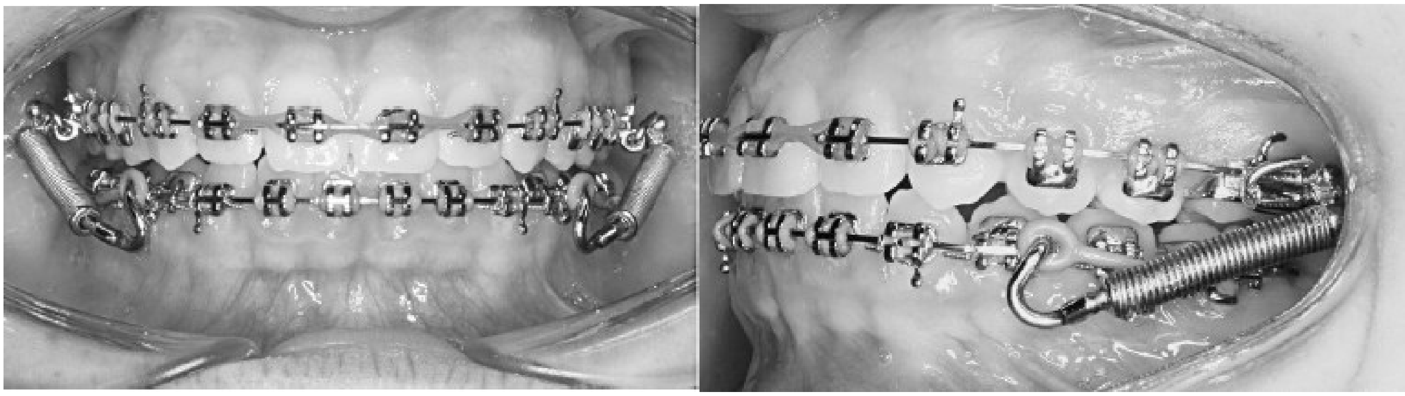

Figure . 1 - Left side: Forsus connected to the archwire (lateral view). Right side: Forsus connected to the archwire (frontal view).

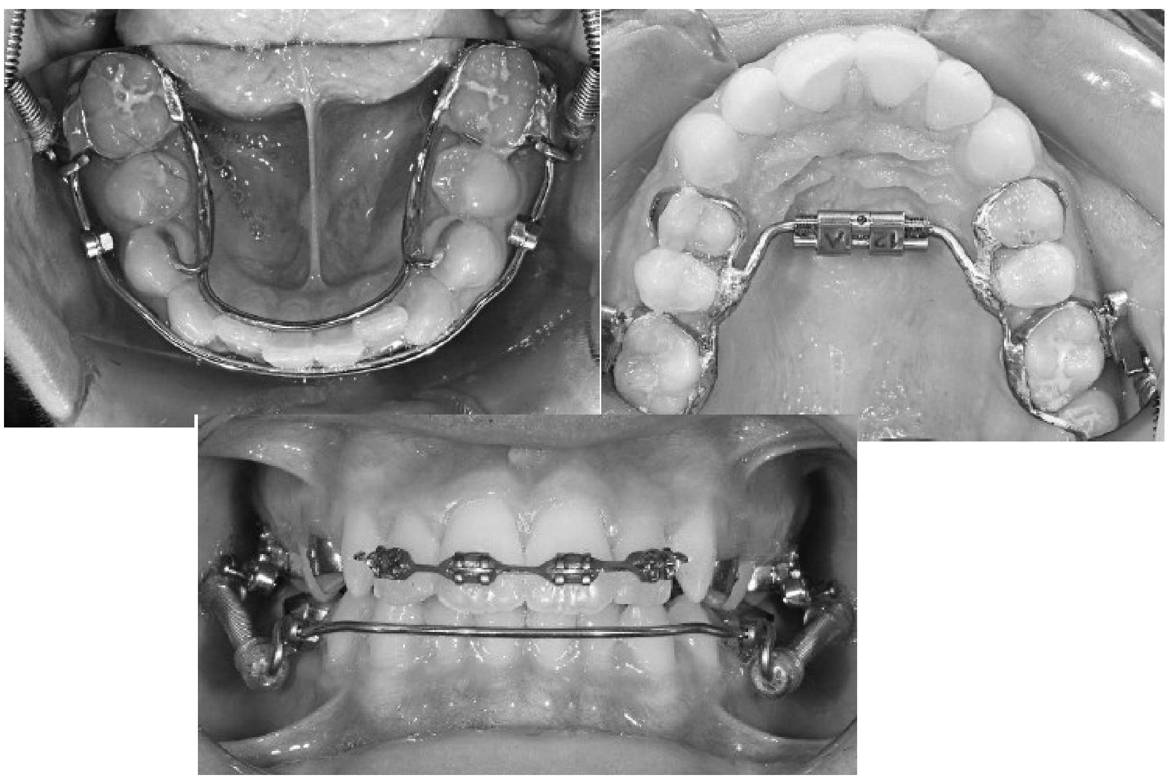

Figure . 2 - Upper Left: Xbow mandibular occlusal view of a lingual arch and labial rail to support the pushrod and the forsus spring. Upper left: Xbow maxillary occlusal with rapid palatal expander connected to the headgear tube. Bottom: Xbow with brackets on maxillary anterior teeth to decompensate incisors during class II correction.

