2010

Effect of mini-screw maximum insertion torque on skeletal orthodontic anchorage

Michelle Marie McManus
University of Iowa

EFFECT OF MINI-SCREW MAXIMUM INSERTION TORQUE ON SKELETAL ORTHODONTIC ANCHORAGE

by

Michelle Marie McManus

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Orthodontics
in the Graduate College of
The University of Iowa

May 2010

Thesis Supervisor: Professor Thomas E. Southard

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Michelle Marie McManus

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Orthodontics at the May 2010 graduation.

Thesis Committee: ___________________________________
Thomas E. Southard, Thesis Supervisor

____
Steve Marshall

____
Robert Staley

____
Fang Qian

____
Nicole Grosland

To my husband Mike whose has always supported me no matter how ambiguous or flighty my life plans have been. Everyday we spend together makes me a better person.

ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Dr. Tom Southard, for all his support and guidance throughout my thesis and education. I, also, would like to thank the other members of my thesis committee, Dr. Nicole Grosland, Dr. Steve Marshall, Dr. Robert Staley and Dr. Fang Qian for their time and contributions to my project.

The faculty members and adjunct faculty members at the University of Iowa have provided me with an amazing education and welcomed me into a profession that will be endlessly rewarding. I have never learned as much or laughed as much as I have these past two years. I cannot thank them enough for the extraordinary future that lies before me. Last, but not least, I would like to thank my co-residents. I could not have hand-picked a better group of individuals to be my extended family. As I leave here, I will never forget how lucky I am to have been given the opportunity to be part of this orthodontic program.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

LIST OF GRAPHS

Graph

INTRODUCTION

It has always been a challenge for orthodontists to avoid unwanted anchorage loss. Burstone concluded that the sum of the forces and the sum of the moments generated in the contemporary edgewise appliance equals zero, resulting in a state of equilibrium where the force applied to one tooth to move it towards its desired destination results in an equal and opposite force to other teeth in the system (Burstone, 1962 and 1965). Multiple appliances have been used to attempt to protect anchorage, but many have failed due to poor patient compliance. Recently, the use of titanium mini-screws to provide orthodontic anchorage has become increasingly popular. In a 2008 survey of 546 orthodontists and 9 orthodontic residents, it was found that 80% had at least one active case involving mini-screws (Buschang 2008). Numerous case reports have documented the successful use of titanium mini-screws, variations of surgical screws used for fixation, to provide orthodontic anchorage without patient compliance (Costa et al., 1998; Gelgor et al., 2004; Kuroda et al., 2004; Ohmae et al., 2001; Park et al., 2001; Park and Kwon, 2004). Compared to traditional endosseous implants which osseointegrate, mini-screws are smaller, easier to place, can be placed in more sites, are more cost effective, can be loaded immediately, and offer less post operative pain. (Lin and Liou, 2003; Melsen, 2005). The primary stability of mini-screws is believed to result from mechanical interlock - a waiting period for osseointegration prior to orthodontic loading is unnecessary as is a second surgical procedure (trephination) for removal (Costa, 1998; Liou et al., 2004; Melsen, 2000, Melsen, 2005). On the other hand, since they are not osseointegrated, their anchorage potential is likely influenced by the quality and quantity of bone into which they are placed (Huja et al., 2005).

Case reports have documented problems associated with mini-screw anchorage, including peri-screw inflammation and screw mobility (Cheng et al. 2003; Cheng et al. 2004; Melsen, 2000; Miyawaki 2003). In a prospective study of the risk factors associated with failure of mini-screws Cheng (2004) looked at a total of 92 mono-cortical mini screws of 2.0mm in diameter and 9-15mm in length. They found that length had no significant effect on implant survival and that loads in the range of 100-200g could be sustained with no significant differences noted between successful and failed implants. While some researchers have failed to reveal major differences in survival of implants placed in keratinized versus non-keratinized mucosa (Adell et. al. 1981; Albrektsson et. al.1986), Cheng's paper did indicate a bacterial role in the failure of orthodontic mini-implants. They found that peri-implant infection was associated with a 71% failure rate. They advised placing implants in keratinized mucosa and using caution when working in dense bone regions such as the posterior mandible, as bone overheating may be responsible for some of this region's higher failure rate.

The type of force system used often leads to failure as was seen by Costa (1998) where a moment was generated that resulted in the unscrewing of the implant. Huja (2005) also cautions that torsional loading of screws may debond any mechanical or chemical integration between the screws and bone interface. It has also been concluded that force placed 3mm from the bone implant junction, giving it a longer lever arm, leads to more failures than force applied 1mm to the bone implant junction (Butcher 2005).

