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Extraction vs. Non-Extraction: Comparing Orthodontic Root Resorption

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Extraction vs. Non-Extraction: Comparing Orthodontic Root Resorption

by

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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CONTENT

FIGURES

TABLES

Tables Page

ABBREVIATIONS

T1	Pre-Treatment
T2	Post-Treatment
3D	Three-Dimensional
LLU	Loma Linda University
Ext	Extraction
Non-Ext	Non-Extraction
EARR	External Apical Root Resorption
OIARR	Orthodontically Induced Apical Root Resorption
RR	Root Resorption
CBCT	Computed Cone Beam Tomography
DICOM	Digital Imaging and Communications in Medicine
UR1	Upper right one (upper right central incisor)
UR2	Upper right two (upper right lateral incisor)
UL1	Upper left one (upper left central incisor)
UL2	Upper left two (upper left lateral incisor)
LR1	Lower right one (lower right central incisor)
LR2	Lower right two (lower right lateral incisor)
LL1	Lower left one (lower left central incisor)
LL2	Lower left two (lower left lateral incisor)

ABSTRACT OF THE THESIS

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Master of Science in Orthodontics and Dentofacial Orthopedics
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Dr. Kitichai Rungcharassaeng, Chairperson

*Introduction***:** Orthodontically induced apical root resorption (OIARR) can be a risk to orthodontic treatment. Advancements in imaging warrant further investigation into potential causes and solutions are worthwhile.

Purpose: This study compared incidence and severity of OIARR in incisors during orthodontic treatment with and without bicuspid extractions.

Materials and Methods: This study included 63 patients (504 teeth). DICOM CBCT images were imported into OsiriX MD software (version 10.0.3) for tooth length measurements from coronal and sagittal views in all incisors and incisal angulation for central incisors. Difference in tooth length from incisal edge to root apex from pre-treatment and post-treatment measurements determined OIARR. Mann-Whitney U and Friedman's analyses compared OIARR and incisal angulation changes. Spearman Rho coefficients expressed correlations between OIARR and age, treatment duration, incisal angulation change, and extraction timing. An ANOVA test determined changes in OIARR based on gender or ethnicity. All analyses were performed at $\alpha = 0.05$.

*Results***:** Mean OIARR in extraction patients (0.16 ± 0.08 mm) was statistically significantly greater than in non-extraction patients (0.09 ± 0.06 mm) [$p < .05$] for coronal and sagittal views. There were no statistically significant differences in OIARR between coronal and sagittal views ($p > .05$). There was a statistically significant difference ($p < .05$) for incisal angulation change for all central incisors between groups. Age, treatment time, and extraction timing exhibited no statistically significant correlation with OIARR ($p > .05$). There was no statistically significant change to OIARR with gender or ethnicity ($p > .05$). Incisal angulation change showed a statistically significant correlation to OIARR for the extraction group ($p <. 05$), but not for the non-extraction group ($p > .05$).

*Conclusions***:** The study demonstrated extraction of four premolars during orthodontics resulted in a statistically significant increase in root resorption compared to treatment without extractions. Positive incisal angulation change accompanies non-extraction treatment and negative incisal angulation change accompanies extraction treatment. Resorption and angulation change are correlated in the extraction group, but not in the non-extraction group. No correlation was observed between OIARR and age, treatment duration, or extraction timing. Gender and ethnicity demonstrated no significant effect on OIARR.

CHAPTER ONE

REVIEW OF THE LITERATURE

Several studies delve into the prevalence of root resorption during and after orthodontic treatment, but few agree on the actual numbers. A study by Kim et al. claimed that 90% of patients show histologic evidence of root resorption, while Weltman et al. describes an incidence of 73% after orthodontic treatment with individual tooth resorption ranging from 6% to 13% depending on the tooth.[13,10] The Weltman et al. study also explains that there is a 15% incidence of external apical root resorption with no orthodontic treatment.[10] A separate study by Aman et al. reported that after treatment with fixed appliances 94% of cases had at least one tooth with 1 mm or more of root resorption.[14] These numbers, regarding the prevalence of root resorption in orthodontic treatment, aren't necessarily considering any differences in treatment modality or tooth movement and, because of the breadth of information regarding these topics, it will be important to delve into that area in a more comprehensive manner. However, as one study by Baumrind et al. states, even when the position has virtually no change in pre- and post-treatment cephalograms, there is incisor root resorption found with orthodontic intervention.[7] The majority of resorption studies focus on upper incisors followed by anterior teeth in general. This can be explained by a Deng, et al. study which shows that root resorption is most common in maxillary lateral incisors followed by maxillary central incisors, mandibular anterior teeth, then maxillary cuspids, in that order.[4] Weltman, et al. provides a slight difference to this ordering in that maxillary incisors, mandibular incisors, then first molars show the highest average root resorption, regardless of the treatment modality or genetic predisposition.[10] Knowing these ranges of percentages and affected teeth is only of nominal importance without an understanding of the severity of resorption in orthodontics. Exploring classifications of severity and prevalence of each classification will make that knowledge more useful.

The same Weltman, et al. study cited previously reports that less than 2.5 mm of resorption of orthodontically treated teeth can be expected, on average, but then defines only severe resorption as being greater than 4 mm or one-third of the root-length of the tooth.[10] Aman, et al. refers to a similar threshold of more than 4 mm resorption affecting 6.6% of patients, but Weltman, et al. undercuts that prevalence number, claiming 1% to 5% of teeth reach that level of resorption.[14,10] While the Aman, et al. study references the 4 mm mark, It conversely defines severe root resorption as both central incisors being affected beyond 25% of their original root-length with an incidence of 3%.[14] This definition is only partially helpful because it is confined to only two teeth in the entire mouth, but it still helps in forming an overall understanding of root resorption. Kim, et al. doesn't use a numerical point as its threshold for severe root resorption but states simply that if a tooth is resorbed enough to affect its long-term health or viability, it would be considered severe, and that this will apply to 1% to 5% of orthodontically treated teeth.[13] Another study by Linge, et al. describes the average resorption for upper incisors as 0.73 mm for girls and 0.67 mm for boys, while the average of the most severely resorbed incisor (for both genders) is 1.34 mm.[16] This brings up another instance where a differentiating factor, in this case gender, changes the outlook for resorption. Considering causative or correlating factors within treatment mechanics followed by patient traits and their effect on this phenomenon will be an important and substantial portion of the puzzle that is apical root resorption.

Discussing treatment tactics and strategies for one case with two different orthodontists will often yield very different treatment plans. And while there are numerous proponents, products, and studies supporting each and every orthodontic modality, how a patient is treated can very much affect the risk of root resorption. The oft-cited study by Weltman, et al. points to magnitude of force, amount of apical displacement, duration of treatment, direction of movement, and method of force application as significant in this realm.[10] Baumrind, et al. attempts to set a baseline measurement of 0.99 ± 0.34 mm of resorption for an orthodontically treated incisor with zero effective tooth movement.[7] Though it may seem common knowledge at this point in time, there have been studies to show that levels of resorption increase when heavy forces are used in lieu of light orthodontic forces. Two important studies that demonstrate this point are those by Topkara, et al. and Chan, et al.[8,9] The Weltman, et al. study seeks to describe what a heavy force is and compare it to a light force when it claims that a force of 225 g produced nearly twice as much root resorption (nine times greater than a control group with no force) than a force of 25 g, which resulted in five times greater resorption than the control.[10] Beyond force magnitude, force distance and direction have emerged as points that cannot be ignored. Baumrind, et al. adds 0.30 mm of resorption to its baseline for each additional millimeter of total apical displacement while a separate study by Segal, et al. claims a strong correlation (r = 0.822) between apical root resorption and total apical displacement.[7,19] While the literature seems to display few who would dispute this point, the same cannot be said for direction of that displacement. Baumrind, et al. goes on to state that certain directions of displacement tended toward more resorption than others.[7] A Sameshima, et al. study claims that apical displacement in a horizontal, and not vertical, direction correlates strongly with increased root resorption.[11] But the later study by Kim, et al. differs by stating that the vital factor in resorption for both maxillary and mandibular incisors is vertical displacement, while horizontal displacement only correlates with an increased resorption of mandibular incisors.[13] Regarding the maxillary incisors, there is the possibility that neither of these aforementioned studies discovered the causative factor that Aman, et al. describes as the position of the apices relative to the palatal cortical plate.[14]

Continuing the trend of conflicting conclusions in apical root resorption studies, the Linge, et al. study goes against the grain with the claim that the length of time teeth were in bands did not correlate with the amount of post-treatment root resorption measured.[16] Baumrind, et al. and Sameshima, et al. veered the other direction with claims that resorption was directly and positively correlated to overall treatment time.[7,11] Baumrind, et al. delineates this with the result that 0.38 mm of resorption was added to their baseline resorption numbers for every elapsed year in treatment.[7] Segal, et al. provides further substantiation with their measured correlation of resorption to length of treatment at $r = 0.852$.[19]

While much of the timeline of treatment is dependent on the needs of the patient's skeletal and dental position and malocclusion, it is well known that compliance with elastic wear, if needed, is one factor that the patient controls that will affect the treatment duration. And again, when searching studies regarding this topic, there is discord between studies on the potential correlation to resorption. Linge, et al. and Topkara, et al. agree that elastics (class II and general intermaxillary, respectively) will increase the amount of resorption noted post-treatment.[16,8] Alas, Sameshima, et al. proves the detractor when their findings indicated that there was no statistically significant change in resorption between patients with or without elastic use during treatment.[11]

When considering specific tooth movements, Topkara, et al. claims that long-term extrusive forces have a strong association with increased apical root resorption while Weltman, et al. states that extrusion does not change the overall resorption.[8,10] The Weltman, et al. study goes on to describe a four-fold increase in measured percentage of resorbed root area with intrusion.[10] Topkara, et al. expands its claim in stating that lingual rotation of the apex increases root resorption.[8] Baumrind, et al. again adds to its baseline resorption a measurement of 0.49 mm per millimeter of root retraction.[7] With each tooth movement there are different types of forces applied to different portions of the root surfaces. Orthodontic movement is a product of a combination of compressive and tensile forces on the roots. The Chan, et al. study describes that purely compressive forces account for the greatest degree of resorption while a combination tensile/compressive force or tensile force alone results in decreased resorption.[9] A lesser-discussed force type, that of jiggling orthodontic forces, is discussed by Topkara, et al. which measures a greater degree of associated apical root resorption.[8]

While an orthodontist may be unable to dictate which direction a tooth needs to be moved, there is a large variation in the type of appliance combination that can be used for that movement. Many studies seek to define which methods affect the orthodontically induced root resorption in either direction. The Weltman, et al. study discusses one aspect of this in detail looking specifically at the maxillary left central incisor for multiple cases and claiming that there is no correlating difference between archwire sequences and resorption.[10] A similar claim is made in the study by Sameshima, et al. in that the type of archwire, slot size, and even type of expansion have no statistical significance in the change in root resorption.[11] One contrasting study is by Linge, et al. which states that the use of rectangular archwires is highly associated with increased apical resorption.[16] While these studies focus solely on continuous archwire mechanics, another study attempts to test the anti-resorption merits long claimed by proponents of sectional arch mechanics. This study, by Alexander, et al. finds that there are no statistically significant differences in resorption levels when comparing sectional and continuous arch mechanics, even considering the amount of retraction and length of treatment time.[20]

Another of the great orthodontic pendulums (figurative pendulums, not the pendulum appliance) is whether to treat certain crowding cases with or without extraction of bicuspids. While this often is dictated by the individual case, practitioner philosophy also plays a role. Unfortunately, the studies attempting to add root resorption to the list of pros and cons do not help clarify this debate. While the Sameshima, et al. and Linkous, et al. studies indicate that cases with extraction of four bicuspids show a higher propensity for overall resorption than non-extraction or two bicuspid cases, the rival study by Baumrind, et al. claims that there is little to no discernible difference in resorption values of side-by-side extraction and non-extraction cases.[11,12,7] For this reason, a larger body of data is needed to investigate this aspect of orthodontic treatment and its potential for increased resorption. Because more recent studies have demonstrated that CBCT imaging can provide more precise and accurate measurements for resorption, utilization of this imaging method has now become the standard for studies of this type.[3,4,5,6]

An additional polarizing point among orthodontic professionals is the use of self-ligating brackets. Some manufacturers and orthodontists claim that the passive forces applied with certain self-ligating brackets can be the reason for decreased root resorption. However, the Weltman, et al. study claims that measuring and comparing these numbers for cases with Damon self-ligating brackets and traditional brackets with elastomeric ties provided no statistically significant difference in resorption values.[10] This transitions into one of the newest hot topics in orthodontics, that of fixed appliances vs. aligner therapy.