(Model: Two-Way Mixed, Type: Consistency)

Tooth	ICC	Reliability
OB	**0.928 [0.808-0.980]**	**Excellent**
OJ	**0.950 [0.862-0.986]**	**Excellent**
ANB	**0.933 [0.820-0.981]**	**Excellent**
L1MP	**0.952 [0.867-0.987]**	**Excellent**
U1PP	**0.939 [0.835-0.983]**	**Excellent**
Y-Axis	**0.968 [0.909-0.991]**	**Excellent**
SnAr	**0.937 [0.829-0.982]**	**Excellent**
FMA	**0.949 [0.859-0.986]**	**Excellent**

Table- 1 - ICC of Variables of Interest from Cephalogram

Treatment Type	**Treatment Length (months)**	**Standard Deviation**	**Significance**
Forsus	30.17	7.66	0.037
Xbow	24.18	5.26	

Table- 2 - Independent t-Test of Treatment Length between Xbow appliance and Full Brackets and Forsus Connected to Archwire While in Full Brackets

Cephalometric Variables	**Forsus**			**Xbow**		
	T1 Mean (SD)	S2Mean (SD)	T2-T1 Mean (SD)	T1 Mean (SD)	S2Mean (SD)	T2-T1 Mean (SD)
L1MP	94.75 (7.64)	98.14 (8.89)	3.39 (7.69)	95.55 (7.95)	100.36 (6.51)	4.80 (8.34)

Table- 3 - Lower incisor angulation (L1MP) of Pre-treatment (T_1) and Post-treatment (T_2) and T_2-T_1 in both Treatment Groups.

	P-Value
Time	0.006
Sex	0.840
TxType	0.395
Sex*TxType	0.628
Time*Sex	0.399
Time*TxType	0.821
Time*Sex*TxType	0.506

Table- 4 - rMANCOVA with Time*Sex*TxType

	p-Value
Time	0.006
Sex	0.840
TxType	0.395
Sex*TxType	0.628
Time*Sex	0.399
Time*TxType	0.821

Table- 5 - rMANCOVA redone without the interaction term (Time*Sex*TxType)

	p-Value
Time	0.006
Sex	0.840
TxType	0.395

Table- 6 - rMANCOVA redone without interaction terms (Sex*TxType, Time*Sex, Time*TxType)

Measure	Mean Difference (T2-T1)	p-Value	95% Confidence Interval	
			Lower bound	Upper bound
OB	-1.789	0.019	-1.659	-1.920
OJ	-2.425	0.170	-2.216	-2.718
ANB	-1.408	0.063	-1.472	-1.343
L1MP	1.896	0.825	1.606	2.059
U1PP	-0.235	0.188	-0.261	-1.053
SnAr	0.590	0.135	0.591	0.671
FMA	0.093	0.954	-0.088	0.327
YAxis	1.300	0.015	1.243	1.333

Table- 7 - Univariate Analysis with Pairwise Comparisons

Chapter 6 – Summary of Findings

6.1 Introduction

Orthodontically induced external apical root resorption (OIEARR) is an unfortunate iatrogenic problem that has complicated treatment for many years. Unfortunately, although the etiology of root resorption (RR) is multifactorial, many general dentists regard this as being avoidable and often hold the orthodontist responsible. Class II malocclusion affects approximately one-third of the population. This risk of RR is further increased in Class II camouflage cases where treatment may cause the root to contact the cortical plate increasing the probability by twenty-fold. Panoramic radiograph are a common diagnostic tool used by clinicians before and during treatment. The main disadvantage of this film is the quality of the image is dependent on the desired anatomical structure being situated within the focal trough. The focal trough is narrow in the incisor area and this can result in distortion of apices and palatal structures. Given the potential long-term consequence of severe root resorption, it is important for orthodontist to be sensitive to root changes throughout treatment.

The objectives of this thesis were to

5. Critically evaluate incisor OIEARR in patients undergoing non-surgical treatment of Class II Division I malocclusion by systematic review of the published data

The research questions of this thesis were

6. What is the prevalence of OIEARR over the course of treatment in a selected sample of patients treated with either the X-bow for Forsus?

7. What is the severity of OIEARR over the course of treatment in a selected sample of patients treated with either X-bow for Forsus?
8. Are the incisor length measurements determined from panoramic radiographs accurate and reliable when maxillary and mandibular incisor angulations are modified in a custom made typodont?
9. When several cephalometric variables are considered simulataneously over time, does sex and or treatment type affect the final outcome in a selected sample of patients treated with either X-bow or Forsus?