Screw diameter has been reported to affect screw stability. A retrospective study by Miyawaki (2003) looked at a total of 134 titanium screws and correlated several variables with success. The authors defined the implant as successful if orthodontic force could be applied for one year or completion of treatment. They placed all screws mono-cortically and found the success rate of 1.0mm diameter screws to be 0.0% which was significantly lower than the 83.9% and 85.0% success rates of the 1.5mm and 2.3mm diameter screws. A high mandibular plane angle was associated with a significantly lower success rate. They also found no significant correlation between success rate and any of the following variables: screw length, kind of placement surgery, immediate loading, age, gender, crowding of teeth, anteroposterior jaw base relationship, controlled periodontitis, and temporomandibular disorder symptoms.

Since orthodontic mini-screws are not osseointegrated; the amount and quality of bone that the screw is exposed to likely influence their anchorage potential (Huja et al., 2005). Since we are unable to change the quality and quantity of bone in our patients, we may need to look at selecting placement sights for mini-screws that provide a higher quality and quantity of bone and still allow the clinician to use the desired mechanics.

In an attempt to address problems with mini-screw stability, a series of studies have been conducted to investigate factors that may be controlled to provide more reliable use of mini-screws. Brettin et. al. (2008) tested the hypothesis that bi-cortical mini-screw placement provides the orthodontist with superior force resistance and stability compared to mono-cortical placement. Deflection force values were found to be significantly greater for bi-cortical screws than for mono-cortical screws placed in both the maxilla and mandible. Morarend et. al. (2009) expanded this in-vitro study series to compare the force resistance of larger-diameter monocortical mini-screws to smaller-diameter monocortical mini-screws and to compare the force resistance of larger-diameter monocortical mini-screws to smaller-diameter bicortical mini-screws. Their findings indicated that larger (2.5mm) monocortical screws provide greater anchorage force resistance than do smaller-diameter (1.5 mm) monocortical screws in both the mandible and the maxilla. Mostly recently, this thesis study series investigated anchorage resistance of mini-screws placed at 30, 60 and 90 degrees to the bone surface at the area of insertion. In vitro, the anchorage resistance offered by mini-screws placed at 90 degrees to the alveolar bone was, on average, greater than the anchorage resistance offered by screws placed at 30 and 60 degrees. Currently, we would like to extend this study series to determine whether maximum insertion torque plays a role in the anchorage resistance of orthodontic mini-screws.

Maximum insertion torque of mini-screws has been investigated in previous studies to determine if placement torque factors into mini-screw success (Motoyoshi, 2006 and 2007; Lim, 2008; Cha 2010, Brinley, 2009). Motoyoshi's in vivo study in 2006 found that mini-screws placed with maximum insertion torque in the range of 5-10Ncm, had significantly higher success rates compared to those placed with less than 5Ncm torque or greater than 10Ncm of torque. This research has provided valuable results, but this study was conducted in a clinical setting and there is some concern whether maximum insertion torque was the only factor leading to the success or failure of the mini-screws. An in vitro study would help to limit patient variables, such as, oral hygiene, differing orthodontic forces, muscle pull and function. Eliminating these patient variables would allow us to isolate insertion torque as a single factor. Investigators have, also, used living animal specimens, non-living animal specimens and/or synthetic bone to research the effect maximum insertion torque has on mini-screw success (Lim, 2008; Cha, 2010; Su, 2009; Wilmes, 2009; Okazki, 2008). A limited number of studies have used a cadaver model to study mini-screws and none were identified that use a cadaver model, while limiting their focus entirely to maximum insertion torque and anchorage resistance (Brinley, 2009). The literature could be strengthened by our proposed human in vitro study that will explore the effect maximum insertion torque has on mini-screws to resist orthodontic forces.

Purpose of the Study

The primary objective of this study was to examine the effect that maximum insertion torque has on force resistance and stability of titanium screws in cadaver maxillae and mandibles. Our hypotheses were:

1) There is no correlation between maximum insertion torque of mini-screws and anchorage resistance.
2) There is no correlation between bone thickness and anchorage resistance.
3) There is no correlation between maximum insertion torque of mini-screws and bone thickness.
4) There is no difference in maximum insertion torque for coronally-positioned versus apically-positioned mini-screws in the maxilla.
5) There is no difference in maximum insertion torque for coronally-positioned versus apically-positioned mini-screws in the mandible.
6) There is difference in bone thickness for coronally-positioned versus apically-positioned mini-screws in the maxilla.
7) There is no difference in bone thickness for coronally-postioned versus apically-positioned mini-screws in the mandible.
8) There is no difference in anchorage resistance for coronally-positioned versus apically-positioned mini-screws in the maxilla.
9) There is no difference in anchorage resistance for coronally-positioned versus apically-positioned mini-screws in the mandible.

