EFFECTS OF A LINGUAL ARCH AS MAXIMUM ANCHORAGE IN ORTHODONTICS

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ABSTRACT

Lingual arches are frequently used in orthodontic extraction treatment, with the intended purpose of achieving maximum anchorage in the mandibular arch; however, little evidence exists in the literature that supports this anchorage approach. The lingual arch is widely supported in the literature for space maintenance and sagittal correction. It has been proven effective at minimizing any decreases in arch depth and perimeter when there is early loss of primary teeth. Theoretically, the lingual arch as a passive maintenance appliance should exert no forces on the teeth, yet studies have shown both the molars and incisors to move. To examine its anchorage efficiency further, we compared incisor and molar position in extraction treatment with and without the use of a lingual arch.

Pre and post-treatment cephalograms that included lower premolar extractions were recruited from a depository of images. Canine retraction with power chain or NiTi closing coils with or without the use of a lingual arch for maximum anchorage were compared for incisor and molar position. Angular and millimetric measurements for IMPA, L1-NB, L1-APog and molar mesialization were measured and compared using a t-test.

The greatest difference between pre and post-treatment was the IMPA with 5.19° more uprighting of the incisors in the group with no lingual arch, followed by 4.38° more uprighting in the L1-APog measurement. However, none of the differences between the groups were significant: IMPA ($p=0.129$), L1-NB (angular $p=0.161$, millimetric $p=0.205$), L1-APog (angular $p=0.197$, millimetric $p=0.196$) and mesialization of the molar ($p=0.308$).

The change in incisor and molar position does not significantly differ with or without the use of a lingual arch in extraction treatment. Clinically, this suggests that the lingual arch does not provide maximum anchorage. Another modality, such as TADs, may provide a better source of anchorage for space closure.

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CHAPTER 1

INTRODUCTION

Lingual arches are frequently used in orthodontic extraction cases, with the intended purpose of achieving maximum anchorage in the mandibular arch. Orthodontic anchorage is important during treatment as it resists unwanted tooth movement, especially during space closure after extraction. The optimal force level for orthodontic tooth movement is the lightest force that produces a near maximum result (Quinn, 1985). The force that is employed does, however, have equal and opposite effects which often must be minimized in order to obtain the goals of treatment. Anchorage may include other teeth, the palate, the head and neck, or the bones of the face. Each tooth has a different anchorage value which is directly related to the surface area of the roots (Proffit, 2014). The molars, which have multiple roots, will have a larger anchorage value than the incisors and may be used in conjunction with intra and extra oral appliances to achieve even greater anchorage for anterior retraction if desired. This idea is not a novel one and was first implemented by Mershon and Oliver in the early 1900's (Mershon, 1918; Oliver 1929). The lingual arch was used in conjunction with intermaxillary elastics for correction of Class II malocclusions, and was a successful treatment modality by their standards. In 1959, Wein et al, enhanced this technique by adding tip back bends in the lingual arch mesial to the molars. This modification and the concurrent use of Class II elastics were employed and evaluated for increased anchorage (Wein, 1959). The results of the study showed an average proclination (L1-MP) of the lower incisors of 2.5 degrees and an average protrusion (L1 to N-Po) of 1.15mm. These suggest that the mandibular dentition is affected when a mesial force is applied, despite being tied together as a single anchor unit. Additionally, bodily movement of the lower molars accompanied the anterior movement of the lower incisors. This bodily movement was later reaffirmed by Villalobos et al, in 2000. The positional changes in mandibular molars and incisors were evaluated after the placement of a lingual arch for a minimum of 12 months. No external forces were placed on the teeth and the lingual arch was simply used as a space maintainer after extraction or early exfoliation of primary second molars. The study showed a maximum of 1.30mm mesial movement of the molars with an average of 0.15mm mesial movement and a maximum 1.53mm of extrusion of the lower molar with an average of 0.29mm of extrusion (Villalobos, 2000). The observed changes helped define a pattern of extrusion and mesial migration of lower molars due to the lingual arch, irrespective of external forces.

In addition to anchorage, the lingual arch is regularly used as a space maintaining device. The premature loss of primary second molars is commonplace and subsequent mesial tipping of permanent first molars is often counteracted with the use of a lingual arch. The lingual arch is meant to be passive, yet it still places forces on the molars as well as on the lingual aspect of the mandibular incisors. Rebellato, et al. reports an average of .054 degrees distal tip and 0.29mm movement of the mandibular molars with the use of a passive lingual arch for space maintenance (Rebellato, 1997). The same study also showed that the lower incisors tipped labially by 0.73 degrees with 0.44mm of movement, despite a passive fit. Similar results were also found by Singer in 1974 (Singer, 1974). Brennan and Gianelly showed that the benefits of preserving the leeway space with a lingual arch were twofold: anterior crowding was relieved and proper eruption of the premolars was facilitated (Brennan, 2000). These uses of the lingual arch are well documented and supported in the literature, however, the effectiveness of a lingual arch as maximum anchorage during active orthodontic treatment still remains unclear.

With the advent of TAD's and other modern devices, the lingual arch may soon become a less desirable treatment modality especially in extraction cases. Flaring of the lower incisors can be detrimental to treatment and must be controlled properly. Flared lower incisors along with mesialization of lower molars can prevent proper space closure of the upper arch causing a need for interproximal reduction of the lower incisors or a compromised Class II finish. While the lingual arch may be a useful tool for short term space maintenance, its effectiveness as an anchorage device necessitates further investigation.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Extractions in Orthodontics

2.1a Extractions to resolve dental crowding

In the most general sense, the goal of orthodontics is to align teeth. This is achieved by finding a harmonious balance between esthetics and the physiologic limitations of anatomic structures. For decades, clinicians and literature alike have debated extraction therapy in conjunction with orthodontics. As with all treatment, no single philosophy is applicable to all patients. The advantages and disadvantages of each should be carefully considered on a case-by-case basis prior to the start of treatment.

In 1911, the "Great Debate" in orthodontics was happening between Calvin Case and Edward Angle. Angle believed in the so called "Bible Theory" which stated that 32 teeth were placed in a person's mouth by the design of God and that malocclusion of these teeth could only be caused by their own degeneration. Because of these beliefs, he practiced non-extraction orthodontics and attempted to place all of those 32 teeth into occlusion no matter the starting malocclusion (Bernstein, 1992).

Angle's theories were combatted by Calvin Case, a scientist who studied biology. Case understood genetics and believed that malocclusion also had a hereditary disposition. Case objected Angle's classification and stated that the occlusion of the buccal teeth did not indicate the true position of the upper and lower dentures in relation to the overlying soft tissue structure. He also believed that these soft tissue structures were the only basis for true diagnosis (Case, 1911). His thoughts on treatment planning are still relevant today with modern appliance systems and philosophies.

An indisputable belief, common to all philosophies in orthodontics, is to protect the welfare of the patient. The movement of teeth by orthodontic means should not contradict this central dogma. This principle is sometimes called into question in cases of severe crowding. Practically speaking, crowding in orthodontics is commonplace. The etiology of dental crowding is usually due to one of the following: a tooth arch length discrepancy (Fastlicht, et al, 1970; Peck and Peck, 1972; Bernabe, et al, 2005) or mesial movement of the permanent first molars due to early exfoliation of the primary dentition (Rebellato et al, 1997). Proffit, *et al* (2014) classifies crowding in three ways based on severity: mild (1-3 mm), moderate (4-7 mm), and severe (7+ mm). When classified as severe, Proffit *et al (*2014), advocates for extraction. This guideline is not absolute, and other considerations may warrant extraction for patients classified as mild or moderate.

Justification of extractions in severely crowded cases stems from preservation of the bony housing surrounding the teeth. Both the alveolus and surrounding periodontium must be considered during orthodontic treatment (Cheney, 1950, Furstman et al, 1972). When the bony housing cannot sufficiently accommodate the teeth one of the following must be done: extraction, interproximal reduction, or arch lengthening via expansion, distalization, or proclination (Yitschak et al, 2016). In patients with severe crowding and a lack of arch perimeter, extraction of teeth may be the only option in order to relieve the crowding and to place the teeth in a correct position within the bony structure. Proffit proposed guidelines for extraction based on the amount of crowding present within a dental arch. Consideration must also be given to the curve of spee, which influences the classification of crowding (Baldridge, 1969). In cases with less than four millimeters of arch length discrepancy, extraction is rarely indicated, except for instances of severe incisor protrusion or a vertical discrepancy. In most of these cases, this small amount of crowding can be eliminated by interproximal reduction of selected teeth and arch development. In cases with arch length discrepancies between five and nine millimeters both extraction and non-extraction treatments are possible depending on the characteristics of the hard and soft tissues and the control of the incisors. Non-extraction treatment in this scenario may include expansion in the premolar and molar areas. When an arch length discrepancy of ten millimeters or more exists, extraction is almost always indicated. In most of these cases, the large amount of crowding is almost equal to the amount of tooth structure being removed. In these cases, there will be very little effect on the support of the lips or facial appearance (Proffit et al, 2014).