6.2 Summary

6. Critically evaluate incisor OIEARR in patients undergoing non-surgical treatment of Class II Division I malocclusion by systematic review of the published data.

    a. Current evidence suggests comprehensive orthodontic treatment to correct Class II malocclusion results in increased prevalence of OIEARR, however given the fact that there was no RCT and only limited prospective data included in this SR, the findings should be considered with caution.
        i. Prevalence ranged between 65.6%-98.1%
        ii. OIEARR -Per patient – 65.6%-98.1%
        iii. OIEARR - Per tooth – 72.9%-94.2%
        iv. Majority of teeth experienced mild-moderate resorption with severe resorption being reported to be between 6.25-17.2%
        v. No Sex difference was reported for RR
        vi. No evidence that either the Mx CI or LI more susceptible to RR
        vii. Weak to moderate positive correlation between Tx duration and RR
        viii. Weak to moderate positive correlation between AP apical displacement and RR

7. What is the prevalence of OIEARR over the course of treatment in a selected sample of patients treated with either the X-bow for Forsus?
    a. Prevalence per tooth 65.3%
    b. Prevalence per patient 98.6%

8. What is the severity of OIEARR over the course of treatment in a selected sample of patients treated with either X-bow for Forsus?
    a. Per tooth – None (34.7%); Mild (45.2%); Moderate (9.3%); Severe (11%)
    b. Per patient – None (1.4%), Mild (32.9%); Moderate (30%); Severe (35.7%)

9. Are the incisor length measurements determined from panoramic radiographs accurate and reliable when maxillary and mandibular incisor angulations are modified in a custom made typodont?
    a. Under experimental conditions, Md incisors appear to respond as expected when compared to theoretical model (assumption – teeth within focal trough)
        i. 10 degrees – 1.4% shorter
        ii. 20 degrees – 6.3% shorter
        iii. 30 degrees – 13.4% shorter
        iv. 40 degrees – 23.7% shorter
        v. 50 degrees – 34.6% shorter
    b. Mx Incisors are more difficult to say. At some angulations yes (80, 90), at others (50,60, 70, 100, 110) the answer isn't clear
    c. Severe Resorption in clinical study was found in 11% of treated incisors and of the 25 patients with at least one tooth with severe RR, 20 of the cases were found on the Md arch

10. When several cephalometric variables are considered simulataneously over time, does sex and or treatment type affect the final outcome in a selected sample of patients treated with either X-bow or Forsus?
    a. No evidence of a Sex (p=0.840) difference in the overall pattern of cephalometric variables.

b. No Evidence of a treatment type (p=0.395) difference in the overall pattern of cephalometric variables.
c. Convincing evidence of a Time (p=0.006) difference in the overall pattern of cephalometric variables.
d. Convincing evidence (p=0.019) that over the course of treatment OB was reduced by 1.79mm [1.66,1.92].
e. Convincing evidence (p=0.015) that over the course of treatment Y-Axis increased 1.3° [1.24,1.33].

11. Additional Findings

a. Shorter treatment length (p=0.037) with X-bow (24.18 months) compared to Forsus (30.17 months)
b. Both compliance free Class II correction protocols (X-bow and Forsus) for the treatment of mild to moderate class II malocclusion appear to generate similar degrees of lower incisor proclination with similar variability.

6.3 Limitations

Panoramic radiographs in this study were taken with 2 different machines. The clinical data was taken with the Instrumentarium OP 100D in Dr. Miller's orthodontic clinic, whereas the panoramic images taken for the rapid prototyping model was taken using the Sirona Orthophos XG in the University of Alberta Graduate clinic. It is well known that each machine has a different shaped focal trough and since the data is not collected using the same machine, there is potential that the data presented may be different if collected on the same machine.

6.4 Conclusion/Final Thoughts

With the continued improvement in the quality of imaging provided by cone-beam computer tomography (CBCT) and the reduction in radiation exposure, it is quite possible that this imaging modality may eventually replace all 2D imaging techniques, however currently 2D radiographs continues to be the predominant imaging modality used by orthodontists. CBCT may be chosen in a risk management capacity to help clinicians assess root resorption in aggressive camouflage cases provided these specific patients are fully informed and understand the risks and benefits.

Overall, treatment with the X-bow averaged 6 fewer months of treatment producing similar final treatment outcome. Given that both treatment protocols produce essentially the same final clinical outcome, the decision to choose Forsus or X-bow becomes a practice management decision. Severe root resorption in this clinical study was found in 11% of treated incisors and of the 25 patients with at least one tooth with severe RR, 20 of the cases were found on the mandibular arch. The clinical data suggests that over the course of treatment with either X-bow or Forsus, the lower incisor proclined approximately 4 degrees with a standard deviation of 8 degrees. Data from the prototyping models suggest that an increase in angulation between 10-20 degrees will result in approximately 1.4-6.3% foreshortening of the mandibular incisors on the panoramic image. It appears than that foreshortening of the image on a panoramic radiograph due to proclination of lower incisors accounts only for a small part, and the larger reason (20% or more) maybe due to the inherent difficulties of accurately measuring the teeth due to distortion caused by the narrow focal trough size and/or superimposition.