10) There is no difference in maximum insertion torque for mini-screws placed in the maxilla versus mini-screws placed in the mandible.

11) There is no difference in bone thickness for mini-screws placed in the maxilla versus mini-screws placed in the mandible.

14) There is no difference in anchorage resistance for mini-screws placed in the maxilla versus mini-screws placed in the mandible.

15) There is no difference in anchorage resistance for mini-screws placed with maximum insertion torque of less than 5Ncm, between 5-10Ncm and greater than 10Ncm.

LITERATURE REVIEW

Dental Anchorage

In order to achieve an acceptable orthodontic result, the orthodontist must attempt to balance many different factors. Some of these factors are in the clinician's control and some are in the patient's control. Those under control of the clinician include an accurate diagnosis of the malocclusion, creation of an appropriate treatment plan, accurate placement of appliances, and using reasonable mechanics during treatment to obtain the desired result. Patient compliance involves various factors including: good oral hygiene; wearing appliances as instructed and not abusing them; following an appropriate diet; and keeping regular appointments so that the goal of a stable, functioning, esthetic dentition can be achieved as quickly and smoothly as possible (Egolf et al., 1990). Since patient compliance is one of the most difficult aspects of orthodontics, it is not surprising that clinicians are always attempting to make less compliance necessary during treatment. In 1963, Salzmann wrote this about compliance: "It should be kept in mind, however, that frequently neither the appliance nor the orthodontist is responsible for failure in orthodontic therapy. Failure may be due to the nature of the malocclusion and the dentofacial malformation present in the patient, as is frequently the case, but also because of a lack of cooperation on the part of the patient in following the instructions of the orthodontist." Regardless of the ability of the clinician, even the most carefully thought out plan is destined for failure if the patient does not follow the instructions of the orthodontist. Patient compliance and the clinician's ability to motivate the patient to follow instructions correctly can be very important when trying to protect orthodontic anchorage.

Anchorage in orthodontics is defined as the amount of allowed movement of the reactive unit in a force system (Freudenthaler et al., 2001). In many situations, movement of the reactive unit is desirable, but quite frequently it is critical for the reactive unit in the orthodontic system to remain absolutely stationary while the active unit is moved in its desired direction. Marcotte (1990) has defined anchorage requirements in three categories: type A, the posterior teeth not moving during retraction of the anterior teeth; type B, reciprocal space closure where space is closed by an equal amount from both sides; or type C, anterior teeth not moving during protraction of the posterior dentition.

Achieving the appropriate movement of the active unit requires that the orthodontist design the ideal force system as dictated by the requirements of the anchorage type. The fact that all appliances are in a state of equilibrium and the sum of the moments and forces generated are always equal to zero makes establishing suitable anchorage very difficult with contemporary orthodontic appliances (Burstone, 1962 and 1995). Newton’s Third Law of Motion sums this up well in orthodontics also; both the active and reactive units experience equal and opposite forces.

Orthodontists traditionally have attempted to enhance favorable tooth movement by establishing a larger anchorage group which displaces one or a few teeth against a larger number of teeth. The assumption in this situation is that the force needed for the displacement of a few teeth is below the threshold of the force needed to displace the larger anchorage unit (Costa et al., 1998). The volume of osseous tissue that must be resorbed for a tooth to move a given distance can be considered the anchorage value of this tooth. In this way, it is the density of the bone surrounding the roots that is of primary importance. If all alveolar bone offered the same resistance, one would expect similar anchorage potential in the maxilla and the mandible but clinical experience has shown otherwise. Experience has shown the anchorage potential of the maxilla and mandible to be quite different with a great deal of variability within the arches themselves as well. For example, greater movement of maxillary molars occurs as compared to mandibular molars while closing space in four premolar extraction cases (Roberts, 1994). In fact, the extent of the difficulty with differential anchorage was shown when it was proven that a tooth can be moved with as little as 4 grams of force which is much less than the expected force on the reactive unit in a typical premolar extraction case (Weinstein et al., 1963). Quinn and Yoshikawa (1985) demonstrated that there is no linear relationship between force and displacement. They, as well as others, have shown time and again that reciprocal movement of the anchor unit is inevitable when only using tooth born appliances as anchorage and very often this anchorage loss is a negative side effect.

Alveolar Bone Anatomy and Physiology

There are two physiological factors that account for the differences in the mesial movement of maxillary and mandibular molars. The first factor is the composition of the bones themselves. The mandibular alveolar bone is composed of thicker cortical plates and coarse trabeculae when compared to the maxilla which has thin cortices and less coarse trabeculae (Adell, 1981). These thicker cortical plates and coarse trabeculae of the mandible offer greater resistance to tooth movement. The second factor is that during tooth translation the bone formed around the leading root of the maxillary molars is not as wide as that of the mandibular molars (Roberts et al., 1992). The finding that new bone formed in the maxilla is remodeled more rapidly than that in the mandible could be the reason for the differing bone density. Parfitt found that bones composed primarily of trabeculae remodel more rapidly than those composed primarily of cortical bone (Parfitt 1983 and 1988). This might also play a role in the fact that clinically, more anchorage loss occurs in the maxilla.

The functional loads and other demands placed on the opposing jaws may also be responsible for the differences in anatomy of the maxilla and mandible. Obviously occlusal forces are equally distrubuted to both the mandible and maxilla, but a large proportion of the load directed to the maxilla is dispersed to the rest of the cranium (Roberts et al., 1992). Muscular pull and masticatory function subject the mandible to significant torsion and flexure while the maxillary alveolus is primarily subjected to compression forces (Atkinson, 1964; Hylander, 1981). To resist the torsional and bending strain of function of the mandible, thick cortices are required. While the mandible has major muscle attachments such as the temporalis, masseter, and various smaller muscles, the maxilla has no major muscular attachments. As a result of having no major muscle attachments and much of the force dispersed to the cranium the bone of the maxillary alveolus is composed of trabecular bone with thin cortices (Roberts et al., 1992).

It is generally accepted that mandibular cortical bone thickness is greater compared to the maxilla. Deguchi (2006) found in a study using computed tomographic scanning of ten patients that the mandibular cortical bone is thicker (2.0mm on average) than maxillary bone (1.5mm on average) measured just distal to the first molar. Another study conducted by Masumoto et al., using 31 dry skulls in a group of modern Japanese males, measured buccal cortical bone thickness at the mandibular first molar. An observed range of 2.27 mm to 3.82 mm was found for bone thickness at the mandibular first molar. Each skull was categorized into three groups: short, average, and long facial type. These categorizes were based upon Frankfort-mandibular-plane angle and correlated to buccal cortical bone thickness. The short facial type and small mandibular plane angle had significantly increased buccal cortical bone thickness. Similar results were reported in 1998 by Tsunori et al. The study correlated facial type and buccal cortical bone thickness at the mandibular second premolar and found average thickness of 2.3 mm, 1.9 mm, and 1.5 mm for short, average, and long faced individuals, respectively. These studies suggest that low mandibular plane angle individuals have thicker mandibular cortical thickness and thinner cortical thickness appear in higher mandibular plane individuals.

Headgear Anchorage

A search for better control and more anchorage led orthodontists to look for an extraoral option. Orthodontic headgear is widely used for anchorage. While it has been a used for a long time by orthodontists it was Dr. Norman Kingsley who used headgear as early as the late 1800's. Kingsley utilized headgear primarily for tooth movement rather than anchorage (Kingsley, 1880). Edward H. Angle, (1907) using an extension of "Wolff's law of bone," which states that the architecture of bone responds to the stresses placed on that part of the skeleton, presented the concept that skeletal growth could be influenced by external pressure. Both Kingsley and Angle were proven right when the widespread use of cephalometric radiography in the 1940's was adopted and superimpositions became possible and by classic cephalometric studies of the 1950's.

Wieslander, in 1963, concluded that headgear indeed had effects on maxillary growth as well as the ability to move maxillary teeth in a distally displaced direction.

Headgear transmits a force to the maxilla by attachments to the molars, typically with bands that have headgear tubes. The effect of headgear, whether orthopedic or dental, is largely dependent on how the appliance is used. The direction of force placed upon the molars is ultimately determined by the relationship between the headgear's resultant force and the center of resistance of the attached molar teeth. If the resultant headgear force passes occlusally or gingivally to the tooth's center of resistance then the molar crown will tip distally or mesially, respectively. Bodily movement will occur if the resultant force passes through the tooth's center of resistance. Proper headgear use will prevent mesial movement of the posterior dentition and increase anchorage when retracting anterior teeth. The clinician should evaluate the specific anchorage needs of the system and adjust the force vectors of the headgear accordingly. Prolonged headgear use can cause unwanted side effects, such as, molar extrusion and tipping of the palatal plane. These must be taken into account, as well as, recognition of the necessary force application to maximize anchorage requirements for the treatment of the particular malocclusion.

Most orthodontists would not dispute the ability of headgear to distalize molars or enhance anchorage; however, the headgear is only effective if worn correctly and consistently by the patient (Jacobson, 1979). Roberts (1994) found that continuous headgear wear for twelve hours daily is recommended compared to longer periods of wear with frequent removal of the force. Although very effective, orthodontic headgear is often poorly received by patients with resultant poor compliance. A study using headgear with electronic timers was done to examine actual headgear use versus the reported wear time from the patient. It found that 69% of patients reported their headgear use at an accuracy level of 84% or greater, and 31% reported their use at an accuracy level of 58% or less (Cole, 2002). Planning treatment mechanics properly and identifying variables associated with poor headgear compliance is important. The most frequent reason cited for not wearing headgear is pain and is therefore a very important variable in compliance (Jones, 1985). Embarrassment and the social stigma of headgear use has also been found to play a significant role with patient compliance (Gabriel 1968). Age is also consistently and significantly associated with patient cooperation. Patients 12 years old or younger, typically will exhibit greater compliance than older children (Weiss, 1977). Socioeconomic status was also found to be related to compliance with patients in lower-middle or lower classes displaying greater patient compliance (Starnbach, 1975). Given all of these factors that play a role in compliance and the importance that anchorage can have on a case, orthodontists have also looked to separate intraoral appliances that would allow them to avoid headgear compliance.

Noncompliance-Appliance Anchorage

Many clinicians have begun to use intraoral distalizing systems that minimize patient compliance and are under the orthodontist's control. These appliances are designed to distalize maxillary molars without the need of patient cooperation. These "non-compliance" distalizing appliances come in many forms. They are typically described as consisting of an anchorage unit, usually premolars or deciduous molars and may also have an acrylic Nance button, and a force-generating unit which is responsible for moving the molars distally (Fortini et. al, 2004). The active components are made from various things including repelling magnets, coil springs on a continuous archwire, superelastic nickel titanium coils, and coil springs on a sectional archwire. Such appliances are known commercially as the pendulum appliance (Hilgers, 1992; Ghosh et al., 1996), the distal jet (Carano et al., 1996; Ngantung et al., 2001), and the first class appliance (Fortini et al., 2004) among others. The basic biomechanical design of this group of appliances use a maxillary premolar or deciduous molar and palatal anchorage unit to resist the reciprocal forces created in response to the active force delivered to drive the maxillary molars distally. The effects of such appliances do indeed provide distal movement of maxillary molars, but that distal movement is in large part due to tipping with minimal translation (Runge et al., 1999). With this distal tipping, unfavorable reciprocal movement occurs similarly to what is seen when trying to obtain anchorage from within the dentition alone. These "noncompliant appliances" also cause varying degrees of anchorage loss which leads to incisor protrusion, as well as, upper lip protrusion (Fortini, 2004).

Endosseous Implant Anchorage

One method of receiving anchorage without relying on compliance of patients or accepting the negative side effects of the non-compliance appliances is to use skeletal anchorage. Two methods of skeletal anchorage which have been reported on in the literature are: intentionally ankylosed teeth (Guyman, 1980; Shapiro, 1984) and endosseous implants (Adell, 1970). Primary teeth which are extracted as atraumatically as possible and subsequently re-implanted and splinted serve as anchorage in the form of intentionally ankylosed teeth. The disadvantages to intentionally ankylosing teeth are the trauma from the surgery and limited longevity due to the eventual root resorption and subsequent exfoliation. An additional disadvantage is that the ankylosed teeth may not be in the correct location for the most optimal biomechanical setup. However, endosseous titanium implants can be placed in various locations within bone depending on the biomechanical requirements and availability of intraoral sites for the implant. Endosseous titanium implants are typically composed of 99.5% titanium with the remaining 0.5% including other elements such as carbon, oxygen, nitrogen, and hydrogen. They are typically placed by an oral surgeon, periodontist, or general dentist. These implants come in sizes ranging from 3-4 mm in diameter and 6-10 mm in length (Lorenzo, 2002). Endosseous implants, once osseointegrated, are strong enough to withstand both masticatory loads and the stresses of orthodontic forces (Kokich, 1996). Normally used for prosthetic replacement of one or more teeth, these implants require specialized attachments for force application directly to teeth or the implant can be rigidly linked to an orthodontic appliance to provide absolute anchorage of the reactive dental units.

Osseointegration or direct contact between vital bone and the implant surface provides the orthodontist with absolute anchorage. