MECHANICAL PROPERTIES OF ELASTIC THREAD FORCE SYSTEMS IN CANINE EXPOSURES AND APPLICATION OF FORCE

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ABSTRACT

Objectives: To investigate differences in the modulus of elasticity, tensile strength, and load at breakage for elastic thread alone and elastic thread with gold chain in combination used in force application of palatally impacted and exposed maxillary canines.

Methods: Two groups with n=6 in each were tested. A circular portion of elastic thread was cut, tied and measured to the nearest hundredth of a millimeter and recorded. Five links of a gold chain were cut and an elastic thread was tied to the fifth link opposite the bondable eyelet. The length of the elastic thread and the total apparatus was measured to the hundredth of a millimeter and recorded. An Instron with a ramp speed of 100 mm/min was used for all testing.

Results: The addition of the gold chain, as compared to the elastic thread alone, increased the modulus from 8.8 MPa (SD 3.7) to 17.0 MPa (SD 5.03), (p< 0.04) and significantly decreased the maximum tensile stress at breakage from 92.1N (SD 5.0) to 84.1N (SD 1.6), (p<0.004) and the tensile stress at maximum load from 107.8 N (SD 6.7) to 93.8N (SD 4.8), (p<0.002). The stress-strain curve for both groups demonstrated an initial linear behavior followed by non-linear behavior, partially obeying Hooke’s Law, due to the inherent nature of the elastic thread. The addition of the gold chain introduced a rigid element by reducing the of length of the elastic thread by one-half, altering the properties of the assembly.
**Conclusions:** The modulus of elasticity (stiffness) increases and the toughness and resiliency decreases when a gold chain is added to the assembly and compared to elastic thread alone. This could indicate that in the gold chain group, more initial force/strain is delivered to the tooth and there is less stress relaxation over time due to the decrease in the amount of elastic thread. Therefore, the elastic thread alone delivers a more constant and continuous force to the tooth. The use of elastic thread alone may provide a biomechanically more efficient approach to orthodontic movement of impacted and open exposed teeth.
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CHAPTER 1

INTRODUCTION

Impaction of maxillary permanent canines is commonly seen in the orthodontic office. With the exception of the third molars, impaction of maxillary permanent canines is the most common form of tooth impaction (Becker 2015b). Treatment and management frequently involves a multidisciplinary approach involving many specialists in the dental field. (Bishara 1992). There are mixed reports in the literature of the overall prevalence of impacted maxillary canines with reports ranging from 0.2-5.2% (Bischara 1992). About 8% of impactions are bilateral and 80% are palatally impacted as compared to labially impacted (Bishara 1992, Kokich 2004). Maxillary canine impaction is twice as common in females (1.17%) than males (0.51%) (Bishara 1992). Canines have the longest period of development of all of the permanent teeth and also have the longest, most tortuous path to erupt into the oral cavity with the bud of the maxillary canine being wedged between the nasal cavity, orbit, and anterior wall of the maxillary sinus (Becker 1983, Bischara 1992).

The etiology of maxillary canine impaction is not fully understood but can be grouped as generalized or localized (Bishara 1992). Many authors in the literature describe the guidance theory versus the genetic theory. There is lack of consensus of which is truly the cause of impaction. Labial impactions are most usually seen with lack of interarch space available for the tooth while this is not usually seen in palatal impactions (Bishara 1992, Kokich 2004). Clinical signs of impaction include delayed eruption past the age of fifteen, absence of canine bulge, presence of palatal bulge and splaying of the lateral incisor (Bishara 1992).
Periapical and occlusal radiographs are sufficient for radiographic evaluation and one must rely on the SLOB rule for proper identification of the location of the impacted tooth (Bishara 1992). In select cases (class I with no crowding) it has been suggested by Ericson and Kurol that if the primary canine is removed by age eleven, it will normalize the position of the permanent canine in 91% of cases if the crown is distal to the midline of the lateral and 64% if the crown is mesial to the midline of the lateral (Bishara 1992).

When treatment planning and managing impacted canines, it is very important to evaluate the esthetics; if the correct approach is chosen then the result is usually esthetic and stable (Persson 1983). There are many surgical treatment options for the impacted canine and each option has risks, benefits, indications, contraindications and limitations to the procedure.

Some surgical procedures include surgical exposure with natural eruption, open surgical exposure with bonded attachment, closed surgical exposure with bonded attachment, and apically positioned flap (Bishara 1992, Kokich 2004, Schmidt 2007). When considering the use of an open or closed exposure with the use of an attachment it is necessary to also consider the mechanical properties of the system being used to apply force to the tooth to bring it into the oral cavity. Pearson et. al. compared a simple open exposure with a closed exposure; a second surgical procedure was needed in 15.3% of simple open exposure cases and 30.7% of closed exposure cases (Schmidt 2007). Ferguson and Parvizi studied open exposures of palatally impacted canines and found 84.6% of all open exposures of maxillary canines were successful (Schmidt 2007).

Orthodontic tooth movement of palatally impacted canines has minimal effects on the periodontium (Schmidt 2007). The impacted canine and the lateral roots adjacent to
the impacted canine were slightly shorter and there were no significant pulpal changes to the canine (Schmidt 2007). Visual differences included discrepancies with torque, gingival architecture and the overall alignment of the tooth (Schmidt 2007).

Research on orthodontic elastic thread used in ligation of the exposed canine is extremely limited. Through a search of the literature, it has been found that most threads that are made from synthetic polymers exhibit good elasticity and have a high force elongation (Persson 1983). However, the stiffness made it difficult to have precise force application and demonstrated that there was rapid degradation of the force after a minor movement (Persson 1983). For adequate tooth movement, the elastic material used must be able to produce a predictable force and the force/relaxation ratio should be low (Persson 1983).

It is important to define terms that are used when discussing the mechanical properties of force systems. Elastic modulus measures an object's resistance to being deformed elastically when a stress is applied to it. It is the slope of the line on a stress/strain curve and can be measured in megapascals. As the modulus of elasticity increases, the stiffness of the material or assembly also increases. Tensile strength at maximum load, measured in Newtons, is the maximum stress that a material can withstand before failure occurs. Load at breakage, measured in Newtons, is the amount of force at which failure actually occurred.
CHAPTER 2
REVIEW OF THE LITERATURE

2:1 Introduction

Correction of impacted maxillary canines represents a significant portion of orthodontic practice (von der Heydt 1975). Published studies on the incidences, surgical and non-surgical approaches, risks, benefits, treatment options and suggestions as well as guidelines for the management and treatment of impacted maxillary canines exist in abundance. Older studies examine the properties of elastomeric materials used in orthodontics but they pertain mainly to power chain and latex and non-latex rubber bands. There is little to no published data or studies on elastic thread or the properties of gold chain used in orthodontics or studies pertaining to the differences in properties between elastic thread alone compared with gold chain and elastic thread that could be found using PubMed, Embase, AJO-DO, The Angle Orthodontist, or Google search.

2:2 Overview

Canines are vital to the continuity of the dental arch. They are found at the angle of the mouth and they occupy a critical position in the arch. The canine is a large and strong tooth that has two faces as well as two cutting edges and has the longest root in the human dentition (von der Heydt 1975). As the most important tooth in the upper arch, its correct anatomical position ensures the proper contour of the face (Johnston 1969). Maxillary canines have the longest course of eruption into the mouth. At the age of three it is high in the maxilla and the crown is directed mesially and lingually. The crown is
located very close to the roots of the lateral incisors during development and as the canine erupts it tends to upright itself and assume a normal position in the oral cavity. The average age of eruption of permanent maxillary canines is thirteen years in males and twelve years three months in females (Bishara 1992, Listas 2011, Parkin 2012). Due to the close proximity to the laterals, caution against flaring laterals during treatment for fear of impacting the developing canines (Bishara 1992).

Management of impacted maxillary canines often involves input, treatment planning and treatment from other specialties including the general dentist, pediatric dentist, oral surgeon, periodontist and/or orthodontist. (Kohavi 1984, Bishara 1992, Listas 2011). Overall, the orthodontist is responsible for the success of the patient and the treatment plan as a whole (Becker 2015a).

Tooth impaction can be defined as the infraosseous position of the tooth after expected time of eruption while displacement can be defined as the anomalous infraosseous position of the canine before the expected time of eruption (Listas 2011). Palatally impacted canine teeth are usually closer to the surface than they appear due to the depth and curvature of the palate (von der Heydt 1975). Impaction can be associated with esthetic impairment if not eliminated or resolved (Cassina 2018).