If removal of tooth mass is not employed to address the discrepancy, then changes in the proclination of anterior teeth are frequently observed (Yitschack et al 2016). In a recent retrospective study, the radiographic and casts records of 96 patients were compared prior to and after non-extraction orthodontic treatment. In the patients sampled, every millimeter of crowding translated into the following: an increase of 0.5 degrees in mandibular incisor proclination and 0.2mm of incisor protrusion (Yitschack et al, 2016). These findings were less when compared to previous studies that evaluated mandibular incisor proclination, and found 1.25 degrees of change (McLaughlin et al, 1999). This inconsistency was attributed to utilization of rectangular arch wires throughout treatment, which the authors claimed aided in transverse expansion (Yitschack et al, 2016).

A common pattern is to extract upper and lower first premolars in Class I cases, or upper first and lower second premolars in Class II cases. If the crowding is found in the anterior, extraction of the first premolars will allow for the greatest amount of space to relieve the crowding due to less mesial movement of the posterior segment (Williams et al, 1976).

2.1 Extractions in Orthodontics
2.1b Esthetic considerations

Orthodontic therapy is not limited to the dentition, but rather encompasses the entire craniofacial complex. Careful consideration must be given to the position of the cranial bases, position of the dentition, and the soft tissue profile. These three factors constitute a dynamic equilibrium, which can be disproportionally altered by changing the position of the bony base or dentition.

From a purely esthetic perspective, certain measurements exist to evaluate the soft tissue profile of patients. Cephalometric analyses compare the upper and lower lips to the position of the nose and to each other, while accounting for their thickness (Konstantonis, 2012). In a retrospective analysis of 62 Caucasian Class I crowded patients, the radiographic pre and post treatment records were compared for differences in soft tissue between those treated with extraction and non-extraction (Konstantonis, 2012). At the completion of treatment, the extraction group finished with more retracted lips, an increased nasolabial angle, and a thicker upper lip. The non-extraction group had protraction of the lower lip, but retraction of the upper lip.

In a similar study, more emphasis was placed on visual soft tissue changes in a retrospective comparison of 120 Caucasians who had either extraction or non-extraction treatment (Bowman et al, 2000). Profile pictures of pre and post treatment for the two groups were given to both dentists and laypersons for esthetic evaluation. After assessment of the observed profile changes, dentists and laypeople alike found that non-extraction treatment had little effect on facial esthetics. Conversely, those patients treated with extraction were found to have an improvement in esthetic appearance, but only when the starting lip procumbency was exaggerated. Moreover, patients treated with extraction who ended treatment with their lips more than 2-3mm behind the E plane were deemed to have a worsened profile. This negative byproduct of treatment is directly correlated to their initial lower lip position in relation to the E plane (Bowman, et al, 2000). Numerical measurements of lip protrusion showed an average of 1.8mm less lip protrusion in the post treatment extraction group when compared to the non-extraction group. Although diminutive in number, this difference correlated into a positive facial change. These findings stress the importance of careful diagnosis and treatment planning prior to the start of treatment.

In addition to considering the patients starting profile, one must consider soft tissue mass and thickness, which is heavily influenced by ethnicity. Attention to racial norms, and sensitivity to cultural views on esthetics must also be given. African American patients often present with more convex profiles and protrusive lips; this may be partially influenced by more procumbent lower incisors (Scott et al, 1999). In a retrospective survey based study, the profiles of African American patients who underwent either extraction or non-extraction therapy were evaluated by both black and white orthodontists and laypersons (Scott et al, 1999). Similar to studies on Caucasian patients, those individuals in the extraction group were classified as having either better or worse profiles. This distinction was heavily dependent on initial soft tissue protrusion (Scotte et al, 1999). Notably, white observers found a reduction in convexity and a flatter profile to be more pleasing. Numerically speaking, white panelists gave a positive evaluation when the lower lip was 2mm in front of Ricketts' E plane. In contrast, black panelists identified a pleasing esthetic result when the lower lip was 4mm in front of the E plane (Scott et al, 1999). These subtle differences in racial preference should be considered as just one of many in the complex treatment planning process.

2.1 Extractions in Orthodontics

2.1c Long- term stability

Certain schools of thought in orthodontics advocate for extraction therapy, with the belief that it creates greater long term stability and limits relapse in certain cases. This idea is founded on the following principle; teeth that finish upright are most stable because they are securely held by the basal bone. This philosophy was first advocated by Tweed and stresses the maintenance of arch form and incisor proclination (Boley et al, 2003). In a retrospective study, 32 patients with severe crowding were treated with extraction of four first pre-molars via Tweed mechanics and evaluated post-retention (Boley et al, 2003). At the completion of treatment, casts were evaluated by Little's irregularity index and found to have had a decrease of 5.3mm. Models were then taken 10 years postretention. Eighty percent of postretention patients had an acceptable index of less than 3.5mm and of the remaining twenty percent none were classified as severe (Boley et al, 2003).

It is clear from the literature, that the decision for extraction in orthodontics is multifactorial and not straightforward. Furthermore, the initial malocclusion and rationale for extraction dictate the mechanics utilized in treatment. It is imperative in non-crowded extraction cases that anchorage be given the utmost consideration. With a basis in extraction therapy established, it is worthwhile to explore anchorage considerations.

2. 2 Anchorage In Orthodontics

2.2a Types of anchorage used

Anchorage in orthodontics is the ability to resist unwanted tooth movements (Proffit et al, 2014). Anchorage can be provided by the orthodontic appliances themselves, but these appliances often require additional anchorage auxiliaries to assist in the desired movement of the teeth while minimizing the effects on others. To do this, the applied force must be concentrated onto the teeth that are in need of movement and an equal amount of force in the opposite direction must be dissipated over as many other teeth as possible, which keeps the pressure in the periodontal ligament of all of the anchor teeth low, thus resisting tooth movement (Quinn et al, 1985). All teeth have a threshold for movement. Below the threshold, the pressure on the tooth does not have any reaction and could provide good anchorage control. The threshold for tooth movement is low, but teeth have different responses to pressure depending on their anchorage value. This anchorage value allows a given force to move some teeth more than others depending on what their individual thresholds for movement are. The optimal force level for tooth movement is the lightest force on a tooth that produces a maximum response(Quinn et al, 1985). Any force that is greater than this level will move the tooth with the same amount of effectiveness but with much greater strain on the anchorage unit. The ideal situation for resisting unwanted tooth movement is to produce an optimal force on the teeth being moved that is below the threshold for the teeth in the anchor unit.

Reciprocal Tooth Movement

Reciprocal tooth movement is when the force applied to teeth or arch segments is equal, as is the distribution of pressure in the PDL (Proffit et al, 2014). If this type of pressure were placed on identical teeth, one would have the same amount of force as the other through the PDL and they would move towards one another by equal amounts. Another example of reciprocal movement is with premolar extraction. In this situation, the incisors and canines in the anterior segment are pitted against the second premolar and first molar either by closing loop or sliding mechanics (Kojima et al, 2010). Ideally, the same force would be felt by the anterior and posterior segments, although true reciprocal movement in this case would only occur if the anterior and posterior teeth had the same PDL area for the applied force to distribute. More likely, the PDL area of the posterior segment is larger than the PDL area in the anterior segment, thus distributing the force over a larger PDL area (Krishnan et al, 2006), allowing the anterior teeth to move more than the posterior teeth. While this is not true reciprocal tooth movement, it is commonly used in clinical situations when space closure is indicated from both arch segments.

Reinforced Anchorage

Anchorage in the posterior segment can be reinforced by the addition of the second molar to the posterior unit. This addition changes the ratio of the root surface areas of the anterior and posterior segments so that relatively more pressure would be felt by the anterior teeth (Proffit, et al, 2014). The force distribution over a larger PDL area in the posterior allows for greater retraction of the anterior segment with less mesial movement of the posterior unit. The decrease in pressure in the posterior segment allows for more anchorage as the force is dissipated over a greater surface area of PDL, thus lowering the force below the threshold for movement of those teeth (Quinn, et al, 1985).

Light forces are key in reinforced anchorage for this very reason. Too much force will overpower the anchorage of the posterior unit and the posterior teeth with "slip" forward, thus losing anchorage.

Cortical Anchorage

Different types of bone have different responses during tooth movement. Cortical bone is much more resistant to resorption than medullary bone and will greatly slow tooth movement if a root comes in contact with it (Reitan, 1964). Some clinicians plan their anchorage by torqueing the roots of the posterior teeth against the cortical plate as to inhibit any mesial movement during space closure (Al-Awadhi et al, 2015). While this may work in theory, the mesial force on the posterior teeth may actually pull the root along the cortical plate, possibly causing root resorption if the buccal root torque is maintained (Horiuchi et al, 1998).

Skeletal Anchorage

More recently, skeletal anchorage has become mainstream in orthodontics. Temporary anchorage devices, or TADs, have changed the way many clinicians close extraction space as it allows for more control over the anchor unit. A successful TAD has similar characteristics to an ankylosed tooth and should not move unless there is degeneration of the surrounding bone (Proffit et al, 2014). Osseointegration of the TAD is unnecessary for long-term success and may actually be undesirable for temporary use. In addition to TADs, other skeletal anchors are available which are placed beneath the soft tissue instead of penetrating through it. Many of these anchorage devises involve bone plates that utilize the palate (Feldmann, 2008) or zygomatic buttress (Kilkis, 2012), allowing for even more control over movement of the teeth. Anchorage differs in the maxilla and mandible. Before the invention of TADs, extraoral force by way of a headgear, and the anterior portion of the palate as with a Nance appliance, were the only ways of obtaining posterior anchorage with minimal force on the teeth.

2.2 Anchorage in Orthodontics
2.2b Maxillary verse Mandibular

Anatomic differences, namely the presence of the palate and absence of the tongue account for differences in maxillary anchorage when compared to the mandible. For this reason appliance design for maxillary anchorage also differs greatly from its counterpart. Some intraoral appliances use the cortical bone in the maxilla by fixing the intermolar distance across the palate, causing the roots of the molars to engage the buccal cortical plate (Al-Awadhi et al, 2015). One example of this type of appliance is the trans-palatal arch, or TPA. The TPA consists of a heavy wire connecting two bands that are cemented onto the first molars in the maxillary arch and is normally contoured to fit passively and comfortably with the wire non-impinging on the tissue of the palate (Zablocki et al, 2008; Burstone et al, 1981). This appliance is commonly used to stabilize the position of the molars in three dimensions or to slightly augment their position, especially if rotational change is needed (Zablocki, et al, 2008). Surpassing its use simply for space maintenance, the TPA is commonly used as an anchorage modality in cases involving the extraction of upper premolars (McNamara et al, 2001). Some clinicians believe that this appliance will provide a rigid anchor unit as it splints the molars together, thus minimizing any mesial movement of the posterior segments (Zablocki et al, 2008), however, the TPA is a tooth borne appliance, which allows for a reciprocal type of tooth movement.

The Nance appliance is a modified version of the TPA and includes an acrylic button that contacts the anterior portion of the hard palate. This addition of the acrylic button is thought to distribute the majority of the forces from the teeth to the maxilla itself which is useful in cases that require greater amounts of maxillary anchorage (Nance, 1947). While the Nance appliance has been proven to be more effective than a TPA in terms of anchorage, mesialization of the maxillary molars is still a side effect when used in maximum anchorage situations (Shpack et al, 2007). In this study, 14 subjects requiring extraction of the maxillary first premolars were observed. Each of the 14 subjects were fitted with a Nance appliance and space closure was completed in two stages, utilizing NiTi closing coil springs to fully retract the canines. While the canines were successfully retracted using this system, there was a mesialization of the molars by an average of 1.2mm for one group and 1.4mm for the other group (Shpack et al, 2007). With these limitations in place for tooth borne appliances, more recent additions to the orthodontic arsenal has allowed for even greater anchorage control of the posterior teeth using the skeleton as anchorage.

TAD, or temporary anchorage devices, are short-term mini implants that can be loaded immediately with no need for lengthy osseointegration (Melson et al, 2000). TADs are commonly used to supplement anchorage in extraction cases because they are thought to increase the anchorage value of the teeth that they are ligated to. One study utilized 78 patients that were equally distributed into three groups utilizing TADs, a Nance appliance, and a headgear for maxillary anchorage during retraction of the maxillary canines (Sandler, 2014). Though the differences were not significant, the study showed an average molar movement of 0.8mm with the TAD, 1.84mm with the Nance appliance, and 1.36mm with a headgear. Feldmann et al, 2008, found even less mesial movement of the molars (0.1mm) when mini-implants were used in conjunction with bone plates placed in the palate to close extraction spaces.

In the mandible, anchorage options are limited in comparison to the maxilla. TADs may be used in the mandible as well to anchor posterior segments during retraction of the lower anterior teeth and have even been shown to allow for distalization of the mandibular molars when used in conjunction with bone anchor plates (Sugawara et al, 2004). Other than TADs, a more common treatment modality for gaining anchorage in the mandibular arch has been a fixed lower lingual arch.

2.3 Lingual Arch as a treatment modality

2.3a Appliance design

The lingual arch was first described in the early 1900's by Mershon. In his 1918 article, he discusses the use for the lingual arch as a treatment modality that does not interfere with the direction of normal growth for the mandible. The original design consisted of two bands cemented to the lower first molars connected by "a wire of suitable size" that may have auxiliaries attached to it to allow for certain orthodontic mechanics. The wire was .036" in diameter and was inserted into a locking mechanism that was soldered onto the lingual side of the molar bands. The wire was first constructed on a plaster model and was fitted to the bands. Just mesial to the tube, the wire was bent to have a step down toward the gingiva before extending mesially toward the anterior teeth. The wire was adapted as to not impinge on the gingiva, but also to follow the contours and irregularities of the specific dental arch. Once the wire was fully adapted, it was then fit to the locking mechanism on the bands and was ready for delivery (Mershon, 1918).

Mershon specified that the best location for the lingual arch was to be near the lingual surface of the teeth as close to the gingival margin as possible. The arch was made to passively fit into the mouth as to minimize any irritation to the patient. Once the wire was in place, force was able to be applied to the teeth in three ways, the first by straightening the wire in any areas which had dental irregularities, the second by soldering auxiliary springs to the wire, and third by stretching the wire intraorally with pliers (Mershon, 1918).

Gifford, also in 1918, discussed the lingual arch as a treatment modality but instead of using a removable type of appliance as Mershon had designed, he advocated for a fully fixed and soldered design. This lingual arch followed closely a design for a labial arch fabricated in the same manner by Lloyd Lourie who stated that his soldered labial arch allowed for individual tooth movement only in the direction that was desired (Lourie, 1918). Lourie also stated that due to the exactness of adjusting and stretching the wire to allow for certain movements, a removable type of arch should be used to avoid complications until the clinician had gained adequate experience.

Still today, the design of the lingual arch remains consistent with the original design from one hundred years ago. Clinicians have augmented the appliance in order to enhance some of its effects like adding a bend mesial to the molar tube as to tip back the lower molar and assist in anchorage preparation when using Class II elastics (Wein et al, 1959). Despite minor adaptations, the lingual arch appliance has stood the test of time in its design as well as its use as a space maintainer and for a form of anchorage in the mandibular arch.

2.3 Lingual Arch as a treatment modality
2.3b Space Maintenance in the mixed dentition

Dental crowding is one of the most common reasons that patients choose to undergo orthodontic treatment. The dental arch undergoes natural decreases in arch perimeter after eruption of the first molar and continues to decrease throughout the transition from primary to permanent dentition (Rebellato et al, 1997). This decrease is commonly caused by mesial migration of the permanent first molar and less often by lingual movement of the incisors (Rebellato et al, 1997). Thanks to nature, primary molars are slightly larger than their permanent premolar replacement, which allows for a small amount of error during tooth exfoliation and eruption. This space, called leeway space or E space, accounts for about 2.5mm of extra space per side of the arch in the mandible and about 1.5mm per side of the arch in the maxilla (Proffit et al, 2014). When the primary second molars are lost during the early stages of the mixed dentition, more often than not the permanent first molar will tip into the adjacent space, thus diminishing any of the leeway space provided by the natural size discrepancy between the deciduous and permanent teeth. To prevent this problem from arising, orthodontic intervention is often needed.

The simplest form of space maintenance intervention is a band and loop appliance. This appliance is useful in unilateral early loss of a primary second molar. While effective, this type of space maintainer was found to have a high failure rate from the cement when used for approximately 18 months (Sasa et al, 2009). When multiple posterior primary teeth are missing, or bilateral early loss of the primary second molars, a lingual arch space maintainer is indicated.

The lingual arch space maintainer requires eruption of the permanent first molars as well as the lower incisors. The position of the mandibular molars are thought to be stabilized against the cingulum of the lower incisors, also preventing any potential for lingual tipping of the incisors (Singer, 1974). Hayes Nance, in 1947, stated that the lingual arch maintains arch perimeter, which occurs along with labial movement of the lower incisors and mesialization of the molars (Nance, 1947). More so than its effective use as a space maintainer, the lingual arch is commonly used as an auxiliary for anchorage in the mandibular arch as well.

2.3 Lingual Arch as a treatment modality
2.3c Mandibular Anchorage in Extraction Cases

Due to anatomical limitations, the options for anchorage in the mandibular arch are reduced in comparison to the maxilla. More recently, TADs have been employed to accommodate anchorage needs in the mandibular arch. Before the advent of TADs, mandibular anchorage had to be supplemented by other auxiliaries such as the lower lingual arch, which is still used today.

As early as the 1930s, clinicians were finding anchorage in the mandibular arch to be a problem. Brodie in 1938 treated a series of Class II patients with edgewise appliances and Class II elastics and found that the majority of the Class II correction was, in fact, coming from forward positioning of the mandibular dentition (Brodie et al, 1938).

To prevent this type of movement, practitioners tried to assist in mandibular anchorage by adding distal tip to the mandibular molars (Tweed, 1945), while others utilized head cap therapy to assist in their Class II correction (Fisher, 1948). Another form of anchorage being used at the time was the mandibular lingual arch. In 1959, Wein described the use of the lingual arch in conjunction with Class II elastics for the correction of Class II malocclusions in forty treated cases. He found the average increase of the angulation of the lower incisors to the lower border of the mandible in the treated cases to have an average of 2.5 degrees and a range of a 3 degree decrease to a 9 degree increase. Along with this increase in angulation, Wein also found an average forward movement of the lower incisors to be 1.15mm to the nasion-pogonion reference line. This trend was also seen in the cephalometric superimpositions, which showed an average incisor protrusion of 1.5mm (Wein, 1959). This function of the lingual arch as an anchorage modality was also described by Kanter in 1956 where it was used as mandibular anchorage in the correction of Class II malocclusions with elastics and an extraoral headgear appliance. Johnson advocated the use of a lingual arch in his twin wire appliance system as well for its added advantage of mandibular anchorage (Johnson, 1938).

While there seems to be a lack of current evidence for the use of a lingual arch for anchorage in the mandible, it is seen commonly in orthodontic practice for this very reason. With every advantage that this appliance may deliver, there are always drawbacks and potential negative effects that may occur, which must be noted and addressed.

2.3 Lingual Arch as a treatment modality
2.3d Deleterious Effects

For every action in orthodontics, we must consider the reaction that it may have in the opposite direction. No orthodontic appliance is perfect, and understanding the side effects of treatment auxiliaries only enhances the treatment capacity of the clinician. The lower lingual arch has been shown to place a labial force on the lower incisors and also to have an effect on the position of the mandibular molars. One study observed the positional change of the molars and incisors of 23 Caucasian patients after the placement of a lingual arch for a minimum of 12 months (Villalobos et al, 2000). The lingual arch was left in place with no other orthodontic appliances present or any other forces placed on the dentition. The results of this study showed positional changes of the molars anteriorly by an average of 0.15mm and a maximum of 1.3mm. This mesial movement was accompanied by a maximum proclination of 1.73mm of the lower incisors (Villalobos et al, 2000).

In a study by Miotti, 31 patients due for extractions were observed. A lingual arch was cemented in each patient prior to extraction of the mandibular first bicuspids. During the observation period of 3 months, no other mechanics or appliances were employed on the mandibular dentition. The findings of the study were in accordance to those of Villalobos with a forward positioning of the mandibular molars (Miotti, 1984). The studies by Villalobos and Miotti both studied the efficacy of the lingual arch as a passive mechanism on the mandibular dentition. Both showed the potential for mesial movement of the mandibular molar, which Miotti attributed to maturation and growth (Miotti, 1984). He also associated growth and maturation to the finding of slight lingual tipping of the lower incisors when the lingual arch was in place. This lingual tipping has been refuted by Rebellato who showed an average labial tipping of 0.73 degrees of the mandibular incisors (Rebellato et al, 1997). His study observed 30 patients, all of which had mobile deciduous second molars and a minimum of 3mm of mandibular crowding. Pre-treatment cephalograms were compared and superimposed with cephalograms that were exposed after the eruption of the permanent mandibular premolars. The treatment group had only a lower lingual arch in place with no other appliances or forces on the dentition. Besides the labial tipping of the lower incisors, results of the study actually show an average distal tipping of the mandibular molar of 0.54 degrees. While this is a small degree of change, all of the findings in the study were statistically significant.

All of the studies mentioned used the lingual arch in a passive manner without any additional force on the dentition. As stated previously, one study by Wein in 1959 utilized the lingual arch as anchorage in conjunction with intermaxillary Class II elastics. His study showed an average increase in labial angulation of the lower incisors to be 2.5 degrees with an average protrusion of 1.15 mm. This study alone shows the potential for labial movement of the lower incisors during orthodontic treatment and must be studied further.

2.4 Cephalometrics

2.4a Reliability of Cephalometric points

The addition of the cephalogram in 1931 to the field of orthodontics enabled clinicians to diagnose and treatment plan patients in a much more accurate way. Prior to Broadbent's invention, most orthodontic cases were treatment planned according to measurements of dental and facial deformities using the existing relations of the teeth and bony structures which were then compared to the same set of measurements after treatment was complete (Broadbent, 1931). The original cephalostat was designed to expose cephalograms from the lateral and posterior-anterior views at the same time, allowing for even greater availability of data for each patient. There have been many studies on cephalometric points along with various analyses which all describe the x-rays in numerical values. These numerical values allow for normative standards to be described and compared to the individual measurements found for each patient. With each point, there are possibilities for error that can augment the outcome measurements for the patient. The first type of error present involves error of projection (Baumrind, 1971). This type of error is due to the 2-dimensional quality of the cephalogram capturing a 3-dimensional shape. X-rays are non-parallel and originate from a small source, expanding to a larger field as they project further from that source. This may cause enlargement of certain anatomical structures in the craniofacial area that must be noted. The second type of error involves the identification of specific anatomical landmarks on the cephalogram while the third involves mechanical errors in tracing and measuring the points and angles (Baumrind, 1971).

The study by Baumrind in 1971 attempted to quantify the errors in landmark identification and the impact that the errors may have on angular and linear measurements. Twenty random lateral cephalograms were selected and traced separately by five observers, marking sixteen standard cephalometric points. Results of the study showed that there were large differences in reliability of several landmarks and that gonion and the apex of the lower incisor were the least reliable (Baumrind, 1971). The lack of reliability for the lower incisor apex was attributed in the paper to "noise" from adjacent structures in the same area as well as bias from the observer on where they believed that the structure should be anatomically.

A second article was published as an addendum to the first and addressed the third type of error in cephalometric tracing, the error of angular and linear measurements using the previously plotted anatomical points. The same 20 headfilms were used and linear and angular measurements were traced and computed. It was observed that there was a large difference in the magnitude of error between measurements with a greater error for angular than linear measurements (Baumrind, 1971). This study makes it clear that errors in cephalometric measurements can cause a great discrepancy when evaluating radiographs and that some measurements may be less reliable than others depending on the specific points that they include.

2.4 Cephalometrics
2.4b Measurements Analyzed

The invention of the cephalostat by Broadbent in 1931 greatly advanced the field of orthodontics. Cephalograms allowed clinicians a new perspective on diagnosis and treatment based on the dental and skeletal patterns that were previously unable to be recognized simply by looking at the patient. In order for cephalograms to be consistently read by a large number of practitioners, specific points, measurements and normative values had to be formulated to provide a reference for comparison when viewing an individual x-ray. While many cephalometric analyses exist, a number of early analyses are still commonly used today.

One of the earliest cephalometric analyses was developed by William Downs in 1948. In a paper published in 1952, Downs states that studying the head is a four-dimensional problem involving height, width, depth and time (Downs, 1952). Of these four, the lateral cephalogram is ideal for studying three of the dimensions, which are height, depth and time. For his analysis, Downs chose to use Frankfort Horizontal as a reference plane to study facial profiles. Frankfort Horizontal is an adaptation from an original anthropologic line introduced by Camper in 1794. This line was used as a reference to demonstrate race-related differences and evolutionary developments (Downs, 1952). Beyond looking at just facial profiles, Downs included dental measurements in his analysis using a line connecting hard tissue A point to pogonion to determine protrusion and angulation of the upper incisors. This line was initially selected because it connected the most anterior limits of the basal bone of both the maxilla and mandible (Downs, 1956). Ricketts included this reference plane in his analysis as well and extended its use to compare the protrusion and angulation of the lower incisor as well as the upper (Ricketts, 1961). In an original study in 1960, Ricketts observed 1000 cephalograms of patients with "usual" orthodontic problems and found averages for protrusion and angulation of the lower incisors in reference to the A-pogonion line to be 1.0+/-1.5 and 22+/-4 degrees, respectively.

Around the time of Downs, Cecil Steiner developed his own cephalometric analysis which was published in 1953. Instead of using A-pogonion as an anterior reference plane, Steiner preferred to use a line connecting Nasion to hard tissue B point. According to him, this line was more useful than others because it was closer to the measurement in question and relied on less moving parts (Steiner, 1953). Relating the incisors to the basal bone had already been done using the mandible as a reference for maxillary and mandibular teeth. Steiner believed that it was important to use points of reference that were close in proximity to each other for effectiveness of the measurement. For this reason, the mandibular basal bone was used for measurements involving the mandibular teeth only (Steiner, 1953). His analysis was based from radiographs from the Bolton Brush Study in the 1930's. This study included 22,000 radiographs of 5,000 individuals ranging in age from 1 to 18. Using this information, averages for children with "normal occlusion" were described for protrusion and angulation of the mandibular teeth in reference to the N-B point line to be 4mm and 25 degrees, respectively.

A third orthodontist of the time created a cephalometric analysis of his own based almost totally around the position of the lower incisor. Charles Tweed, in 1946, first described the Tweed Triangle in cephalometrics (Tweed, 1946). The triangle consisted of three angles: FMA – angle of the mandibular plane to Frankfort horizontal, IMPA – angle of the lower incisor to the mandibular plane, and FMIA – angle of the mandibular incisor to Frankfort horizontal. In his study, he described that all patients with good facial proporitons had mandibular incisors that were upright over the basal bone and that facial disharmony was often accredited to the degree to which the anterior teeth had been displaced in protrusion. To insure uprighting of the lower incisors, Tweed suggested 87 degrees, with a 5 degree deviation, as the ideal angle of the lower incisor to the mandibular plane. After practicing for a number of years under the guidance of Angle and his non-extraction philosophy, Tweed discovered that he was unable to achieve good stability and esthetics in many cases due to the location of the incisors, which led to his approach on extraction treatment.

While there have been many studies on the position of the mandibular incisors and their position in an antero-posterior direction, there is a significant lack of evidence on the position of the lower molar in the same dimension. One study in 2000 looked at the position of the lower first molar on 24 individuals with the use of a lower lingual arch as a space maintainer (Villalobos et al, 2000). In order to measure positional changes of the molar, a line was drawn through the long axis of the tooth, connecting the mesiobuccal cusp to the mesial root tip. After superimposition, the linear and angular changes were given a positive value in the mesial direction and a negative value for distal movements. Due to the lack of evidence on other forms of measurements for the molars in an A-P direction, this method by Villalobos seems promising and needs to be studied further.

CHAPTER 3

AIMS OF THE INVESTIGATION

- To investigate the effectiveness of a lower lingual holding arch as an anchorage modality during extraction treatment.
- Hypothesis 1: The utilization of the lingual arch as maximum anchorage offers less uprighting and retraction when compared to the control group.
- Hypothesis 2: The lingual arch does not have an effect on restricting the mesial movement of the lower first molar when compared to the control group.

CHAPTER 4

MATERIALS AND METHODS

4.1 Subjects

Pre and post-treatment cephalograms of 25 subjects ranging in age from 10 to 30 years old were recruited from a depository of images from the Temple University Kornberg School of Dentistry Department of Orthodontics. Inclusion criteria for the study were comprised of comprehensive orthodontic treatment involving four premolar extractions, or extraction of two premolars on the lower arch along with two-stage retraction of the canines and incisors.

All individuals had started and completed their treatment at the dental school between the years 2012 and 2016 and had received extraction of all four first premolars or lower first premolars only. 12 of the individuals had a lingual arch in place as an auxiliary anchorage appliance during canine retraction. The remaining 13 individuals had no additional anchorage appliance on the mandibular arch. All subjects included in the study signed an informed consent upon their first visit at the Kornberg School of Dentistry allowing for the use of images for research purposes. The research protocol was validated by the Temple University IRB committee but did not allow any health information of the patient to be used, including age for each subject.

4.2 Landmarks

The following landmarks were identified on each cephalogram: sella, nasion, hard tissue A point, hard tissue B point, gonion, gnathion, pogonion, menton, lower incisor tip and root apex, midroot point on lower first molar and most inferior point on the internal border of the mandibular symphysis. The cephalometric points used are described in Table 1 (Jacobson, 2006).

Table 1
Cephalometric point definitions

Cephalometric Points	Definition
Sella	The geometric center of the pituitary fossa
Nasion	The most anterior point on the frontonasal suture in the midsagittal plane
A point	The most posterior midline point in the concavity between the ANS and the prosthion (most inferior point on the alveolar bone overlying the maxillary incisors)
B point	The most posterior midline point in the concavity between the most superior point on the alveolar bone overlying the mandibular incisors and pogonion
Gonion	A point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and the inferior border of the mandible
Gnathion	A point located by taking the midpoint between the anterior (pogonion) and inferior (menton) points of the bony chin
Pogonion	The most anterior point on the chin
Menton	The lowest point on the symphyseal shadow of the mandible seen on a lateral cephalogram
Lower incisor tip	Most superior point on the lower incisor crown
Lower incisor root apex	Most inferior point on the lower incisor root
Midroot of lower first molar	The point bisecting a line drawn from the mesial cusp tip to the mesial root apex

4.3 Measurements

From the landmarks defined above, six measurements were made on each cephalogram. Millimetric and angular changes in incisor position were evaluated with the first five measurements defined in Table 2 (Jacobson, 2006). These measurements are components of classic cephalometric analysis and well cited throughout the literature. To quantify the amount of molar movement the mandibular plane was used as a reference plane. The position of the mandibular first molar was located at the midpoint of the mesial root; a perpendicular line from the mesial cusp to the mesial root apex was bisected to locate this point. The most inferior point on the internal border of the mandibular symphysis was located and a line was drawn perpendicular to the mandibular plane. The millimetric difference between these two points served to measure mesial movement of the first molar (Figure 1).

Table 2
Lower incisor angular and millimetric measurements defined

Measurement	Definition
IMPA	Position of the lower incisor angulation established by the mandibular plane
L1-NB (angular)	The relative angulation of the mandibular incisors determined by the angle formed by the long axis of the lower incisor to the line from nasion to point B (NB)
L1-NB (millimetric)	The relative anteroposterior location of the mandibular incisors determined by relating the most labial portion of the crown of the incisor to the line from nasion to point B (NB)
L1-APog (angular)	The relative angulation of the mandibular incisors determined by the angle formed by the long axis of the lower incisor to the line from point A to Pogonion (A-Pog)
L1-APog (millimetric)	The relative anteroposterior location of the mandibular incisors determined by relating the most labial portion of the crown of the incisor to the line from point A to Pogonion (A-Pog)

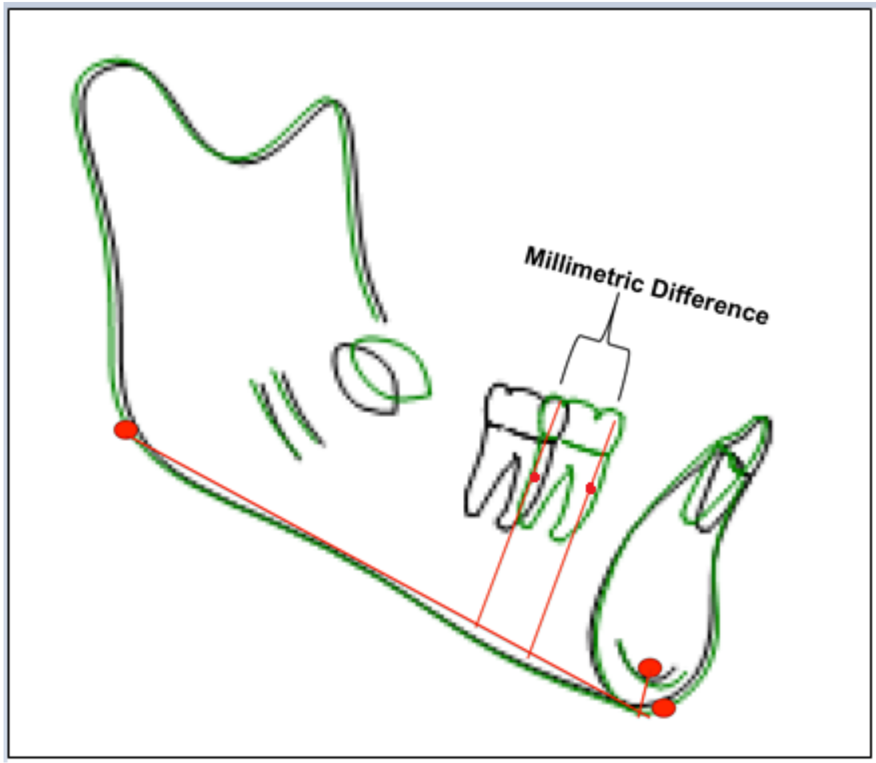

Figure 1. Example of measurement for mesial movement of the lower first molar

4.4 Reliability of Landmarks and Measurements

To ensure that landmarks and measurements were reliable, all cephalograms were traced and measured again one month after initial measurements, by the same investigator. Intra-examiner reliability was then assessed with a Student's t-test.

Pre-treatment cephalograms for each case were traced and measured using Dolphin imaging software version 11.5 (Figure 2). Angular and millimetric measurements for the lower incisors, including IMPA (Tweed, 1946), L1-NB (Steiner, 1953) and L1 to A-Pog (Ricketts, 1960) were evaluated. Post-treatment cephalograms were traced as well and superimposed on the pre-treatment radiographs using the structural method proposed by Bjork to eliminate any discrepancies due to growth (Bjork, 1969). All measurements were completed twice by the lone examiner to ensure reliability of the cephalometric tracings. The angular and millimetric changes for the lower incisors in the pre- and post-treatment cephalograms were evaluated using a Students T-test along with changes in position of the lower first molars as described by Villalobos (Villalobos et al, 2000). The midpoint of the mesial root of the lower first molar was used as a reference for anchorage loss. A perpendicular line from this point to the mandibular plane was drawn and the distance from that point to the point on the mandibular plane perpendicular to the most inferior point of the internal symphysis of the mandible was measured. This was repeated for all subjects pre- and post-treatment.

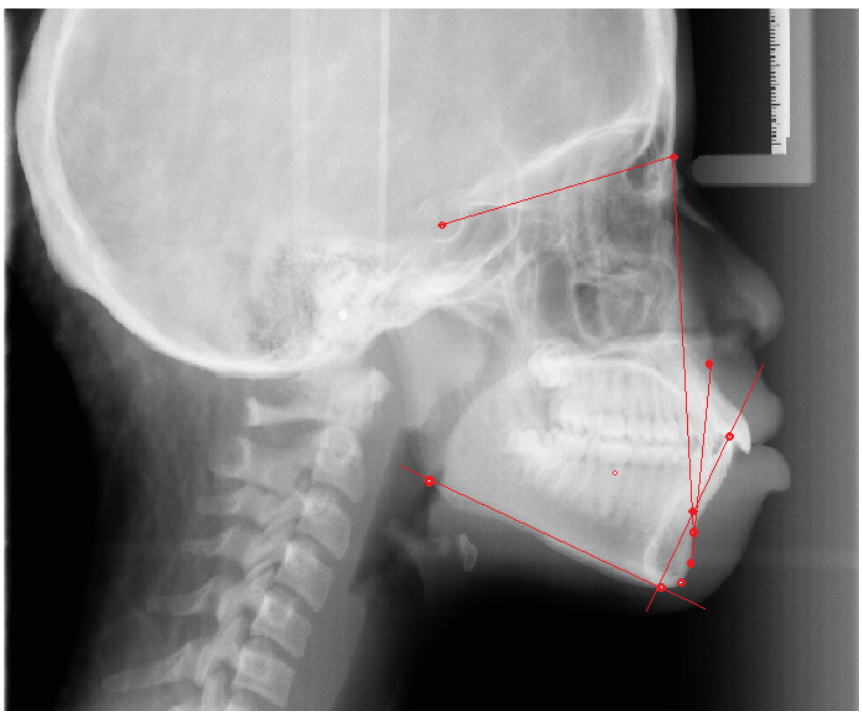

Figure 2. Traced cephalogram using Dolphin Imaging software version 11.5

CHAPTER 5

RESULTS

5.1 Results Overview

The pre- and post-treatment Cephalometric x-rays of 25 patients that underwent extraction of upper and lower first premolars during orthodontic treatment, were obtained from a list of achieved patients. Of these 25 patients, 12 of them utilized a lower lingual arch for anchorage during canine retraction while the remaining 13 utilized no anchorage auxiliary other than archwires. Differences in angular and millimetric changes in the lower incisors and millimetric mesialization of the lower first molar were compared between the two groups.

No significant differences were found between the subject and control groups for any of the six measurements tested.

5.2 Millimetric Changes in Incisor Position

The average pre and post-treatment values for L1Apog and L1NB for both groups are listed (**Table 3**). No statistically significant difference was found between the initial values for L1Apog (p=.071) or L1NB (p= .119). The post treatment values did not differ between groups for L1Apog (p=.431) or L1NB (p=.510). The average differences between the pre and post treatment cephalograms (**Table 4**) did not vary significantly between groups for the L1Apog (p= .197) or L1NB (p=.161) measurement.

Table 3
Average Incisor Millimeteric Measurements

	Pre-Treatment **L1NB**(mm)	Post-Treatment **L1NB**(mm)	Pre-Treatment **L1Apog**(mm)	Post-Treatment **L1Apog(**mm)
LLA (n=12)	9.56 ± 2.51	6.92 ± 2.78	7.78 ± 1.92	4.95 ± 2.53
No LLA (n=13)	11.46 ± 2.88	7.68 ± 2.81	9.45 ± 2.43	5.68 ± 2.43

Table 4
Differences in Pre and Post Treatment Incisor Millimeteric Measurements

	LLA (n=12)	**No LLA (n=13)**	P value
Change in **L1Apog** between pre and post treatment	2.84	3.76	.197
Change in **L1NB** between pre and post treatment	2.64	3.78	.161

5.3 Angular Changes in Incisor Position

The average pre and post-treatment values for L1Apog and L1NB for both groups are listed (**Table 5**). No statistically significant difference was found between the initial values for IMPA (p= 0.761), L1Apog (p= 0.566) or L1NB (p= 0.368). The post treatment values did not differ between groups for IMPA (p=0.291), L1Apog (p=.324) or L1NB (p=.672). The average differences between the pre and post treatment cephalograms (**Table 6**) did not vary significantly between groups for the IMPA (p=0.129), L1Apog (p= .196) or L1NB (p=.205) measurement.