While the majority of orthodontic education and literature points to a case-by-case determination of the benefits and detriments of clear aligners, there are many with extreme views in either direction. According to the available literature and through the filter of apical root resorption, this question is still under review. Multiple studies report that aligner therapy has a decreased risk of root resorption incidence. One of these is Linge, et al. which claims that there is significantly more risk of resorption with fixed appliance cases than with aligner treatment.[16] Another by Fang, et al. reported that while resorption cannot be entirely avoided with clear aligners, it does produce cases with less incidence and severity of resorption on average.[21] The Aman, et al. study covers this more comprehensively, reporting a decreased average external resorption with a range of between 0.47 ± 0.61 mm and 0.55 ± 0.70 mm and even a decrease in cases of severe resorption, which they classify as 25% reduction in root length, from 3% in fixed cases to 1.25% in aligner cases.[14] While these studies do seem promising for one of the newer and more patient desired treatment modalities, other studies aren't quite as optimistic. Many do not go as far as to say that aligner therapy increases the risk of root resorption, but report a near equal outlook when directly comparing fixed and aligner treatment. These studies include the Weltman et, al. research which compared light force to thermoplastic appliances, or aligners, and found similar resulting losses of cementum.[10] Another would be Gay, et al. where a detailed search into aligner therapy provides a similar severity attributed to traditional fixed therapy with an average resorption as less than 10% of the original root length and 3.69% of teeth experiencing severe resorption, which they defined as more than 20% decreased root length.[22] One study by Iglesias-Linares, et al. took the interesting approach of adjusting the study results to account for differences in patient genetic (genotype) resorptive predisposition, clinical data, and radiographic study which resulted in the conclusion that resorption values are similar between aligner and fixed orthodontic cases.[23] While these different treatment modalities may affect the end result in regard to resorption, it may be as simple as whose hands are performing those treatments. The Sameshima, et al. study followed six different orthodontic practices and found one practice that averaged an entire millimeter of increased resorption for each anterior tooth.[11] Becoming acquainted with this knowledge can help in deciding treatment plans for patients, but there are numerous factors, namely patient traits, that cannot be changed regardless of treatment modality.

A responsible orthodontist may want to consider some non-treatment factors and their relationship with apical root resorption before deciding on a treatment plan. One of these factors is age. While treatment age, chronologic and dental, has always been an important factor in orthodontic treatment plans another reason to consider this may be root resorption. While the Baumrind, et al. study claims that age of treatment does not have a significant association with root resorption, one study by Lopatiene, et al. states that beginning treatment after age eleven may cause an increase in risk of root resorption.[7,15] Another factor to consider is gender and its effect on resorption. Continuing the theme of discord, the study by Linge, et al. reports little to no difference in apical resorption between male and female patients.[16] But Aman, et al. and Baumrind, et al. claim a higher incidence of root resorption measured among male patients with a per-tooth average resorption increase of 1.20 mm over that of the female patients included in the study.[14,7] The previously cited Iglesias-Linares, et al. study uses a screening method to attempt to prevent biological bias in its results and states that there are some patients that may have a genetic predisposition for orthodontically induced external apical root resorption.[23] Weltman, et al. also references patient genetics as a factor to consider when assessing resorptive risk.[10] Lopatiene, et al. expounds a little on this idea, supposing that root resorption predisposition could be an autosomal dominant, autosomal recessive, or hereditary trait and adding that dividing the results by race indicated a higher propensity for resorption among Asian patients relative to Caucasian or Hispanic patients.[15] A study by Jiang, et al. attempts to pin this added risk and predisposition down to a specific genotype with the interleukin-1 family type of IL-1β rs1143634, claiming all of the subjects found to have external apical root resorption in their small study were common to this trait, but the study itself reports there is not enough data in their sample size to substantiate the information as a claim.[24] One factor that many, including the study by Linge, et al., believe to be associated with increased root resorption is previous trauma.[16] However, the Weltman, et al. study contradicts this belief in the claim that incisors studied with signs or reports of previous trauma were measured to have statistically similar amounts of resorption as those incisors with no previous indicators of trauma.[10] The study previously cited by Lopatiene, et al. pointed to multiple factors that may add to a potential increase of orthodontically induced root resorption including habits like bruxism, tongue thrust, and nail biting, pipette-shaped roots, and short roots (which resulted in double the resorption of those with normal lengths).[15] Some key indicators for orthodontic treatment have also been shown to provide an increased incidence of root resorption. One of those, shown in the study by Linge, et al. is cases that begin with impacted canines.[16] The same study claims that differences in overbite and overjet do not correlate to differences in resorption. And while Baumrind, et al. claims that there is no difference in resorption values between class I and class II malocclusion cases, Aman, et al. contradicts this in saying that malocclusion along with crowding can be found to affect the percentage of change in the length of the root at conclusion of treatment.[7,14]

When discussing the risk and probability of root resorption with any patient, the question may arise as to why this is important. What is the real-life affect this will have on the patient? Jonsson, et al. performed a long-term study following patients who were affected by resorption and found that teeth that had severe resorption with a resulting root length of less than 10 mm were expected to have increased mobility with age, while stability was found in teeth that had 10 mm or more of length, even after orthodontically induced apical root resorption.[25]

By internalizing and applying the information about this important topic found in the literature, an orthodontic professional can begin to employ strategies to prevent or minimize root resorption. Some studies discuss these strategies specifically. The study by Topkara, et al. implores orthodontists to use light forces and longer intervals between activation to decrease the risk of resorption.[8] Lopatiene, et al. placed the optimal force to induce orthodontic movement while avoiding root resorption at 7-26 g/cm^2.[15] Weltman, et al. approaches the solution from the other angle, studying the effect of interrupted forces. The experimental group received 12-hours of 100 g activation followed by 12-hours of inactive time each day while the control group received continuous, 24-hour 100 g force. The interrupted group finishes with an average of 0.4 ± 0.7 mm resorption while the continuous force group averages 1.5 ± 0.8 mm.[10] A fifteen-week split-mouth study by Ozkalayci, et al. places force on bicuspids that are planned for extraction including one group that has continuous force and another that has force for 28 days followed by a 7-day rest period. After the force application period, the teeth are extracted, and resorption numbers are analyzed with the result that the intermittent force group has statistically significant decreases in resorption. The study suggests, based on the results, that orthodontic treatment of individuals at higher risk to apical root resorption could include this type of intermittent force approach.[26] The Lopatiene, et al. study recommended the acquisition of radiographs in the six-to-nine-month period after beginning treatment to monitor for any apical shape changes or obvious resorption as this is the time period that is most crucial in determining risk for further resorption.[15] Regarding radiographs, there is a clear trend in recent literature on how resorptive studies are completed. With the technology of cone beam computed tomography (CBCT) becoming more available to the dental community, many studies have shifted to these measurements as the standard for gathering data. There is much that can be learned regarding this shift, even through the narrow filter of apical root resorption.

Two of the most commonly used radiographs practitioners use in diagnosing root resorption are periapical and panoramic images. Unfortunately, there are inherent problems with both of these methods. A study by Ponder, et al. briefly discusses how there are angular changes between periapical radiographs and reality that affect the linear measurement, even noting that sequential radiographs can’t be trusted due to inevitable positional changes caused by the patient or technician.[17] Regarding panoramic radiographs as a source for resorption monitoring, the Deng, et al. study mentions image distortions and magnification errors that are evident even in the misrepresentation of different cephalometric landmarks on panoramic images.[4] It follows that this applies even more so to the precise measurements needed to discover root resorption severity. Deng, et al. compounds this condemnation of panoramic resorption study by explaining that a three-dimensional phenomenon cannot be accurately depicted in a two-dimensional image.[4] But the solution to these issues isn’t simply to switch to CBCT for all needs. A study by Kamburoğlu, et al. explains some of the factors that complicate the CBCT shift. Radiation dosage could fill multiple literature reviews in and of itself, but the study explains that comparative dosage should be weighed against diagnostic benefit and that increases in accuracy with decreased radiation will come with advancing technology. The same study also touches on the potential legal ramifications of CBCT utilization, explaining that this is the most comprehensive imaging available to non-radiologists, and that even those untrained in the subtleties of radiographic diagnostics are responsible to interpret the entire volume of data.[27] Regarding the accuracy of measurements made with CBCT, one Lascala, et al. study focuses on the NewTom CBCT unit and discovers that although linear skull measurements may be underestimated, the dentomaxillofacial structures can be measured more reliably.[18] The Ponder, et al. study looks deeper into the difference between high-resolution and low-resolution CBCT imaging and finds that they have similar reliability for measurement of root resorption on extracted teeth with simulated resorption lesions, and that both options are a significantly more accurate measure than periapical imaging. The caveat described in this study is that more research is needed to determine accuracy in live patients with real resorption.[17]

Knowing the additional accuracy that is coming with more CBCT studies makes it even more important to note those studies that used two-dimensional imaging for measurement of apical root resorption. The following is a list denoting those studies discussed in this literature review:

- Aman, et al. used panoramic radiographs for measurement and did not account for age or gender in results.[14]
- Baumrind, et al. used lateral cephalogram for apical position of incisors and panoramic radiographs for resorption measurements.[7]
- Linge, et al. used periapical radiographs for all measurements.[16]
- Sameshima, et al. used lateral cephalogram for apical position of incisors and periapical radiographs for resorption measurements.[11]
- Alexander, et al. used panoramic and occlusal radiographs for all measurements.[20]
- Iglesias-Linares, et al. used panoramic radiographs for all measurements.[23]

Since the turn of the century, studies have become more reliant on CBCT data.[3,4,5,6] While this has increased the accuracy of resorption measurements, the overall body of knowledge can be improved with more studies delving deeper into different aspects of each of these variables. One such study could research the resorption changes of extraction cases compared to non-extraction cases, with emphasis given to incisal angulation changes.

Drawing conclusions for this topic of study is akin to shooting at multiple moving targets simultaneously. However, there are a few themes that seemed to resonate throughout the literature. First, while apical root resorption is a phenomenon that would exist without the introduction of orthodontics, treatment of this kind can, and often does, exacerbate the issue. Second, not only do light forces work more efficiently in orthodontic tooth movement, but they also decrease the risk and severity of any resulting apical root resorption. Third, case selection, treatment modality, and the chosen mechanics have a significant effect on resorption values and should be considered carefully for each patient. And lastly, future studies should continue to utilize three-dimensional imaging whenever possible to increase the accuracy of findings and conclusions.

CHAPTER TWO

EXTRACTION VS. NON-EXTRACION: COMPARING ORTHODONITC ROOT RESORPTION

Abstract

Introduction: Orthodontically induced apical root resorption (OIARR) can be a risk to orthodontic treatment. Advancements in imaging warrant further investigation into potential causes and solutions are worthwhile.

Purpose: This study compared incidence and severity of OIARR in incisors during orthodontic treatment with and without bicuspid extractions.

Materials and Methods: This study included 63 patients (504 teeth). DICOM CBCT images were imported into OsiriX MD software (version 10.0.3) for tooth length measurements from coronal and sagittal views in all incisors and incisal angulation for central incisors. Difference in tooth length from incisal edge to root apex from pre-treatment and post-treatment measurements determined OIARR. Mann-Whitney U and Friedman's analyses compared OIARR and incisal angulation changes. Spearman Rho coefficients expressed correlations between OIARR and age, treatment duration, incisal angulation change, and extraction timing. An ANOVA test determined changes in OIARR based on gender or ethnicity. All analyses were performed at $\alpha = 0.05$.

Results: Mean OIARR in extraction patients (0.16 ± 0.08 mm) was statistically significantly greater than in non-extraction patients (0.09 ± 0.06 mm) [$p < .05$] for coronal and sagittal views. There were no statistically significant differences in OIARR between coronal and sagittal views ($p > .05$). There was a statistically significant difference ($p < .05$) for incisal angulation change for all central incisors between groups.

Age, treatment time, and extraction timing exhibited no statistically significant correlation with OIARR ($p > .05$). There was no statistically significant change to OIARR with gender or ethnicity ($p > .05$). Incisal angulation change showed a statistically significant correlation to OIARR for the extraction group ($p <. 05$), but not for the non-extraction group ($p > .05$).

*Conclusions***:** The study demonstrated extraction of four premolars during orthodontics resulted in a statistically significant increase in root resorption compared to treatment without extractions. Positive incisal angulation change accompanies non-extraction treatment and negative incisal angulation change accompanies extraction treatment. Resorption and angulation change are correlated in the extraction group, but not in the non-extraction group. No correlation was observed between OIARR and age, treatment duration, or extraction timing. Gender and ethnicity demonstrated no significant effect on OIARR.

Introduction

Statement of Problem

One of the many reasons dental professionals are drawn to orthodontics as a specialty, is the fact that, unlike most other dental procedures, rarely is orthodontic treatment irreversible. A tooth that is moved to an undesirable position can be moved back. This notion is a viable reason that orthodontic research so often addresses one of the most common irreversible side effects of treatment, i.e., root resorption. Whether it is called external apical root resorption (EARR), orthodontically induced apical root resorption (OIARR), or inflammatory root resorption (IRR), literature can be found discussing this phenomenon from as far back as the mid 19th century[1] and is a common topic in journals today. Like any topic that has had this much attention for this long, there are many different viewpoints and conclusions that can be drawn from various sources. And though it is unlikely that this issue will ever truly be solved, a comprehensive understanding of root resorption and its range of prevalence and severity, causative factors – related and unrelated to treatment variables, long-term effects, prevention strategies, and measurement properties is valuable for orthodontic practitioners.[2]

While there are myriad studies regarding almost every conceivable orthodontic variable that could affect root resorption, it is only more recently that these studies have begun to rely on CBCT.[3,4,5,6] It is important to build the data and knowledge base with this technology to get a more accurate understanding of how orthodontists can treat patients safely and effectively.

One of the historical pendulums of orthodontic treatment is the whether or not to utilize strategic extractions to create the space needed for ideal orthodontic treatment.

Depending on the amount of crowding, this has the potential to create a situation where the anterior teeth will require a lot of movement during orthodontic treatment. The combination of increased root apex displacement,[7] increased lingual root torquing movements,[8] and oft required retraction of incisors[9] gives extraction orthodontics a high potential for increased OIARR. This study had the potential to provide a better-informed decision in the treatment planning process. If the extraction group showed no increase in OIARR, clinicians could decide between treatment with or without extractions without added concern for the resulting root resorption. Conversely, if the extraction group did have increased resorption, the result would be a better understanding of the risks of extraction in treatment. Because maxillary incisors have historically shown the highest incidence of OIARR, these have been the most commonly measured teeth in orthodontic research.[10] However, the decision of whether to extract premolars in treatment is often a result of mandibular crowding. Therefore, additional studies are needed in these teeth to understand this phenomenon more completely.

Hypothesis

The null hypothesis stated there was no statistically significant difference in the amounts of OIARR present between treatment utilizing extraction of bicuspids vs. treatment without extractions. Additionally, the null hypothesis stated that there were no correlations between OIARR and age, treatment duration, incisal angulation change, gender, ethnicity, or timing of extractions.

Materials and Methods

Patient Selection

This study was approved by the Institutional Review Board (IRB). The study patients were selected from those that had completed orthodontic treatment the graduate orthodontic clinic between 2010 and 2022. The patients were divided into two groups as follows: the extraction group whose treatment included extraction of both maxillary and mandibular first or second premolars, and the non-extraction group whose orthodontic treatment included no extractions. Table 1 details the inclusion and exclusion criteria for patient selection.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria
- Received comprehensive treatment with fixed orthodontic appliances in the graduate orthodontic program
- 10-75 years of age at start of treatment
- Presence of complete permanent dentition (except third molars) at the start of treatment
- Complete CBCT records at T1 and T2 time intervals
Exclusion Criteria
- Orthognathic surgery utilized in treatment plan
- Reported medical history of autoimmune diseases, arthritis, or bone disease
- Use of bisphosphonates or radiation treatment
- Maxillary or mandibular incisors that were endodontically treated or reported as ankylosed
- Existing restorations on maxillary or mandibular incisors
- Incisal edge adjustment/reduction of incisors denoted in treatment

Data Collection

The following data were collected for each patient:

- Age (years) at T1
- Gender
- Treatment duration (months)
- Ethnicity
- Timing of extractions (number of months into orthodontic treatment)

The CBCT volumes were anonymized and imported into OsiriX MD (version 10.0.3, Pixmeo, Bernex, Switzerland) as Digital Imaging and Communication in Medicine (DICOM) files for the T1 and T2 measurements to be made. Each maxillary and mandibular incisor was viewed with axes bisecting the root canal of each tooth from the sagittal, axial, and coronal views on the software (Figure 1) and measured for length from both sagittal and coronal views using points along the marked axis at the incisal edge of the crown and the apical tip of the root (Figure 2). Both measurements (sagittal and coronal) were recorded and analyzed separately to ensure accuracy of resorption measurement. An incisor was categorized as having a curved root if the straight-line axis left the root canal at any point before reaching the apical tip. In these cases, the open polygon measurement tool was used to trace the curvature to get a more accurate length for that tooth (Figure 3). The angle between the sella-nasion plane and upper incisor plane (UI-SN) as well as the angle between the mandibular plane and lower incisor plane (IMPA) was recorded for each central incisor from the T1 and T2 CBCT volumes (Figure 4). The amount of root resorption was then determined by subtracting the T2 length from the T1 length for each tooth. These values were recorded and organized on an Excel spreadsheet and stored on an external USB storage device dedicated solely for this research.

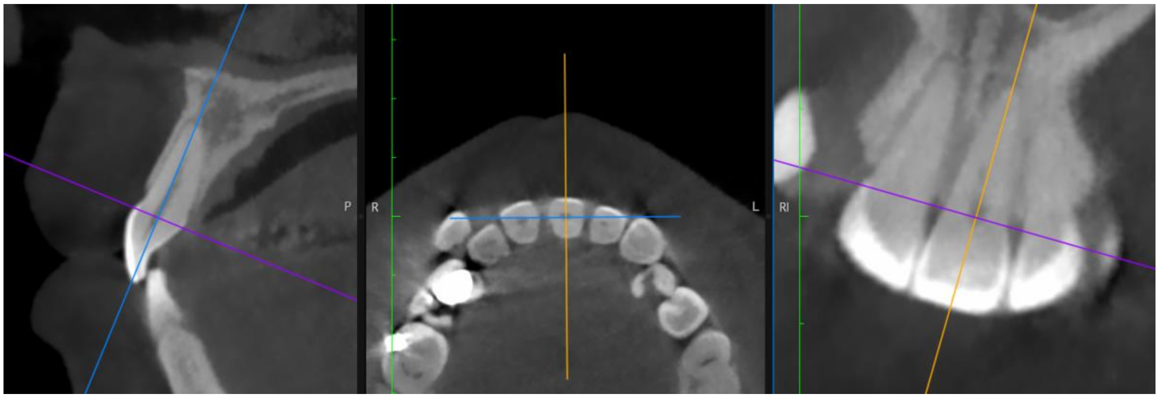

Figure 1: Maxillary central incisors with axis lines centered on the crown **Left)** Sagittal View **Center)** Axial View **Right)** Coronal View

Figure 2: **Left)** Sagittal and **Right)** coronal views with measurement from incisal edge to apex of maxillary central incisors

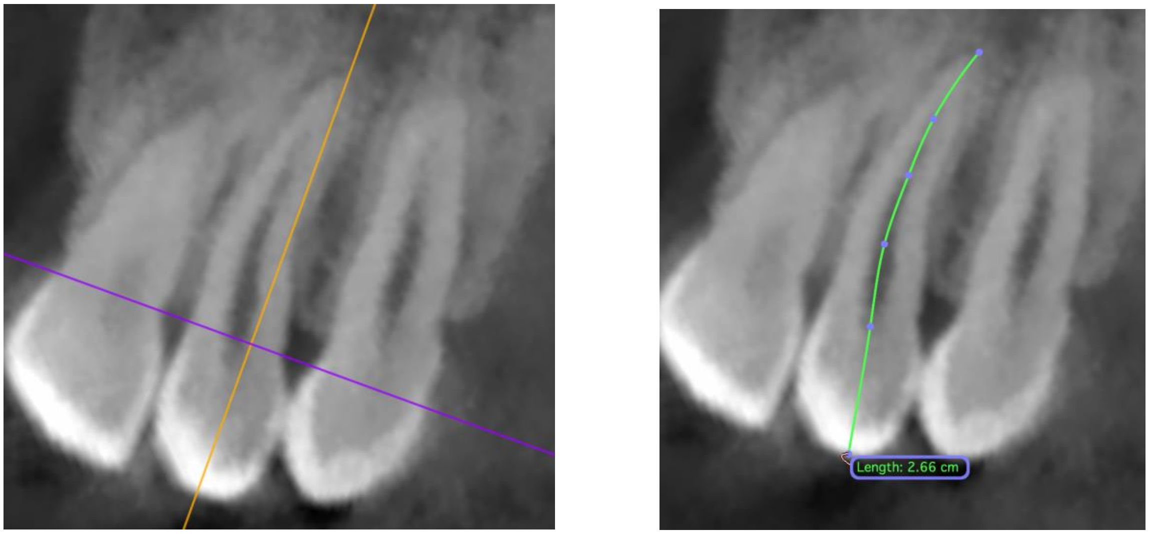

Figure 3: Curved root procedure shown **Left)** Straight line incisor axis from coronal view leaves the root canal **Right)** Length measured using open polygon measurement tool, maintaining measurement through root canal to root apex

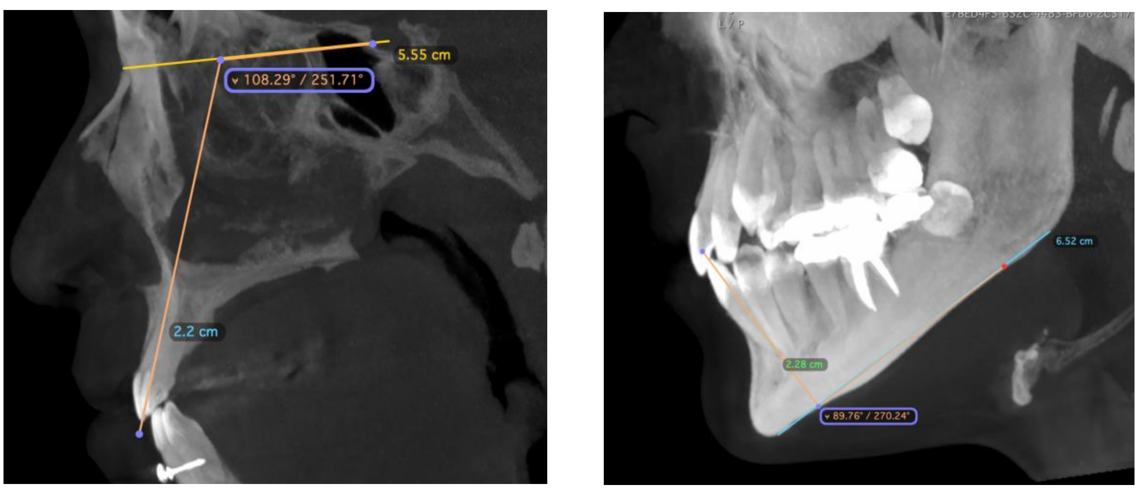

Figure 4: Incisal angulation measurements shown **Left)** Upper Incisor-Sella Nasion (U1-SN) Angle **Right)** Lower Incisor-Mandibular Plane Angle (IMPA)

Statistical Analysis

Statistical analysis was completed for the data using Jamovi Version 2.0.0.0 and Microsoft® Excel. Comparison of root resorption between extraction and non-extraction patients was accomplished with the Mann-Whitney U Test. Different views were compared within extraction/non-extraction using Friedman's analysis with Durbin-Conover pairwise comparisons. If there was a statistically significant difference among each individual tooth per treatment modality, Friedman test was used to for analysis. Spearman's Rho was used to express the correlation between OIARR and age, treatment duration, incisal angulation change, and timing of extractions (if applicable). Analysis of Variance (ANOVA) was used to determine correlation between OIARR and gender and ethnicity. The intra-examiner reliability of measurements was evaluated by using repeat measurements on 18 randomly selected patients taken at least 2 weeks apart and expressed as intraclass correlation coefficient. For all statistical analyses the significance level was set at $\alpha = 0.05$.

Results

Table 2 shows patients' information regarding gender, mean age, mean treatment duration in months, Ethnicity, and mean timing of extraction if utilized for treatment.

Table 2: Descriptive Statistics for Extraction and Non-Extraction Patients

	Extraction	Non-Extraction
Total	31	32
Male	10	11
Female	21	21
Mean Age (Years) [Range]	14.67 [10.42-27.00]	16.97 [10.67-57.92]
Mean Treatment Duration (Months) [Range]	36.68 [22-59]	28.25 [11-55]
Ethnicity (Hispanic)	21	18
Ethnicity (Caucasian)	5	11
Ethnicity (Middle Eastern)	1	1
Ethnicity (Asian)	1	1
Ethnicity (African American)	3	1
Mean Timing of Extractions (Months into treatment) [Range]	2.61 [0-25]	N/A

The measurement method was highly reproducible as evidenced by the intraclass correlation coefficient values consistently reaching a level above 0.95 for all views. Non-parametric tests were utilized for each analysis because of the lack of normal distribution between each of the variables and descriptive statistics measured. The most resorption view was gathered from the comparison of the measurements from the coronal and sagittal views, and all three of these statistics were compared in Table 3. Comparing the measurements for all measured teeth overall, extraction patients experienced statistically higher levels of root resorption than their non-extraction counterparts ($p < 0.001$, Table 3). The Friedman's Test with Durbin-Conover pairwise comparison p-values indicate that the ‘Most Resorption’ aggregate was statistically significant in its higher level of resorption than either coronal or sagittal view alone.

Table 3: Comparison of root resorption between Extraction and Non-extraction on different views at α = 0.05

	Mean ± Standard Deviation of Root Resorption (cm) [Range]		
View	Extraction {31}	Non-Extraction {32}	p-value$^{\varphi}$
Coronal	-0.14 ± 0.11[a] [-0.00 to -0.23]	-0.07 ± 0.10[a] [-0.01 to -0.39]	< .001*
Sagittal	-0.16 ± 0.12[a] [-0.01 to -0.29]	-0.09 ± 0.10[a] [-0.03 to -0.43]	< .001*
Most Resorption	-0.16 ± 0.08[b] [-0.00 to -0.29]	-0.09 ± 0.06[b] [-0.01 to -0.43]	< .001*
p-value$^{\Psi}$	< .001*	< .001*	

{N}
[a,b]Different letters denote statistically significant difference
* Statistically significant difference
$^{\varphi}$ Mann Whitney U Test
$^{\Psi}$ Friedman Test with Durbin-Conover Pairwise Comparison

Table 4 shows which view produced the highest level of root resorption measured for each tooth.

Table 4: Highest measured root resorption for each tooth

View with most Root Resorption	Sagittal	Coronal	Equal Resorption
Number of teeth	283	160	61

Percentage of Total Teeth (504)	56.2%	31.7%	12.1%

(N)

Individual Tooth Comparisons

Table 5 shows that measurements from the coronal view demonstrated consistently greater statistical root resorption ($p < .05$) in the extraction group for all incisors in this study. When looking at the aggregate of all teeth from this view, there was no statistically significant difference in the amount of root resorption noted in the non-extraction group ($p > .05$), but the extraction group did show statistically significant differences ($p < .05$).

Table 5: Comparison of root resorption in the coronal view between Extraction and Non-extraction on different teeth at $\alpha = 0.05$

Mean ± Standard Deviation of Root Resorption (cm) [Range]			
Tooth	Extraction {31}	Non-Extraction {32}	p-value$^{\varphi}$
UR2	-0.18 ± 0.12 [-0.55 to -0.02]	-0.096 ± 0.10 [-0.43 to 0.08]	.003*
UR1	-0.14 ± 0.12 [-0.51 to 0.02]	-0.09 ± 0.94 [-0.37 to 0.02]	.031*
UL1	-0.12 ± 0.11 [-0.39 to 0.07]	-0.09 ± 0.12 [-0.55 to 0.02]	.033*
UL2	-0.19 ± 0.12 [-0.44 to 0.02]	-0.09 ± 0.14 [-0.72 to 0.03]	<.001*
LR2	-0.13 ± 0.12 [-0.43 to 0.11]	-0.06 ± 0.08 [-0.22 to 0.11]	.009*
LR1	-0.11 ± 0.10 [-0.29 to 0.10]	-0.07 ± 0.07 [-0.22 to 0.05]	.038*
LL1	-0.12 ± 0.08 [-0.33 to 0.02]	-0.07 ± 0.07 [-0.29 to 0.06]	.008*
LL2	-0.15 ± 0.10 [-0.43 to 0.01]	-0.06 ± 0.06 [-0.20 to 0.05]	<.001*
p-value$^{\theta}$	.001*	.603	

{N}
* Statistically significant difference
$^{\varphi}$ Mann Whitney U Test

$^{\theta}$ Friedman Test

Table 6 shows that measurements from the sagittal view demonstrated greater statistical root resorption ($p < .05$) in the extraction group for all incisors except upper central incisors ($p = 0.103$ for upper right central, $p = 0.171$ for upper left central). Within these exceptions, average root resorption was still higher for the extraction group, but not to a statistically significant level. When looking at the aggregate of all teeth from this view, there was no statistically significant difference in the amount of root resorption noted in the non-extraction group ($p > .05$), but the extraction group did show statistically significant differences ($p < .05$).

Table 6: Comparison of root resorption in the sagittal view between Extraction and Non-extraction on different teeth at $\alpha = 0.05$

Mean ± Standard Deviation of Root Resorption (cm) [Range]			
Tooth	Extraction {31}	Non-Extraction {32}	p-value$^{\varphi}$
UR2	-0.19 ± 0.13 [-0.60 to 0.10]	-0.10 ± 0.11 [-0.48 to 0.13]	.002*
UR1	-0.15 ± 0.12 [-0.52 to 0.01]	-0.11 ± 0.11 [-0.46 to 0.00]	.103
UL1	-0.12 ± 0.11 [-0.41 to 0.04]	-0.11 ± 0.14 [-0.57 to 0.03]	.171
UL2	-0.20 ± 0.13 [-0.52 to -0.02]	-0.10 ± 0.12 [-0.65 to 0.00]	< .001*
LR2	-0.15 ± 0.13 [-0.54 to 0.05]	-0.06 ± 0.07 [-0.22 to 0.13]	.005*
LR1	-0.15 ± 0.11 [-0.44 to 0.07]	-0.08 ± 0.07 [-0.30 to 0.06]	.008*
LL1	-0.14 ± 0.09 [-0.36 to 0.02]	-0.09 ± 0.07 [-0.27 to 0.01]	.007*
LL2	-0.19 ± 0.10 [-0.43 to -0.02]	-0.07 ± 0.07 [-0.20 to 0.10]	< .001*
p-value$^{\theta}$	.004*	.561	

{N}

* Statistically significant difference
φ Mann Whitney U Test
θ Friedman Test

Table 7 shows that there was a statistically significant difference ($p < .05$) in angulation change for all central incisors between the extraction and non-extraction groups. As one could expect, the extraction group had, on average, an angulation decrease while the non-extraction group showed an increase in these measurements. When looking at the aggregate of all central incisors, there was no statistically significant difference in the incisal angulation noted in either the extraction or non-extraction groups ($p > .05$).

Table 7: Comparison of angulation change between Extraction and Non-extraction on different teeth at $\alpha = 0.05$

	Mean angulation change ± Standard Deviation (degrees) [Range]		
Tooth	Extraction {31}	Non-Extraction {32}	p-value$^{\varphi}$
UR1	-7.08 ± 8.21 [-24.80 to 3.42]	5.12 ± 9.25 [-8.96 to 34.70]	< .001*
UL1	-6.67 ± 7.78 [-21.90 to 6.90]	5.41 ± 8.99 [-11.50 to 26.20]	< .001*
LR1	-3.00 ± 7.25 [-13.90 to 17.90]	4.29 ± 7.72 [-6.24 to 28.10]	< .001*
LL1	-2.65 ± 7.57 [-14.60 to 18.70]	5.30 ± 9.09 [-12.40 to 23.50]	< .001*
p-value$^{\delta}$	.073	.252	

{N}
* Statistically significant difference
φ Mann Whitney U Test
δ ANOVA

Relationship of Root resorption with Other Factors

It was found that age, treatment duration, and extraction timing had no significant statistical correlation to root resorption for either extraction or non-extraction group (p >

.05, Table 8). And while the non-extraction group showed no significant correlation to angulation change, the extraction group did demonstrate an increase in root resorption with increased incisal angulation change during treatment.

Table 8: Correlation Coefficient (Spearman's Rho) between RR and Other Factors

Factor	Ext (p-value)	Non-Ext (p-value)
Age	-0.001 (.997)	0.117 (.522)
Treatment Duration	-0.003 (.988)	-0.196 (.288)
Angulation Change	0.469 (.008*)	0.275 (.128)
Extraction Timing	0.243 (.188)	N/A

*Statistically significant correlation

No statistically significant difference in root resorption was observed for gender or ethnicity among the extraction and non-extraction groups. (p > .05, Table 9).

Table 9: ANOVA Test (F) for RR and Gender/Ethnicity

Factor	Ext (p-value)	Non-Ext (p-value)
Gender	0.931 (.342)	0.251 (.620)
Ethnicity	0.322 (.861)	0.367 (.830)

Discussion

The results of this study show that there is a statistically significant increase in root resorption with extraction of four bicuspids evident in both coronal and sagittal orientations as well as the most resorption category (p < .05, Table 3). Earlier studies show mixed conclusions when discussing extraction vs. non-extraction orthodontic treatment. This study falls in line with Sameshima, et al. and Linkous, et al. that claimed an increase in OIARR with extractions.[11,12] The overview of resorption measured showed that the highest level of OIARR was found in the sagittal view, which may correlate to the root torquing motion needed for retraction in extraction cases, or protraction in the non-extraction group (Table 4). Individual tooth measurement analysis showed consistent results with the overall analysis, as each resorptive value showed a significant increase in both views with the only exception being upper central incisors from the sagittal view (Tables 5 and 6). In this exception, mean resorption was still higher for the extraction group, but not to a statistically significant level. Multiple studies describe severe OIARR as 4mm or more of root resorption over the course of orthodontic treatment and claim that occurrence is between 1-5%.[10,13,14] That statistic is consistent in this study as it was found that 3.77% of teeth measured (3.63% of extraction group, 3.91% of non-extraction group) fell into the severe resorption category. This shows a very similar spread of severe resorption between the two study groups. It is important to consider other factors.

Proof of a statistically significant increase in root resorption in the extraction group is not equal to proof of clinically significant increased resorption. For the most resorption category, there was a 0.71mm mean difference in root resorption between the extraction and non-extraction groups. While this was proven to be statistically significant, it is unlikely that this level of additional resorption would change the long-term viability of otherwise healthy teeth. For the majority of incisors studied, the increased mean root resorption for the extraction group was not enough to change that resorption value to the severe resorption category defined earlier.[10,13,14]

Incisal angulation change was measured for all maxillary and mandibular central incisors and a significant difference in incisor angulation change was found between the two groups. As could be expected, treatment with no extractions present resulted in a positive incisal angulation change or increased labial crown torque while the opposite was true for those treated with extractions (Table 7). When relating the angulation changes with root resorption, it was found that the extraction group did have a statistically significant correlation to increased root resorption (Table 8). This result fits with previous studies that have reported increased root resorption with increased distance of apical root travel during treatment.[7,8,9,10] One curious finding, however, was that the non-extraction group measured no statistically significant correlation between angulation change and resorption. One thought is that this occured simply because there was less angulation change among the non-extraction group, and therefore less tooth movement overall. This is not the case though, as the average incisal angulation change was a positive 5.04 degrees for the non-extraction group, and negative 4.85 degrees for the extraction group. This could point to the fact that the direction of tooth movement or, more accurately, the direction of incisal angulation change, is associated with a difference in root resorption. There are other factors to consider as well, like treatment modality for the retraction of incisors to fill the extraction space and how much actual apical movement there was in comparison to the movement of the incisors in the non-extraction group. Further study should be explored to better understand these findings.

This study discovered no correlation between age and root resorption for either group (Table 8). This is in line with the Baumrind, et al. study that shows a similar lack of correlation.[7] It does not have a sufficient sample demographic to challenge the Lopatiene, et al. study, which correlates increased OIARR with treatment over the age of

11, because the average age of the patients in the extraction and non-extraction groups were 14.67 and 16.97 years old, respectively.[15]

The Weltman, et al. study discussed in this paper claims that treatment duration is a significant factor in the incidence and severity of root resorption.[10] However, this study found a lack of correlation in either study group to support that claim (Table 8). Because this correlation is repeated in other studies, it is worth exploring further to determine if this study proves to be an anomaly on this topic. There was also no correlation found between resorption and timing of extractions. This statistic could be challenged with an increase in sample size though, as over 77% of the extraction group had extractions completed either before treatment began, or within two months of commencement. There was no significant difference found in root resorption for gender (Table 9). This challenges Aman, et al. and Baumrind, et al. which claim an increase in resorption for each tooth measured for male patients.[7,14] But this data agrees with the Linge, et al. study which also found little to no relationship between resorption and gender.[16] Ethnicity was also found not to have a difference in resorption (Table 9).

The null hypothesis that stated no statistically significant difference exists between the amounts of OIARR present in treatment utilizing extraction of bicuspids vs. treatment without extractions was proven false The null hypothesis that stated there were no correlations between OIARR and age, treatment duration, incisal angulation change, gender, ethnicity, or timing of extraction was proven true in all regards except angulation change, which did correlate to a change in OIARR for the extraction group.

Conclusions

1. Patients treated with extractions experienced 0.71 mm increased mean root resorption on each incisor than those treated without extraction, which is statistically significant.
2. Patients treated with extractions averaged a decrease of 4.85 degrees of central incisor inclination, which correlated with an increase in root resorption, while those without extractions averaged an increase of 5.03 degrees of central incisor inclination, which did not correlate with a change in root resorption.
3. Age, treatment duration, and extraction timing did not demonstrate a statistically significant correlation with changes root resorption for either treatment modality.
4. Gender and ethnicity had no effect on root resorption.

CHAPTER THREE

EXTENDED DISCUSSION

Study Limitations and Further Directions

One benefit of this study was the ability to obtain resorption measurements of both upper and lower incisors, with angulation measurements for upper and lower central incisors, where many previous studies focus solely on upper incisors. It was determined that for lateral incisors, stable landmarks like sella turcica, nasion, posterior mandibular borders, and menton were more difficult to locate and replicate within the data volume. The study would have benefitted by increased scope and useable data if the angulation for the lateral incisors would have been available. Another area of interest that could be considered in future studies would be the resorption of the teeth adjacent to the extracted premolars in cases utilizing extractions for treatment. This would be simple to add onto this particular study with the randomized patient selection already complete. Adding to the overall sample size and including a greater mix of age and ethnicity would also provide a more complete picture of the reality of root resorption in extraction treatment.

Another limitation of this study was the fact that all measurements were completed by a single person which increases the possibility of decreased reliability or potential bias. Adding additional researchers would alleviate these possible pitfalls. The data was collected from Loma Linda University School of Dentistry Graduate Orthodontic Clinic, which means that each patient had the potential to be treated by multiple graduate students and attending faculty doctors throughout their treatment. This decreases the homogeneity of treatment and introduces more potential complicating variables. Utilizing data from a single practitioner may alleviate some of these complications.

As discussed previously, measurements from CBCT data have the potential for increased accuracy due to the elimination of angulation and magnification errors present with periapical and panoramic radiographs.[4,17] But the decrease in these issues does not mean that all accuracy problems have been accounted for. It is worth noting that one study discussed in Lascala, et al. described a mean difference of 0.37 mm to 0.58 mm when calibrating the accuracy of Planmeca CBCT tooth measurements.[18] Considering this brings into question the accuracy of all measurements which allows the potential for overestimating or underestimating the true root resorption that occurred during orthodontic treatment. And even though CBCT is a three-dimensional image, most studies, including this one, ultimately rely upon two-dimensional images rendered from that data. Tooth and root lengths do not tell the entire story of root resorption, as there are some width or circumferential root differences before and after treatment. Increasing the accuracy of these images, and therefore measurements, as well as utilizing a three-dimensional volume measurement of root structures before and after treatment could go a long way into providing more accurate and useful data in a study like this. Improved radiographic technology and innovative ways to measure those radiographs are needed to reach that goal.

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