During the examination of a patient, a clinician should be looking for signs of impaction. If the canine tooth is completely developed, the angle to the midline and the overlap with the lateral incisors are good indications of impaction; the degree of mesial overlap of the lateral has a strong influence on the severity of the canine impaction (Uribe 2017). Results from Ericson and Kurol indicated that when the canine tooth was positioned mesially to the lateral incisor the risk of complications increased three fold.
Increased age and increased severity of impaction can increase the risk of ankylosis of the impacted tooth (Cassina 2018).

In 1978 Becker et. al. stated that palatally impacted canines require active orthodontic traction in cases in which surgical exposure alone will not allow them to erupt. Decisions about how to treat the impaction are based on the prediction of the expected periodontal, esthetic and stability outcomes of the procedure (Becker 2016).

Common early approaches for the management of palatally impacted canines include extractions, autotransplantation, or surgical exposure with orthodontic alignment (Cassina 2018). Some canines can be exposed and left to naturally erupt into the oral cavity while others need extensive intervention and treatment (Kohavi 1984). When an oral surgeon and orthodontist work as a team, the impacted teeth can be successfully brought into alignment and can be made completely indistinguishable from other teeth that erupted normally (Becker 2016). The aims of the surgical phase of treatment are to eliminate any soft or hard tissues impeding canine eruption, to provide the orthodontist with access to the impacted tooth and to create an environment that is suitable for dental bonding all while causing minimal harm and damage to the patient and associated teeth (Becker 2016).

There is a wide range of preferred clinical protocols to exposing impacted teeth. These differ in the depth, width and flap design of surgical exposures (Becker 2016). There is controversy about the amount of tissue to be removed around the impacted tooth and how deep and how far the tissue removal should continue (Becker 2016).
Common complications that can accompany the management of impacted canines include increased treatment time, bone loss around the canine and adjacent teeth, root resorption of the canine or adjacent teeth and gingival recession (Listas 2011).

If orthodontic treatment has not begun when the impaction is initially noted, there is risk for resorption of the roots of permanent incisors (Ericson 1988). Root resorption of neighboring teeth may be the most detrimental side effect as it is often hard to diagnosis and assess clinically (Bishara 2004, Listas 2011). Before surgical intervention, 4.1% - 12% of patients are found to have root resorption on teeth adjacent to the impacted canine with the maxillary lateral being affected in 80% of cases (Ericson 1988, Listas 2001, Sajnani 2013). Overall, 48%-67% of impacted canines are said to be associated with resorption of lateral incisors (Becker 2016). When the angulation of the impacted canine to the lateral exceeds twenty-five degrees, the risk of root resorption is estimated to be 50% (Listas 2011). Resorption of teeth prior to intervention is said to be more common in females with prevalence ranging from 2:1, 4:1, to 10:1 (Listas 2011, Sajnani 2013). The accurate amount of resorption can be obscured by the radiographic technique used (Sajnani 2013). Palatally impacted teeth can also cause migration of neighboring teeth, loss of arch length and even cystic lesions or infections. (Listas 2011).

The early diagnosis and intervention of palatally impacted could save time, expense and overall more complex treatment as the patient ages (Listas 2011). However, the palatal impaction is usually detected after the age of thirteen and requires surgical treatment (Becker 1983).
2:3 Etiology

The etiology of canine impaction is believed different causes within an individual and can also be considered obscure to unknown. During development, the crown of the permanent canine lies directly lingual to the apex of the root of the primary canine (Johnston 1969). Any changes in the position of the primary canine due to caries or premature loss of a primary tooth can be reflected along the root of the primary canine and may cause deviation in the position and direction of the eruption of the permanent canine (Johnston 1969). Delayed resorption of the primary canine may divert the permanent canine and may cause the permanent canine to migrate palatally causing impaction due to the hard, dense tissue of the palate (Johnston 1969).

One etiologic theory describes the causes as localized or generalized. Localized causes of impaction, also known as primary causes of impaction, are more common than generalized causes and can include tooth size arch length discrepancy, prolonged retention or early loss of the primary canine, abnormal position of the developing tooth bud, trauma, premature root closure, rotation of tooth bud, clefting, ankylosis, cysts, neoplasms, dilacerations, or idiopathic effects (Bishara 1976, Becker 1983, Bishara 1992, Ericson 1988, Listas 2011). Generalized causes, or secondary causes, are less common and can include endocrine deficiencies, febrile diseases or irradiation (Bishara 1976, Bishara 1992).

Many authors have discussed two other etiologic theories of impaction, the guidance theory and the genetic theory. The guidance theory relates to the canine tooth lacking guidance during eruption due to extra space in the apical maxilla due to hypoplastic or missing lateral incisors (Leonardi 2004, Listas 2011, Uribe 2017). An
important variable for proper eruption of the permanent canine is the presence of neighboring teeth in the area of the canine. Lateral incisors with the correct root length at the proper time during development are important for facilitating eruption of the canine (Bishara 1992). Eruption of the maxillary lateral and first premolar precedes the canine (Becker 2015b). If the premolar has erupted with mesiobuccal inclination, the palatal root will be rotated into the path of the canine, which can then cause deflection of the path of eruption (Becker 2015b). If the incisors block the path of eruption of the permanent canine, impaction is likely to result (Becker 2016). In unilateral cases of central incisor impaction there is a high frequency of disturbance of the eruption of the canine on that same side (Becker 2015b).

The genetic theory relates canine impaction to developmental disturbances in the dental lamina (Leonardi 2004, Listas 2011). Impaction is seen within families and bilaterally in the same person (Leonardi 2004, Listas 2011). Canines that are palatally displaced are commonly seen in individuals who also have peg shaped or missing lateral incisors (Leonardi 2004, Listas 2011). Initially, in 1981 Becker et. al. stated that there was 2.4x increase in palatal impaction in a site with a missing lateral while in 2015 they argued that it was far less common to see an impacted canine when a lateral incisor was missing (Bishara 1992, Becker 2015b). It was more common to see an impacted canine with hereditary lateral incisors anomalies of size and shape, seven times more than on the side with a missing lateral (Becker 2015b). Excess palatal width can also cause impaction as there is a lack of guidance for eruption (Listas 2011). Other contributing genetic factors include sex differences and as associations with other dental anomalies including
ectopic molars, infraocclusion of primary molars and aplasia of third molars (Listas 2011).

As others have argued that canine impaction is under mainly genetic control, in 2015 Becker et. al. argued that this cannot be the case. They state that if canine eruption and impaction were under total genetic control then the impaction should be bilateral in most patients with a small percent showing variations as genetics occurs on both sides and does not show left-right variability (Becker 2015b). It can be concluded that the factors in the area of the impacted canine create an environment that is under genetic control, which deprives the canine of its guidance causing it to assume an abnormal eruption path (Becker 2015b).

Other factors to consider are the long path of development and eruption as well as the large size of the canine tooth, as much as twenty two millimeters (von der Heydt 1975, Listas 2011, Becker 2015b). Delayed dental development in relation to age is also an indication of canine impaction as well as skeletal features such as class II division two with deep overbite, hypodivergence and abnormal maxillary width (Uribe 2017).

2:4 Incidence of Impaction

Maxillary canines are the second most commonly impacted teeth following third molars. (Kokich 2004, Matthews 2013). Incidence in the literature is inconsistent and has been reported to be between 0.2%-5.2% (Ericson 1988, Vermette 1995, Baccetti 2009, Leonardi 2004, Listas 2011, Parkin 2012, Sajnani 2013, Urbie 2017, Cassina 2018). The cumulative prevalence of impacted canines as reported by Thailander and Myerberg is 2.2% in seven to thirteen year olds (Bishara 1992). Ericson and Kurol report that it is
twice (1.17%) as common in females than males (0.51%) while Johnston reported it is three times more common in females (Johnston 1969, Bishara 1976, Bishara 1992, Listas 2011, Cassina 2018). One third of canine impactions are labial while two thirds are palatal with palatal impactions exceeding labial impactions 3:1 (Johnston 1969, Bishara 1976, Bishara 1992, Kokick 2004, Baccetti 2009). Bilateral impactions occur in 0.35% of cases according to Bishara et. al. and in 8% of cases according to Listas and are more common in females than males (Bishara 1992, Listas 2011).

Jacoby reported that 85% of palatally impacted canines have sufficient space in the arch while only 17% of labial impactions have enough space in the arch (Bishara 1992). Palatally impacted canines do not have the chance to erupt on their own due to the thickness of the palatal bone and tissue thus making space may not be the easy answer to eruption (Bishara 1992).

2:5 Diagnosis of Impaction

The most critical point in prevention of impacted maxillary canines is the clinician’s ability to recognize the tooth displacement early and predict this failure of eruption (Listas 2011). The most opportune time to notice a potential issue is during the early mixed dentition and appearance of this anomaly may indicate appearance of others later in life (Listas 2011).

A thorough clinical and radiographic exam should be completed on every patient. The clinician should clinically be looking for delayed eruption of the permanent canine or retention of the primary canine past the age of fifteen, absence of a normal labial canine bulge, presence of a palatal bulge, delayed eruption or distal tipping of the lateral incisors
Predictors of an impacted canine in the early mixed dentition include peg or missing laterals, hypoplasia of the enamel or missing premolars or infraoccluded primary molars (Bishara 1976, Listas 2011).

Radiographs can be used to obtain information about the position of the tooth. Johnston suggested in 1969 to take an ordinary periapical film with the cone of the X-ray tube at ninety degrees and a sufficient diagnosis can be made (Johnston 1969). Use of the SLOB rule can be used with 92% accuracy to locate the tooth (Bishara 2004, Kokich 2004). A periapical radiograph relates the canine to the neighboring teeth mesiodistally and incisogingivally (Bishara 1976, Bishara 2004). An occlusal radiograph can be used to determine the buccolingual position of the tooth while a panoramic radiograph can also be useful (Bishara 2004, Bishara 1976). The overlapping of the canine with the lateral incisors on panoramic X-ray can be an indicator of impaction (Listas 2011).

2:6 Non-Surgical Approaches

Not every impacted canine needs to be treated surgically. Often times, if the impaction or potential impaction is diagnosed early enough, simple non-surgical approaches can be taken. As reported by Ericson and Kurol, early extraction of the primary canine can help prevent the impaction or ectopic eruption of the permanent canine (Kokich 2004). This method is highly predictable if the crown of the permanent canine is positioned no further than the mesial root surface of the lateral incisor (Kokich 2004). If the crown of the permanent canine is beyond the mesial root surface of the lateral incisor, extraction of the primary tooth will not allow for self-correction (Kokich 2004). In a class I malocclusion without crowding, extraction of the primary canine by
age eleven allows for normalization of the permanent tooth in 91% of cases if the crown of the canine is distal to the midline of the lateral incisor and in 64% of the cases if the crown is mesial to the midline of the lateral incisor (Ericson 1988, Bishara 1992).

Ericson suggests that the primary canine be extracted between the ages of ten and thirteen for the correction of palatally ectopic canines to prevent further impaction (Ericson 1988). This approach can be utilized until the late mixed dentition phase of development as the retained primary tooth acts as a mechanical obstacle for the eruption of the permanent tooth (Listas 2011). For success, there should be normal space in the arch as well as no evidence of resorption of the lateral incisors (Ericson 1988). In a study by Ericson in 1988, a total of forty-six ectopically erupting canines were examined and treated. The primary canine was extracted and the patients were followed every six months for a total of eighteen months. Thirty-six of the forty-six canines with palatal eruption assumed normal eruption in the given time frame. At the twelve-month mark, all except for nine of the forty-six canines examined had normal or improved positioning of the tooth on radiographic exam. If a change in the eruption is not detected within one year of extraction then alternative treatments should be explored. A positive change in about 50% of cases can be seen radiographically with this approach (Ericson 1988). However, in a repeated study in 2004 by Leonardi et. al., it was also found that extraction of the primary canine lead to eruption of the palatally displaced canine in 50% of cases but was considered highly unsuccessful (Leonardi 2004). Leonardi et. al. does not recommend extraction of a primary canine as an effective procedure to increase the rate of normal tooth eruption of a palatally displaced maxillary canine (Leonardi 2004).
Extraction of the primary canine as well as use of cervical pull headgear and brackets has also been suggested to increase or maintain maxillary arch length and create space during the mixed dentition (Leonardi 2004, Baccetti 2009, Matthews 2013). This can be successful in over 80% of cases (Leonardi 2004, Baccetti 2009). However, the addition of the headgear does not influence the time of eruption of the impacted canine (Leonardi 2004).

The use of rapid maxillary expansion has also been suggested for the treatment of impacted canines. Some have observed transverse maxillary deficiencies in subjects with impacted canines (Baccetti 2009). Expansion lead to successful eruption of impacted canines in 65.7% of cases and can be attributed to intraossesous improvement of the position of the canine (Baccetti 2009, Listas 2011).

Beyond the age of thirteen, extraction of the primary tooth as well as orthodontic treatment to make space in the arch results in 75% spontaneous eruption and 94% decrease in severity of the impaction (Listas 2011).

### 2:7 Surgical Approaches

The description and use of different surgical procedures has changed through the years. Surgical uncovering of the tooth signals the tissue around the tooth to be transformed into a functional periodontal ligament that will allow for eruption (Matthews 2013).

As early as 1969, Johnston suggested in office anesthesia and use of bard Parker blade to remove the palatal tissue over the tooth, uncovering the tip of the canine and removal of the enamel organ. Bone was only removed if necessary and no attachments
other than cemented onlays were used (Johnston 1969). At one point it was though to be advantageous to expose the tooth by removing bone and gingiva and packing gutta percha into the space between the tooth and the bone with the purpose of the tooth moving away from the area of pressure (von der Heydt 1975).

When the permanent canine is the incorrect axial inclination and does not need to be uprighted, an open exposure with natural eruption is the treatment of choice (Bishara 1976, Bishara 1992, Sajnani 2013). Allowing the canine to erupt into the palate and then moving the tooth toward the arch allows the root to be moved through bone, which leaves bone behind as it travels. This also allows for eruption away from the lateral incisors decreasing the risk for root resorption and allowing ample time for formation of a functional periodontal ligament (Matthews 2013).

When the canine is superficial and no bone is over top, a wedge-shaped piece of tissue can be removed and the tooth is covered with a pack (Kohavi 1984). If the tooth is situated deeper in the palate then the full thickness flap is sutured back into place (Kohavi 1984).

Matthews suggests that if a tooth is deeply embedded then a cleat should be placed on the tooth after exposure to retain a surgical dressing for up to five months to allow for eruption without forces. There is minimal morbidity with open exposure with no traction as compared to a closed surgical approach (Matthews 2013). Schmidt et. al. agrees with surgical uncovering and natural eruption into the palate stating fewer exposures and improved hygiene are among the advantages.

In 1992, Bishara et. al. described the Lewis two-step approach to surgically uncovering the impacted tooth, packing with a surgical dressing and removing the pack
and placing an attachment in three to eight weeks. In a one-step approach the attachment is placed on the tooth at the time of uncovery (Bishara 1992). Advantages of this approach include the ability of the clinician to see the crown of the tooth and have better control over the direction of the tooth movement (Bishara 1992).

The more common surgical techniques involve either an open or closed exposure with or without placement of an attachment at the time of the surgery. Surgical modalities have variation and are designed for individual treatment approaches (Becker 2016). The auxiliary attachment is not used in every cause but can be directly bonded to the exposed tooth or indirectly via a cemented band or crown (Bishara 1992).

An open exposure risks leaving a large defect in the soft tissue and bone and is not indicated when the canine is deep in the maxilla (Becker 2016). The open exposure is associated with a reduced treatment time, which could be due to the location of the canine to start (Cassina 2018). Open exposures are also associated with a lower risk of ankylosis; for every nine impacted canines treated with a closed exposure, an additional ankylosis of an impacted canine would be observed than if it was treated with an open exposure (Cassina 2018).

As defined more recently in the literature, an open exposure can be either that of the window technique or of a full thickness flap. The window technique is the simplest form of an open exposure and involves removal of mucosa and bone over the impacted tooth. The full thickness flap requires reflection of a flap which reveals the crypt of the canine, removal of bone and resuturing part of the flap back with a circular portion of mucosa over the tooth removed (Parkin 2012, Sajnani 2013, Becker 2015a, Becker 2016,
A closed procedure is generally recommended when the canine is high above the attached gingival band and buccally displaced and when the tooth is in a position that is far from the alveolar process, which is usually indicated in labial impactions and not in palatal impactions (Becker 2016, Sajnani 2013). This provides better access to a buried tooth due to reflection of a wide mucosal covering allowing for better visualization and hemostasis (Becker 2016). A closed exposure should demand a less radical surgical approach and should not expose the cementoenamel junction as this allows for a more favorable periodontal outcome (Becker 2015a).

Several variations of closed exposures for the palatally impacted canine are reported including minimal exposure technique, maximal exposure technique and tunnel approach. In the minimal exposure technique a full flap is reflected in the thick keratinized palatal mucosa revealing the bone underneath. The bone over the tooth is removed, the follicle is left intact, an eyelet with ligature chain is bonded, flap is closed and sutured and traction is applied immediately. Maximal exposure includes removal of bone and complete enucleation of the follicle covering the tooth, bonding of an eyelet with ligature chain, closing the flap and suturing and applying traction immediately. The tunnel approach draws the impacted canine down through the socket of the extracted primary canine, which is removed at the same time (Schmidt 2007, Parkin 2012, Becker 2016, Cassina 2018). The tunnel approach is only indicated in instances where the canine is high in the maxilla and in close relation to the line of the arch (Becker 2016). A closed
procedure followed by orthodontic traction produces a successful and predictable outcome with minimal complications (Sajnani 2013).

Cassina et.al. recommended that traction only be applied only after healing has taken place. The disadvantage to bonding an attachment at the time of the surgical procedure is that the process is technique sensitive and the use of ligature wire to facilitate traction is not reliable (Sajnani 2013). Complications with the eyelet and ligature chain include bonding too close to the cementoenamel junction, pain during traction application and fenestration of the palatal mucosa (Parkin 2012).

Overall, 9.6% of open exposure patients required re-exposure and 2.9% of closed exposures needed re-exposure (Parkin 2012). There were no statistical differences in the length of time of the surgical procedure; each being about thirty four minutes and no difference in patient reported outcomes (Parkin 2012). Recovery is said to be longer in an open procedure (five days) than closed procedure (three days) with regard to pain, analgesic intake and difficulty with eating and swallowing (Becker 2016). Parkin et. al. reported no difference in the pain between two groups. In a systematic review by Cassina et. al. in 2018, it was found that there were no statistical differences between open and closed exposures with regard to re-exposure needed, canine discoloration, post operative pain, difficulty in eating speech or esthetics.

An open exposure was constantly superior to closed exposure in both labial and palatal impactions (Cassina 2018).

Extraction of the impacted canine is not the treatment option of choice but should be considered when the canine is ankylosed, when there is evidence of internal or external root resorption, dilacerations of the tooth or the severity of the impaction does
not allow for movement (Bishara 1992). When it is not desirable to bring the canine into the arch of it is unable to be brought into the arch, treatment options include extraction of the impacted tooth with movement of the premolar into its location, segmental osteotomy of the posterior segment and movement forward or prosthetic replacement of the canine (Bishara 1992).

2:8 Methods of Applying Traction

Whether surgical or non-surgical, there may be times when it is necessary to apply traction to the canine to move it into the oral cavity. Over the years there have been many suggested ways to apply traction to the impacted tooth.

In 1969 Johnston et. al. published his protocol; about four to six months after the tooth was surgically exposed and partial eruption had occurred, a cast onlay made with a small loop wire was cemented to the crown of the tooth. Traction can then be applied forty-eight hours after cementation of the onlay.

In 1976 Bishara et. al. published his suggestions; after exposure of the crown, use of a 0.020 dead soft brass or stainless steel wire was ligated below the cingulum with the ends twisted and allowed to pass through palatal tissue so the flap could be closed. A gold chain with soldered links could be attached to the wire that was wrapped around the tooth. An auxiliary wire is then soldered to the base wire with the other end in the shape of a hook to attach to the links of the gold chain. The number of links of gold chain is counted at each visit to monitor the movement of the tooth. A band can also be fit around the tooth and cemented at the time of surgical uncovery if all the surfaces of the tooth are visible. The band can have a bracket, hook or button welded to it. The opposing canine
that erupted properly can be used for sizing of the band. After the tooth is uncovered and healing has occurred, an impression can be made of the exposed crown and a gold onlay with hook can be fabricated and cemented to the crown of the tooth. An attachment can be directly bonded to the tooth at the time of uncovering or after some eruption has occurred. A hole can be drilled into the tooth and a pin can be threaded or cemented to the hole. The pulp chamber must be avoided and the tooth will need restoration after this method is used. Finally, a wire loop can be embedded into a cavity prepared in the tooth and used to move the tooth in the desired direction.

In 1978 Becker et. al. suggested exposing the tooth and cementing a preformed band at the time of exposure or using a lasso around the neck of the tooth. A small eyelet was welded onto both the labial and palatal portions of the band. A steel ligature was then threaded through the eyelet, twisted and exited the surgical flap. Kohavi used this same method and further suggested application of twenty to thirty grams of force to begin moving the tooth. Becker et. al. suggested using a lingual wire to provide an initial downward directional force to the canine to prevent interfering with neighboring teeth.

The suggestions of Bishara et. al. in 1992 included using light wire springs that were soldered to a heavy labial or palatal base wire. The introduction of elastic thread and elastomeric chains allowed for better control of the force magnitude and direction when moving the canine after exposure. It was suggested to obtain adequate space in the arch and use of a large base wire before actively moving the tooth using light forces not exceeding sixty grams. However, as early as 1975 von der Heydt was using elastic thread to position the canine in the arch and stated that as the length of the elastic thread decreased, steel ligatures were substituted.
More recently it has been suggested that the orthodontist should be present on the day of uncovering to bond the attachment in the correct location, as this is not a common practice of oral surgeons (Becker 2015a). In an open exposure, the tissue around the exposed tooth heals within a few days and the tooth may be covered by tissue again and need re-exposure (Becker 2015a). A low profile round eyelet is considered to be the attachment of choice (Becker 2015a). Bonding a traditional orthodontic bracket at the time of exposure can cause periodontal inflammation as it is large and bulky (Becker 2016). While the patient is still anesthetized force should be applied immediately to the exposed canine (Becker 2015a).

There are disadvantages to using elastomeric chain or springs to move teeth towards the ridge, especially immediately after the surgical procedure. If the crown of the canine is still be beneath the palatal bone, applying force to it places the enamel in direct contact with the bone. Enamel does not resorb bone and the resorption will occur via pressure necrosis. This can create an alveolar defect on the distal of the lateral incisor. Immediate traction can also increase root resorption on the lingual surface of the lateral incisor. The canine may also not initially respond to the force applied; when the canine has been submerged for a number of years the tissue in the area can atrophy. In an adult, there may not be a functional periodontal ligament that responds to pressure and it may take a few months for a functional periodontal ligament to develop (Matthews 2013).
2:9 Periodontal and Esthetic Concerns

It is important to consider and evaluate the periodontal and esthetic outcomes of any approach before the procedure is performed. Treatment may be considered unsuccessful if the outcome is not esthetic or if there are long term periodontal problems. The overall prognosis of the impacted canine is partially due to the position, angulation, potential for ankylosis and the distance the tooth needs to be moved (Parkin 2015).

Kohavi et. al. defined heavy exposure as removal of enough bone to allow for complete curetting of the follicular sac and fully exposing the cementoenamel junction. The more bone that is removed during uncovery, the more bone lost after treatment (Bishara 1992). Light exposure was exposure of the tooth is enough tissue and bone removed to place a band but did not extend past the cementoenamel junction. There was more bone loss in the heavy exposure group (mean resultant support of 86.5%) than in the light exposure group (mean resultant support 91.9%). When there is light exposure with heavy movements or heavy exposure with light movements, considerable amount of bone loss results (Kohavi 1984).

When the exposed canine is brought into the arch, the bone levels on the distal of the lateral incisor and mesial of the canine are almost always more apical compared to their counterparts. Root resorption was present on the lateral and canine and devitilization of the lateral was a complication in some cases (Ericson 1988, Kokich 2004).

In 1983 Becker et. al. reported that the periodontal implications of the impacted canine were not clear but there were alterations of the health of the tissues supporting a previously palatally displaced canine. Becker’s study included twenty three patients who had completed orthodontic treatment involving resolution of a unilaterally impacted
canine were examined two years after all appliances were removed. The contralateral normal canine was used as a control. The results indicated that there were no significant differences in the plaque index and amount of attached gingiva but there were significant differences in the gingival index, pocket depth and bone support with four percent loss of supporting bone of the previously impacted canine.

In a study by Schmidt et. al. in 2007, twenty two patients were included in a split mouth study involving autonomous eruption and orthodontic treatment of impacted canines. There were no differences in bleeding and plaque between the groups. The probing depths and distance between the pocket and cementoenamel junction were significantly greater on the distolingual aspect of the lateral incisor on the affected side. The crestal bone was lower on the mesial (0.29 mm lower) and distal (0.76 mm lower) of the lateral on the side with impaction. The roots of the impacted canine and the adjacent lateral were significantly shorter than their control.

The most serious damage occurs when the tooth is exposed past the cementoenamel junction, which results in considerable amounts of bone loss (Kohavi 1984). In this case, the junctional epithelium is severed and pushed apically. This results in a long clinical crown, loss of bone and recession of the gingiva (Becker 2015).

A closed procedure, which heals by primary intention, has been reported to have satisfactory outcomes. There are minimal increases in probing depths and only minor amounts of bone loss (Becker 2016). In an open procedure, which heals by secondary intention, there was a significant amount of attachment lost (Becker 2016). While the design of this study was poor and the canines were unmatched it is still important to examine the potential outcomes of different procedures.
To the layperson, the esthetic differences between an impacted canine and non-impacted canine that are both in the arch are generally not distinguishable. In a study by Parkin et. al. in 2015, a previously impacted canine was identifiable by a layperson in 49.7% of cases, which is no better than chance but an orthodontist had a higher chance of identifying a difference. Overall, the non-impacted canine had a better general appearance than the previously impacted tooth. There was no evidence in terms of clinical attachment level after treatment with open versus closed exposures (Parkin 2015). The main reasons for ability to identify the differences in the canines included torque, gingival health and alignment with torque being the most common reason with inability to bring the root buccally (Schmidt 2007, Parkin 2015).

The overall esthetic impact of aligning a palatally impacted canine in the arch is minor and unlikely to be able to be detected by a lay person (Parkin 2015).

2:10 Recommendations

The most critical step in prevention of impacted maxillary canines is the clinician’s ability to recognize the tooth displacement early and predict this failure of eruption (Listas 2011). Early diagnosis is essential for success of the case (Ericson 1988, Listas 2011, Sajnani 2013).

The most opportune time to notice a potential issue is during the early mixed dentition and appearance of this anomaly may indicate appearance of others (Listas 2011). If the case can be handled non-surgically then the primary canine should be extracted early and allow for the favorable eruption of the permanent canine within one year (Ericson 1988, Sajnani 2013, Parkin 2015). If there is no change in the position of
the permanent tooth after one year then alliterative treatments should be explored (Ericson 1988).

Earlier timing is recommended for uncovering palatally impacted canines and can begin in the mixed dentition before orthodontics has begun (Kokich 2004). In the mixed dentition, a full thickness flap with all bone removed to the cementoenamel junction is recommended and spontaneous eruption should be seen in six to eight months. This approach improves bone levels and decreases the risk for root resorption (Kokich 2004, Schmidt 2007).

During surgical procedures, exposure of the cementoenamel junction should be avoided to avoid damage to the tooth (Kohavi 1984). The aim of a more radical surgical procedure is to improve the chances of the tooth erupting spontaneously but if the radical procedure is going to compromise the bone and periodontal support of the tooth then the surgical approach should be reevaluated (Kohavi 1984). Wedging of softened gutta percha or other packing to the follicular space of the impacted tooth as well as wire lasso around the cementoenamel junction should be avoided and is likely to compromise the bone support of the tooth (Kohavi 1984).

It is difficult to standardize the surgical and clinical approach of the treatment of maxillary impacted canines, as there are too many variables involved surgically and in the hands of the orthodontist (Becker 2016).

After the impacted tooth is brought into the oral cavity successfully, the state of the supporting tissues should be assessed and periodontal treatment should be done in the cases that require it (Becker 1983).
Based on a very limited number of small, randomized and non-randomized clinical trials open exposure seems to be superior in treatment duration and risk of ankylosis compared to closed exposures (Cassina 2018). Overall, the reports of a Cochrane review as reported by Becker et. al. suggests that there is insufficient evidence to prefer one technique to another in the exposure of an impacted maxillary canine.

2:11 Elastomerics in Orthodontics

Majority of the literature refers to elastomerics in the form of elastic power chain or latex and non-latex rubber bands while the area of interest is elastic thread that is used in the application of force to an exposed canine. Of the literature on elastomerics in orthodontics, comparisons between products are difficult as there are many different experimental methods used. The chemical composition of the materials in question are seldom released from the manufactures and upon contact, information is difficult to obtain. Composition of the elastomers such as Omolast, AlastiKs, Zing String and Power Thread are secrets of the trade (Wong 1976). A major shortcoming of the literature is the language and verbiage used to describe elastic materials. Elastic chain, power chain, power thread, threads, and alastic were common terms that were not well described or differentiated throughout publications. Changes in names and manufacturers could have also have influenced the wording.

Elastomerics made their debut in the orthodontic world around the late 1960s. Andreasen and Bishara published early information about elastomerics in the 1970s and were among the first to openly use elastics as a method of space closure in orthodontic tooth movement (Evans 2017). The use of use of latex and polymeric elastic elements in
orthodontics has become standard in recent years regardless of the practitioner’s
treatment philosophy (Howard 1979).

Most literature sought to answer a common question about force degradation of
the elastic material in different environments as well as the effect of prestretching on the
resultant forces.

Elastic elements in orthodontics can be classified as bands, rings, modules, chains
or threads (Howard 1979). These elastic elements are known to possess linear force-
elongation characteristics, which experience internal energy losses in the process of
activation and deactivation (Howard 1979). Synthetic elastomerics are currently being
used in several areas of orthodontics including space closure, correction of rotations and
ligation of archwires to brackets (Brantley 1979). Materials used to apply force to move
teeth include archwire loops, coil spring, latex elastics and synthetic elastomers (Wong
1976). Elastics role in orthodontics includes retraction of teeth into extraction sites,
closing diastemas, shifting of the midline and space closure and are irritation free as
compared to ligature wires (Wong 1976).

For use in orthodontics, the force generated by the elastic thread must be
predictable from the time of initial application and the reduction of force with time needs
to be low; significant reduction shouldn’t occur due to relaxation of the material (Persson
1983).

In 1975, the plastic module was a newer development in the orthodontic world.
Their use was common but little was known about their elastic properties. Hershey
examined how elastic materials behaved in a clinical setting by studying different elastic
chains from different manufacturers. All modules lost considerable force with time, with
about 50% lost in the first twenty four hours (Hershey 1975). When tooth movement was simulated on the bench top, there was a further increase in the rate of force loss; if closing 0.25 mm of space per week you can expect to retain about one third of the original force of the chain in a month while closing 0.5 mm of space per week you can retain one quarter of the original force of the chain (Hershey 1975). Similar force decay was seen between different manufacturers (Hershey 1975). Persson et. al. agreed and found that variations among products of the same brand showed changes in the force-elongation relationships but they were too small to be of clinical significance (Persson 1983). A conclusion drawn by Hershey is that despite the force decay of the elastomerics, there is clinically effective tooth movement to be seen in four to six week periods with elastic chains.

Persson’s testing in 1983 began due to little published information in force-extension relationships. Orthodontic elastic threads are composed of mainly synthetic polymers (Persson 1983). The synthetic polymers demonstrate good elasticity, high force elongation ratios and high strength but the stiffness of the material made it difficult to apply precise forces to a given tooth (Persson 1983). Young et. al. found that synthetic elastic polymers are imperfect due to permanent staining, greater force variability compared with latex elastics, deformation of 60% of the original length compared with 23% that of latex and loss of 50% power in the first day (Young 1979). Force decay of synthetic elastomers could have as much as 73% force loss in the first day with slower loss over the remaining twenty one days (Wong 1976). Polymers are not ideal for elastic material as their mechanical properties are dependent on the function of time and temperature (Young 1979).
Wong et. al. also observed that elastomerics are permanently elongated and undergo plastic deformation, which is related to the time and amount of stretch applied to the product (Wong 1976). Rapid force reduction after minor tooth movement was a common finding among all literature on elastomerics in orthodontics. In 1979 Howard found that the force-time plot of elastomeric materials is non-linear with the force-loss rate greatest immediately after stretching and decreasing over a period of hours or days, demonstrating properties of Hooke’s law.

Persson et. al. found that after an initial application of force there was a total decay of 65% within the first three weeks, but after the initial decay in the first day, the force remained constant (Persson 1983). At the end of a three-week test, the force decay varied from 20% to 65% (Persson 1983). These were also common findings among all of the literature on elastomerics.

The synthetic polymer elastic threads had steep, almost linear force-elongation relationships, which indicated high moduli of elasticity, and that changes in the force are marked with only slight changes in the length (Persson 1983). As with any elastic material there is force decay with time; the viscous behavior of the elastic material makes it hard to predict the resultant forces and the percentage of force remaining varied between products with no general difference between elastic or synthetic material (Persson 1983).

A study Buchmann et. al. focused on the elastic chains ability to deliver light continuous forces over a four to eight week period. It was found that there was a large amount of decay of force in the first twenty four hours with in significant changes between one day and three weeks. (Buchmann 2012).
Andreasen looked at the properties of elastomerics over fixed distances as if teeth were not moving. Alastic chains are good a condensing spaces but not good at retracting canines as there is little force left in the chain after three to four weeks (Andreasen 1970). However, the range of action is greater in elastics compared with springs and closing loops (Andreasen 1970). A clinical observation was that the plastic material permanently elongated; chains are deformed 50% of the original length and elastics 23%. The permanent deformation increased with time; the less of the stretch, the less permanent deformation that occurs (Andreasen 1970).

In vivo testing of elastic chain was completed by Evans et al. in 2017. Using a split mouth study, they investigated if unaltered elastic chain would be able to continue to move teeth versus chain that was replaced every twenty eight days. They found that statically significant amounts of tooth movement occurred at both the altered and unaltered sites with space closure being minimally greater at the altered site. The chain on the unaltered site continued to move teeth for up to sixteen weeks; the force was less than one hindered grams but tooth movement was still seen (Evans 2017). Overall, there was a rapid decrease in the force by four weeks with continued decrease until sixteen weeks.

Overall, Wong, Andreasen and Hershey all demonstrated through their studies that elastomerics lose 50% to 70% of its initial force during the first day of load application and 10% more by three weeks, and retain only 30% to 40% of the original force after four weeks.

Latex products showed more variation than did the synthetic polymers. Testing in dry versus wet environments had an effect on the properties of the elastic materials, as the
threads were softer after storage in a wet environment and allows for questioning the reliability of the force when the elastomeric is inserted into the oral environment (Persson 1983). When comparing latex and non-latex elastics for use in orthodontics the cross-sectional area, breakage fore, peak load, peak stress, stiffness, modulus, hysteresis, and twenty four hour load relaxation were examined (Russell 2001). Forces generated by the elastics decreased over a twenty four hour period to a load about 75% of the manufacturers reported value and 60% for that of non-latex elastics (Russell 2001). Overall, the mechanical properties of non-latex elastics were comparable to those of the latex elastics and the clinical choice should be based on medical history and desired mechanical properties (Russell 2001).

Beginning around 1980, the theory and thought of prestretching to decrease the subsequent reduction in force was of interest. Prestretching the material may explain the more variable and less viscous response that was found after exhaustion (Persson 1983). The act of prestretching was suggested to reduce the initial force, counteract the loss of force of the chain over time, reduce discomfort and reduce undermining resorption (Kim 2015). Kim et. al. studied the effects of prestretching elastic chain, which was then submerged in water. Prestretching demonstrated significantly lower initial forces than non-prestretched chain with the force decay between the prestretching and the control being similar with differences only noted in the first hour (Kim 2015). At the end of the four-week study, the remaining force of the control group was 191.7 grams and the prestretched group 189 grams, both of which are sufficient to move teeth; the true effect of prestretching is questionable (Kim 2015).
Brantley et. al. examined Alastic C Spool Chain by Unitek and Power Chain II by Ormco. They studied prestretched and non-prestretched elastics in room temperate water (thirty seven degrees) with the prestretching carried out from twenty four hours to three weeks. In the room temperature water, the most rapid force loss occurred during the first hour with much lower force decay following. Elastics that were prestretched maintained 15%-20% more of the initial force through the first day and 10% more through a four-week period but lost 70% of the original force over a three week period (Brantley 1979). For practical use, the chain needs to be used immediately after the prestretching has occurred to avoid the relaxation of the elastic material (Brantley 1979). Wong et. al. suggested prestretching the elastic chain to one third of their length to pre-stress the molecules in the polymer chain. This was said to increase the strength of the material. However, if overstretched to near breaking, the elastic remaining fixed in that position and permanent plastic deformation occurs (Wong 1976).

In a study by Young et al, prestretching of alastic chain and use of Instron showed greatest force decay within the first six hours. Those that were not prestretched had 21% of original force remaining after four weeks and those that were prestretched had 40% original force remaining after four weeks (Young 1979). Rapid prestretching and returning to a selected distance significantly increased the amount of force remaining after twenty four hours (Young 1979).

Yadiv et at. in 2011 examined force systems of three commonly used appliances to move palatally impacted canines; kilroy springs, Echain and ligature wire. They concluded that both the Kilroy spring and the Echain have a diminishing force and that
due to the visoelastic properties of the Echain in which there is diminished force in the first hour, frequent reactivation is needed.

Overall, there are little to no studies focusing on elastic thread used in the application of force to an exposed canine with respect to the material science and behavior. Furthermore there are no published studies that involve a gold chain in testing as well as elastic thread.

2:12 Hooke’s Law

Robert Hooke was an English biologist, physicist and architect who discovered the diffraction of light. His law of elasticity dates back to 1660 and has been studied ever since. Hooke’s law states that the amount in which a spring is stretched or compressed beyond its relaxed length is proportional to the force that is acting on it. Strain is a function of stress in continuous elastic materials. When stresses acting on a material increase significantly, the material deforms more than predicted by Hooke’s law and reaches its elastic limit where it becomes plastic. The elastic properties of material are determined by the underling molecular structure. Hooke’s law is a linear relation between force and extension and incorporates parts of Young’s modulus as well as Poisson’s ratio. When a force is not too strong, almost any solid body pulled at one end and anchored at the other will react like a real spring. This demonstrates that the interatomic forces are elastic when only displaced slightly from their original positions. Young’s modulus is a measure of instretchability; the larger it is the harder it is to stretch a material.

Normal materials will contract in a direction transverse to the direction in which it is extended. This is because in an isotropic material, there are atomic bonds in all
directions. When the bonds are stretched they create tension in the transverse dimension, which can only be relieved by contraction in the transverse dimension. Poisson’s ratio is a material parameter, which characterizes isotropic materials.

Hooke’s law is for isotropic materials, which is expressed by the linear relationship between stress and strain. It is only valid for stressed up to a certain strain, the proportionality limit. Beyond this limit, the relationship becomes nonlinear and eventually reaches the elastic limit where the material undergoes permanent deformation. This results in no further increase in stress but increased loss of energy to heat and may lead to fracture. Hooke’s law is a good approximation for most metals under normal conditions where the stresses are small compared to modulus of elasticity (Latrup 2011).
CHAPTER 3
SIGNIFICANCE

After completing a thorough search of the literature, little information is published about the properties of elastic thread used in the ligation of an impacted tooth. Majority of the elastomeric property testing has been completed on single ligature elastics, elastic power chains or latex/non-latex rubber bands. Furthermore, there was no published research or data about the elastic and mechanical differences of the assemblies used in canine exposures. As it is advisable to deliver light, continuous forces, it would be advantageous to determine the elastic moduli of different systems in regard to how much force is potentially reaching the tooth. Decay of the elastic material, the ductility of gold and the length of the elastic material are of clinical importance. It will be of great clinical significance to examine the properties of the elastic thread that is used in canine exposures as well as to potentially conclude if one system is clinically and biologically more beneficial.
CHAPTER 4

SPECIFIC AIMS

It is widely known that there are different treatment methods for a patient that presents with one or more maxillary impacted canines. Each procedure has risks, benefits, indications and contraindications for use. It is not known if there is a difference in the mechanical properties due to the elastic thread component of two different force systems used in the treatment of impacted canines.