Table 5
Average Incisor Angular Measurements

	Pre-Treatment **IMPA**	Post-Treatment **IMPA**	Pre-Treatment **L1NB** (angular)	Post-Treatment **L1NB** (angular)	Pre-Treatment **L1Apog** (angular)	Post-Treatment **L1Apog** (angular)
LLA (n=12)	95.43 ± 6.46	91.85 ± 9.02	33.28 ± 5.70	27.95 ± 7.95	29.55 ± 4.96	25.46 ± 7.99
No LLA (n=13)	95.96 ± 8.75	86.50 ± 9.57	35.65 ± 8.02	26.14 ± 9.13	31.15 ± 6.84	22.42 ± 7.34

Table 6
Differences in Pre and Post Treatment Incisor Angular Measurements

	LLA (n=12)	**No LLA (n=13**	P value
Change in **L1Apog** between pre and post treatment	4.09	8.72	.196
Change in **L1NB** between pre and post treatment	5.33	9.51	.205
Change in **IMPA** between pre and post treatment	3.85	9.46	0.129

5.4 Mesial Movement of the Mandibular First Molar

The average initial and final position of the first mandibular molar is listed (**Table 7**). The average difference between the initial and final position of the first molar are denoted in the table as well. The difference for the LLA group was 2.58mm ± 1.33mm and the difference for the group with no LLA was 1.85mm 1.05mm. Both of these numbers were positive, meaning that the molars in both groups had an average mesial movement and did not move distally. The average differences between the pre and post treatment cephalograms did not vary significantly between the two groups ($p=0.308$).

Table 7
Differences in Pre and Post Treatment Mesial Movement of the Lower First Molar

	Mesial Movement of the Lower Molar (mm)		
	Initial	Final	Difference
LLA (n=12)	24.7 ±3.09	22.13 ±3.48	2.58 ±1.33
No LLA (n=13)	22.9 ±3.59	21.1 ±4.21	1.85 ±1.05
P value	0.308		

CHAPTER 6

DISCUSSION

The lower lingual holding arch is frequently utilized throughout orthodontic treatment; however, most research on lower lingual holding arches is devoted to its use as a space maintainer (Rebellato, 1997). In common orthodontic applications, the lower lingual arch is used to provide anchorage in the lower arch during space closure. Literature supporting the use of a lower lingual holding arch as an anchorage modality is scarce (Wein, 1959). To date, its use as maximum anchorage during extraction treatment for the lower arch has not been studied. A general consensus exists that the lingual arch is successful in maintaining space in the lower arch after premature loss of deciduous teeth (Villalobos, 2000). Supplementing this is the established belief that lower lingual arches maintain space and allow for partial alignment of the lower incisors (Brennan and Gianelly, 2000). However, when discussing anchorage modalities for the lower arch, there is a lack of evidence supporting its efficacy.

To investigate the effects of a lingual arch as an anchorage modality pre- and post-treatment cephalograms of 25 patients with first premolar extractions on the lower arch were analyzed and compared to controls. Millimetric and angular measurements of each group were calculated to estimate unwanted tooth movement. There were no statistical differences between the control and treatment groups for pre and post treatment measurements. However, the control group showed on average more uprighting and retraction of the lower incisors than the experimental group that utilized a lingual arch.

Mesial movement of the lower first molar was also compared between the two groups and the difference was not found to differ significantly.

In regards to the lower incisors, it was an interesting, though not surprising, finding that there was no significant difference between the two groups. We hypothesized that the incisors in the control group would have more uprighting and retraction than those in the experimental group; this was evident when comparing measurements, despite a lack of statistical significance (L1-NB angular, $p=0.205$; L1-NB millimetric, $p=0.161$). When retracting the lower canines through the first premolar extraction space, an equal and opposite mesial force is placed on the second premolar and first molar. It logically follows that this force is transmitted to the lower four incisors when a lower lingual arch is in place. Furthermore, this force transferred via the anterior bow proclines and protrudes the incisors. Proclination of the anterior teeth also happens naturally in the alignment phase of orthodontics.

To correct crowding there must be an increase in arch perimeter, which often also results in an increase in arch length. When lower incisors are crowded to start, they will naturally flare forward when an initial alignment archwire is in place. One source of error in this study was that the amount of initial crowding for each case was not accounted for. It is possible that cases with greater initial crowding, may have had more severe flaring with the lingual arch in place than cases with minimal crowding.

After incisor alignment and canine retraction, the lower lingual arch is usually removed. At this stage of the treatment, the incisors are commonly retracted together using either closing loop or sliding mechanics. These mechanics place a lingual tipping force on the incisors as well as bodily retraction. These latter movements present additional complexities and may have influenced the measurements obtained. Ideally, cephalograms would be exposed at the beginning of treatment and at the end of canine retraction. Superimpositions of these time points would show the true effects of the lingual arch prior to any additional mechanics that were completed after its removal.

Mesial movement of the lower first molar was compared for the same subjects. In order to measure the mesial movement, I devised a technique using a time-tested superimposition method by Bjork (Bjork, 1969). Bjork found the lower internal border of the mandibular symphysis to be a stable point for cephalometric superimposition. Using this concept, I drew a perpendicular line from the lowest point on the inferior curvature of the symphysis to the mandibular plane. This point was then measured along the mandibular plane to a perpendicular line drawn from the midroot point of the mesial root of the first molar. Other methods of measuring the mesial movement of molars have been described using the palatal plane as a reference line (Heo, 2007). However, that previous study looked at the mesial movement of the upper molars instead of the lower. The palatal plane was used in that study because the teeth that were being measured were in the same bone. To accurately measure any movement of the teeth and minimize error, it is advisable to use a reference plane within the same region (Steiner, 1953). To avoid potential measurement error, I used the mandibular plane as a reference line, confining the measurements to the mandible.

Utilizing the mandibular plane as a reference is not a cure-all; it does present potential confounders. The mandible remodels as the patient matures, potentially causing error in the measurements. Often times during retraction of the incisors, Class II elastics are worn to increase the anchorage in the upper arch. These elastics have a mesial force on the lower molar, which could also protract the molars to some degree. Elastic wear of the subjects were not taken into account and could be a cause of measurement error.

Another source of error in the study was the lack of matched controls for age, sex, and ethnicity. Due to the limitations of patient records available, these factors were unable to be accounted for in the study.

Six measurements were used to describe changes in the position of the lower incisors and first molar after completion of extraction treatment with or without the use of a lingual arch as mandibular anchorage. None of the changes that occurred were significant, which should be noted by clinicians. When using any appliance, it is important to understand what potential negative effects the appliance can have and how those effects can influence the treatment, both clinically and financially. While the lower lingual holding arch may be a great appliance for space maintenance, it may not have the positive effect needed for maximum retraction of the lower anterior teeth.

CHAPTER 7

CONCLUSIONS

1. The angular change in lower incisor proclination did not differ significantly between the group that utilized the LLA and the group that did not. The lower incisors on average were more upright post-treatment in the control group that did not utilize the LLA.
2. The millimetric change in the lower incisor retraction did not differ significantly between the group that utilized the LLA and the group that did not. The lower incisors on average were retracted more post-treatment in the control group that did not utilize the LLA.
3. The millimetric mesial movement of the lower first molar did not differ significantly between the group that utilized the LLA and the group that did not.
4. Although none of the differences were statistically significant, the cephalometric measurements between the two groups could have clinical implications on the use of an LLA.

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APPENDICES

APPENDIX A
ANGULAR AND MILLIMETRIC MEASUREMENTS FOR THE LOWER INCISORS WITH LINGUAL ARCH IN PLACE (FIRST MEASUREMENTS)

LLA												
Number	1	2	3	4	5	6	7	8	9	10	11	12
IMPA (Pre)	102.2	99.9	92.5	94.8	88.4	98.4	85.3	87.4	87.7	98.4	104.1	96.5
IMPA (Post)	99.7	105.8	92.7	87.6	83.7	92.7	83.8	74.3	90.0	92.8	104.2	82.1
L1-NB mm (Pre)	10.1	8.6	7.1	6.1	6.9	8.2	8.2	10.5	10.0	12.3	14.7	13.0
L1-NB mm (Post)	8.7	6.8	4.9	4.8	3.1	2.7	5.2	8.1	7.5	10.6	11.7	9.1
L1-NB Angular (Pre)	37.4	33.9	26.9	34.8	25.6	32.1	26.6	31.4	30.8	37.0	43.7	39.4
L1-NB Angular (Post)	34.0	37.2	23.0	27.1	18.1	23.4	24.0	17.4	31.5	32.1	44.4	23.6
L1-APog mm (Pre)	8.6	6.1	5.8	5.4	5.7	8.2	6.7	10.0	8.9	7.7	11.2	8.5
L1-APog mm (Post)	7.2	3.1	3.4	2.7	2.9	3.0	2.9	7.2	5.7	5.9	10.3	4.4
L1-APog Angular (Pre)	37.3	31.3	24.4	32.2	23.5	33.1	23.4	29.5	23.2	29.2	35.7	29.8
L1-APog Angular (Post)	33.1	33.0	22.1	23.4	22.4	25.2	20.0	16.0	27.7	25.9	41.4	14.5

APPENDIX B
ANGULAR AND MILLIMETRIC MEASUREMENTS FOR THE LOWER INCISORS WITHOUT A LINGUAL ARCH IN PLACE (FIRST MEASUREMENTS)

NO LLA													
Number	1	2	3	4	5	6	7	8	9	10	11	12	13
IMPA (Pre)	104.2	101	109.3	95.7	101.9	95.6	79.5	86	97.6	95.4	96.3	78.3	102.2
IMPA (Post)	90.7	76.5	87.3	101.9	97.4	98	77.8	90.7	84.3	82.2	88.6	64.3	85.8
L1-NB mm (Pre)	13.5	10.6	14.4	11.9	12.7	9.3	5.9	9.3	14	12.9	11.7	6.9	15.9
L1-NB mm (Post)	10.1	3.6	9.1	11.1	9	8.3	3.1	6.6	11.8	7.9	8.5	3.7	7.2
L1-NB Angular (Pre)	46.2	37.4	41.7	33.6	42.4	31.8	21.6	31.6	42.7	38.4	35.3	21.1	41.7
L1-NB Angular (Post)	30.8	13.8	22.1	38.1	36	32.8	18.6	33.9	31.8	23.6	30.5	8.9	23.9
L1-APog mm (Pre)	11.6	8.5	12.2	7.9	13.3	6.7	6.3	7.4	10.9	11.3	8.2	6.2	11.8
L1-APog mm (Post)	7.1	2.5	6.6	7.5	9.8	6.1	2.9	4.5	7.7	7.1	6	1.7	4.4
L1-APog Angular (Pre)	39.6	35.1	38.1	23.1	39.7	27.8	24.8	23.9	33.3	34.1	28.8	20.1	31.2
L1-APog Angular (Post)	23.3	13.8	17.8	30.5	31.2	29.8	21.6	29.8	23.9	20.8	25.3	6.7	16.4

APPENDIX C
MILLIMETRIC MEASUREMENTS FOR MESIAL MOVEMENT OF THE LOWER FIRST MOLAR WITH LINGUAL ARCH IN PLACE (FIRST MEASUREMENTS)

LLA												
Number	1	2	3	4	5	6	7	8	9	10	11	12
Initial mm	20.2	26.3	25.1	24.4	26.9	27.4	25.3	29.8	22.2	22.4	19.8	27.2
Final mm	19	22.2	22.9	20.3	25.8	23.6	22.4	28.1	18.9	18.3	17.2	27
Difference mm	1.2	4.1	2.2	3.9	1.1	3.8	2.9	1.7	3.3	4.1	2.6	0.2

APPENDIX D
MILLIMETRIC MEASUREMENTS FOR MESIAL MOVEMENT OF THE LOWER FIRST MOLAR WITHOUT LINGUAL ARCH IN PLACE (FIRST MEASUREMENTS)

NO LLA													
Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Initial mm	21.2	24.8	22.3	20.3	17.2	19.8	31.4	23.1	22.9	23	22.2	27.9	22.1
Final mm	18.1	22.7	20.1	17.4	14.1	19.1	30.2	20.9	21.7	22.8	20.3	27.7	19.3
Difference mm	3.1	2.1	2.2	2.9	3.1	0.7	1.2	2.2	1.2	0.2	1.9	0.2	2.8

APPENDIX E
ANGULAR AND MILLIMETRIC MEASUREMENTS FOR THE LOWER INCISORS WITH LINGUAL ARCH IN PLACE (SECOND MEASUREMENTS)

LLA												
Number	1	2	3	4	5	6	7	8	9	10	11	12
IMPA (Pre)	103.1	100.8	91.2	97.1	90.1	99.8	87	86.3	89.3	99.2	105.3	96
IMPA (Post)	99.9	106.3	91.8	90.9	85.2	93.5	86.4	75.1	90.9	93.7	105.5	83.1
L1-NB mm (Pre)	9.9	8.8	7	6.3	7.1	7.9	8	10.8	9.8	12.1	14.2	12.8
L1-NB mm (Post)	8.8	7	4.6	5.1	3.8	2.2	5.4	8.3	7	10.1	11.5	9.2
L1-NB Angular (Pre)	37.1	34	26.3	35.5	25.2	32.4	26.2	31.1	31.2	36.5	43.5	40.3
L1-NB Angular (Post)	33.5	37.6	23.2	26.7	17.5	23.9	23.8	17.9	32.1	31.4	44	23.8
L1-APog mm (Pre)	8.5	6.4	5.7	5.8	5.3	8.4	6.4	10.2	9	7.5	11.4	8.7
L1-APog mm (Post)	7.3	3.2	3.8	2.5	2.5	3.4	2.6	7.5	5.8	5.5	10.7	4.6
L1-APog Angular (Pre)	37.5	32.1	24.9	32.5	22.8	33.6	24	29.2	23.7	28.9	36.1	29.3
L1-APog Angular (Post)	33.6	33.7	22.4	23.1	21.9	25.8	19.8	15.7	28.3	25.5	41.9	13.8

APPENDIX F
ANGULAR AND MILLIMETRIC MEASUREMENTS FOR THE LOWER INCISORS WITHOUT A LINGUAL ARCH IN PLACE (SECOND MEASUREMENTS)

NO LLA													
Number	1	2	3	4	5	6	7	8	9	10	11	12	13
IMPA (Pre)	105	101.8	108.1	96.7	100.3	95.1	81.1	86.5	98.2	96.3	95.9	79.5	103
IMPA (Post)	91.7	77.3	86	101.5	96.5	98.2	78.2	90	83.9	82.5	87.9	66.1	84.7
L1-NB mm (Pre)	13.2	10.3	14.1	12.1	13	9.5	6.2	9.1	14.2	13.1	11.9	6.8	15.5
L1-NB mm (Post)	9.9	3.4	9	10.8	9.3	8.8	3.5	6.2	12	7.5	8.5	3.5	7.4
L1-NB Angular (Pre)	45.7	37.6	42.6	33.1	43	31.2	20.8	32.4	42.1	37.5	35.9	20.4	41.1
L1-NB Angular (Post)	30.1	13.2	22.6	37.9	36.1	33.1	17.4	33.5	30.9	23.1	30	7.8	24.1
L1-APog mm (Pre)	11.5	8.9	12.3	7.6	13.2	6.5	7	11.1	11.2	8.6	8.6	6.3	11.5
L1-APog mm (Post)	7	2.7	6.7	7.2	10	6.4	2.6	4.2	7.9	7.1	6.3	1.6	4.2
L1-APog Angular (Pre)	40.9	35.4	38.8	22.8	40.5	27.4	25.1	24.6	34	34.7	29.2	20.4	31.1
L1-APog Angular (Post)	23	14.3	17.1	31.1	30.6	29.9	21.8	30.4	24.2	21.3	24.9	7.1	15.3

APPENDIX G
MILLIMETRIC MEASUREMENTS FOR MESIAL MOVEMENT OF THE LOWER FIRST MOLAR WITH LINGUAL ARCH IN PLACE (SECOND MEASUREMENTS)

LLA												
Number	1	2	3	4	5	6	7	8	9	10	11	12
Initial mm	20.3	26.2	25.2	24.4	26.7	27.3	25.1	29.9	22.3	22.1	19.6	27.3
Final mm	19.2	22.1	23.1	20.5	25.5	23.4	22.2	27.9	18.8	18.2	17.4	27.2
Difference mm	1.1	4.1	2.1	3.9	1.2	3.9	2.9	2	3.5	3.9	2.2	0.1

APPENDIX H
MILLIMETRIC MEASUREMENTS FOR MESIAL MOVEMENT OF THE LOWER FIRST MOLAR WITHOUT LINGUAL ARCH IN PLACE (SECOND MEASUREMENTS)

NO LLA													
Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Initial mm	21.3	24.9	22.1	20.2	17.2	19.9	31.5	23.2	22.7	22.9	22.3	27.8	22.1
Final mm	18.2	22.7	20.3	17.2	14.2	18.9	30.1	21	21.6	22.7	20.2	27.8	19.2
Difference mm	3.1	2.2	1.8	3	3	1	1.4	2.2	1.1	0.2	2.1	0	2.9