The aims of this study are to determine if there are differences between two force systems commonly used in the treatment of impacted canines. We will explore how the introduction of a gold chain alters the mechanical properties of a clinical assembly; specifically the modulus of elasticity, tensile strength and maximum load and load at breakage.

The null hypothesis is that there is no statistically significant difference between the mean values of the parameters tested comparing the two force systems evaluated in this study. The force systems to be tested are described as (1) eyelet/elastic thread and (2) gold chain/elastic thread. The elastic thread will be tested alone for material properties.
CHAPTER 5
MATERIALS AND METHODS

Two separate groups were examined. A single type of elastomeric orthodontic elastic thread measuring uniform diameter from the same spool and manufacturer was used in all testing groups (American Orthodontics clear plastic tie (dura-flex) 0.030 inches, 0.76 mm diameter (REF 854-230)). Group I illustrated open exposure and was tested using orthodontic elastic thread alone. Group II illustrated the closed exposure with bonded attachment group (gold chain/elastic thread). All gold chains were from the same order from the same manufacturer (Ortho Technology, REF G16950 Eruption appliance round base). No teeth were used in this experiment. The length (in mm) of the two systems was recorded prior to initiation of the application of force (Table IV). There was n=6 systems in each group (Russell 2001).

In group I, a circular portion of elastic thread was cut, tied and measured to the nearest hundredth of a millimeter and recorded. Excess elastic thread was tied to each end to facilitate placement into the hex grips of the Instron machine (Figure 1).

In group II, the gold chain was cut to equal five complete links and a circular portion of elastic thread was cut and tied to the fifth link of the gold chain opposite the bondable eyelet (Figure 2). The length of the elastic thread and the total experimental unit (base of gold chain to length of elastic) was measured to the nearest hundredth of a millimeter and recorded. Excess elastic thread was tied to the base of the gold chain as well as the top of the circle of elastic thread to facilitate placement into the hex grips of the Instron machine. All measurements were taken with #0400-EEPE Electronic Digital
Caliper Orthodontic Tip (OrthoPli Philadelphia, PA) and calibrated to 0.00 mm before each reading.

An Instron testing machine was used to complete all testing and collection all of the data. The ramp speed of the Instron machine (strain-rate or cross-head speed) was set to 100 mm/min for all experimental groups. The thickness was set to 0.76 mm (width of the elastic thread) and width set to 1.52 mm (as the elastic thread was doubled when tied in a circle) and then length was entered individually for each experimental unit. Each experimental unit was loaded into the Instron machine and stretched to ultimate failure (breakage of the test assembly). Method of failure was recorded; failure of the elastic thread or of the gold chain. The amount of strain (elongation) as a function of force was also be determined and used to calculate the stiffness or modulus of each specimen tested.

Figure 1: Group I, a circular portion of elastic thread was cut, tied and measured to the nearest hundredth of a millimeter and recorded. Excess elastic thread was tied to each end to facilitate placement into the hex grips of the Instron machine.
in each group evaluated. This was repeated until all data (stress at ultimate failure, modulus of elasticity and tensile strength) was collected for all groups. (add "the")

Descriptive statistics (mean values and standard deviations) were determined for both groups and each measured parameter. Pairwise comparison via a student t-test (statistical add-on package in Microsoft Excel software) of the mean values for the two groups, for each measured parameter, were utilized to determine statistically significant differences between the groups (95% confidence limit, alpha = 0.05).

Figure 2: Group II, the gold chain was cut to equal 5 complete links and a circular portion of elastic thread was cut and tied to the 5th link of the gold chain opposite the bondable eyelet
CHAPTER 6

RESULTS

The results for tensile strength, load at breakage and modulus of elasticity are reported in Tables I and II. The means, standard deviations and \( p \)-values (for pairwise t-Tests) are reported for each measurement category. Only four measurements for modulus of elasticity were reported per group. The measurements for the length of the testing assemblies as well as the mode of failure are reported in Table III.

All elastic threads in the elastic only group failed due to breakage of the elastic thread. Four of the six gold chain and elastic thread systems failed due to breakage of the elastic thread while two of the six failed due to breakage of the gold chain element (Figure 3).

Figure 3: Failure of the gold chain and elastomeric orthodontic thread assembly due to breakage of the gold chain element.
### Table I: Data for no chain group (elastic thread alone)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tensile Strength (N)</strong></td>
<td>111.8</td>
<td>115.91</td>
<td>105.5</td>
<td>110.5</td>
<td>96.59</td>
<td>106.69</td>
<td>107.83</td>
<td>6.65</td>
</tr>
<tr>
<td><strong>Load at Breakage (N)</strong></td>
<td>95.87</td>
<td>82.81</td>
<td>94.18</td>
<td>96.04</td>
<td>90.58</td>
<td>92.9</td>
<td>93.06</td>
<td>4.97</td>
</tr>
<tr>
<td><strong>Modulus (MPa)</strong></td>
<td>7.99</td>
<td>10.08</td>
<td>4.22</td>
<td>13.05</td>
<td>--</td>
<td>--</td>
<td>8.83</td>
<td>3.71</td>
</tr>
</tbody>
</table>

* indicates failure of the gold chain.

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### Table II: Data for chain group

<table>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean</th>
<th>SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tensile Strength (N)</strong></td>
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<td>94.44</td>
<td>97.07</td>
<td>87.55</td>
<td>98.61</td>
<td>96.96</td>
<td>93.78</td>
<td>4.81</td>
<td>0.00185*</td>
</tr>
<tr>
<td><strong>Load at Breakage (N)</strong></td>
<td>82.96</td>
<td>85.33</td>
<td>83.3</td>
<td>83.02</td>
<td>83.19</td>
<td>86.89</td>
<td>84.1</td>
<td>1.63</td>
<td>0.00398*</td>
</tr>
<tr>
<td><strong>Modulus (MPa)</strong></td>
<td>22.87</td>
<td>13.27</td>
<td>19.57</td>
<td>12.42</td>
<td>--</td>
<td>--</td>
<td>17.03</td>
<td>5.03</td>
<td>0.03946*</td>
</tr>
</tbody>
</table>

*p-value (significance – p ≤ 0.05) from pair-wise student t-Test comparing chain vs. no-chain for each parameter listed in Tables I & II.

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### Table III: Length of all testing assemblies in Groups I and II

<table>
<thead>
<tr>
<th>Length of Testing Assembly (mm)</th>
<th>Elastic only</th>
<th>Elastic and Gold Chain</th>
<th>Overall Length</th>
<th>Length of Elastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.54</td>
<td>1</td>
<td>20.22*</td>
<td>9.28*</td>
</tr>
<tr>
<td>2</td>
<td>18.88</td>
<td>2</td>
<td>19.98</td>
<td>8.90</td>
</tr>
<tr>
<td>3</td>
<td>17.67</td>
<td>3</td>
<td>23.07</td>
<td>11.91</td>
</tr>
<tr>
<td>4</td>
<td>18.15</td>
<td>4</td>
<td>20.03*</td>
<td>9.74*</td>
</tr>
<tr>
<td>5</td>
<td>15.50</td>
<td>5</td>
<td>21.54</td>
<td>11.58</td>
</tr>
<tr>
<td>6</td>
<td>15.51</td>
<td>6</td>
<td>22.29</td>
<td>11.42</td>
</tr>
</tbody>
</table>

* indicates failure of the gold chain.
CHAPTER 7
DISCUSSION

The addition of the gold chain significantly reduced both the maximum strength of the total assembly as well as the tensile strength at failure (Table II). More importantly, the modulus of elasticity (stiffness) of the gold chain group was statistically significantly higher (Table II) with almost a 100\% increase in the modulus as compared to the elastic thread only group.

The capacity of a solid material to absorb energy during deformation is measured by two properties, resilience and toughness. Resilience is the ability of a material to absorb energy when it is deformed elastically and release that energy upon unloading. Toughness is the ability of a material to absorb energy and plastically deform without fracturing up to the point of material failure or breakage. These energy values are determined by calculating the respective areas under the stress-strain curve and are expressed as units of energy (usually Joules) per unit volume. Using this concept, it is obvious than a material with a higher elastic modulus (greater slope of the stress-strain curve) and lower ultimate strength will have a lower resilience and toughness. The data presented here therefore suggests that the introduction of a gold chain with the elastic thread reduces the resilience and toughness of the assembly. As a result, the overall energy absorbing capacity of the assembly is reduced.

The sum total of the preliminary data suggests that the gold chain assembly absorbs less energy to the point of failure than elastic thread alone. The differences in ultimate strength values (N) are small (on the order of approximately 10\%), yet the \( p \) values (\( P<0.004 \)) based on pair-wise statistical comparisons suggest that these differences
were statistically significantly different. Additionally, based on these preliminary tests, the introduction of the gold chain introduces an additional, undesirable mode of premature failure. This phenomenon appeared for several samples in this testing (Figure 3). From a clinical perspective, why introduce another element in the system (that can fail at multiple points) when there is no real benefit?

Elastic thread, as an elastomer, obeys Hooke’s law for an initial portion of the stress-strain curve, however, under constant stress the strain no longer remains linear and the stress is dissipated by energy absorption within the elastic material (Figure 4, stress-strain plot). Hooke’s Law states that the modulus of elasticity is a constant for elastic materials in the linear portion of the stress-strain curve during compressive or tensile stress. Elastic thread, whether connected to the gold chain or not, cause a deviation from that behavior. As a result, the stress-strain curves for both systems display an initial, short-term linear segment, but a non-linear portion for the rest of the curve (Figure 4)

**Figure 4**: Stress-strain curve demonstrating initial short-term linear behavior followed by non-linear behavior until breakage
The basic question considered in this investigation was to examine how placing a gold chain in series with an elastic thread alters the mechanical properties of the system, as compared to the use of elastic thread alone to facilitate tooth movement of an impacted tooth. Gold, as a metal, displays linear, elastic behavior until plastic deformation occurs. However, there were dramatic differences in mechanical properties when comparing the gold chain to the elastic thread alone. The gold chain group introduces an essentially rigid element replacing approximately one-half the length of the elastic thread. This change in the dimensions of the elastomeric can potentially affect the mechanical properties of the entire clinical assembly. One must also consider the different clinical presentations of a gold chain and elastic thread assembly. For a set distance from the impacted tooth to the archwire there may be a variable amount of both elastic thread and gold chain for a given distance. A clinician who uses longer gold chains and less elastic thread, based on the findings of this study, may well create a more rigid, inelastic system than one who uses less links of a gold chain and more elastic thread. As a result, the force system needs to be evaluated in each clinical case as the amount of gold chain and elastic thread for a given distance may well significantly impact the properties of the system as well as the force delivery to the tooth.

If we assume a pseudo-linear stress-strain behavior for these systems being tested (understanding this behavior deviates from their true non-linear behavior), one can assume the behavior of the elastomeric element approximates that of a spring; thus letting one use the equations that define the mechanics of a spring. Since in spring mechanics, the force (F) is equal to the term \(-Kx\), where "K" is the spring constant and "x" is the strain or displacement. Going further, the spring constant can be related to the apparent
modulus of elasticity of the assembly using the equation; \( k = \frac{EA}{L} \) where \( E \) is the Young's modulus of the material or assembly, \( A \) is the unstrained cross-sectional area, and \( L \) is the unstrained length of the elastomeric. Note that the spring constant is proportional to the modulus but inversely proportional to the elastic elements length. So reducing the elastomeric element length by one-half should double both the spring constant and the modulus at small values of initial strain. Therefore, adding the gold chain changes the modulus because it behaves essentially as a rigid element and undergoes little or no strain in tension. In addition to the gold chain and elastic thread group demonstrating a significantly higher modulus (i.e. stiffness, or greater resistance to being stretched), the force that is exerted by the elastic thread alone (no gold chain) is significantly higher (\( p=0.0018 \)) than the gold chain and elastic thread group. This apparent force reduction for the gold chain and elastic thread assembly may also be explained by the reduction in the length of the elastomeric element; which (due to its inverse relationship) reduces the "spring constant", which reduces the resultant force to failure.

Another consideration is the property that elastomeric materials deviate from Hooke's law due to their ability to absorb and store energy in their polymeric network during elongation under tensile force. It was noted above that the introduction of the gold chain impacts the resilience and toughness of the clinical assembly, reducing both properties. The apparent higher initial modulus and stiffness of the gold chain and elastic thread group may also potentially place excessive forces on the tooth initially without the compensating element of a sufficient mass of an elastic element that could more adequately absorb and redistribute the energy of the applied tensile stress. Therefore, the gold chain assembly may not allow sufficient stress relaxation thus placing higher initial
stress (force) on the tooth. This higher initial force may result in undesirable hyalinization necrosis and a lag in tooth movement due to use of excessive forces. By the same token, the higher initial stress per unit strain along with the reduced capacity of the gold and elastic thread assembly to store residual energy during elongation, may also contribute to the ultimate reduction in the force (stress) at failure for this group. Similar amounts of displacement or strain (i.e., tooth movement) occur at significantly greater force levels for the gold chain and elastic thread group as compared to lower forces necessary when elastics alone are used. Therefore, the elastic thread alone group delivers, with its inherently greater energy absorbing ability, more constant and continuous force as compared to the gold chain and elastic thread combination.

It is also important to think about the properties of the gold chain and interaction with the palatal mucosa in a closed exposure. If the gold chain is embedded into the palatal tissue and has the opportunity to grow through the links of the gold chain, this may affect movement of the tooth as well as introduce another complexity created by the gold chain. This ingrowth of palatal tissue to the gold chain may interfere with tooth movement and may introduce a mode of unnecessary trauma to the palatal tissue. While a potential advantage of the use of a gold chain would be the chain's inherent favorable biocompatibility after surgical exposure of the tooth; its apparent altering effects on the biomechanics of the elastic thread, as well as introducing an additional possible mode of failure (chain breakage) as well as area for ingrowth of palatal tissue; all suggest that this orthodontic assembly combining a gold chain with an elastic thread may be the least desirable approach for this clinical situation and indication.
To summarize, the tensile strength at maximum load and the load at breakage was significantly higher for elastic thread only, while the modulus of elasticity was marginally significantly higher for the gold chain and elastic thread group. In addition to the equal to or better than load at breakage values for the elastic thread alone group compared with the gold chain elastic thread group (Table II), the simplicity of the latter also serves as a benefit of this approach. Load to breakage of the elastic thread alone was 92 N compared with 84 N when the gold chain was added.

This study can be used a pilot study as there are no searchable published literature about mechanical properties of elastic thread itself or the addition of a gold chain with the elastic thread. To our knowledge, this is the first data about the mechanical properties of gold chain and elastic thread.

Future studies can include testing of the gold chain alone as well as an analysis of the gold chain's contribution to both elastic and inelastic behavior resulting in effects that alter the force exerted on the tooth and the speed at which the tooth can be moved.
CHAPTER 8

CONCLUSIONS

Two clinical approaches, one using a single element elastic thread and the other an assembly of a gold chain in conjunction with elastic thread series, both utilized for mechanical exposure of impacted teeth, were evaluated with respect to their tensile biomechanical behavior. From the data, the following conclusions can be made:

(1) While the orthodontic elastic thread consistently demonstrated a similar failure mode (breakage of the elastic), the assembly of a gold chain and elastic thread in series demonstrated different points of failure within the assembly.

(2) The elastic thread demonstrated an approximately 10% higher mean load to failure and mean tensile stress at maximum load values compared to the assembly of a gold chain and elastic thread in series which was determined to be a statistically significant difference in the comparative mean values for both of these parameters (p<0.05).

(3) The assembly of a gold chain and elastic thread in series demonstrated a significantly higher modulus of elasticity (stiffness), compared to the elastic thread alone, with the comparative modulus of elasticity increasing by almost 100%.

(4) The higher modulus in the gold chain group implies that similar amounts of displacement or strain (i.e., tooth movement) occur at significantly greater force levels when compared to lower forces necessary when elastics alone are used. The elastic thread alone group delivers, with its inherently greater energy absorbing ability, more constant and continuous force as compared to the elastic thread with gold chain combination.
(5) The use of elastic thread alone may provide a simpler and more straightforward clinical approach to orthodontic movement of exposed teeth, while providing similar and adequate biomechanics for tooth movement.
BIBLIOGRAPHY


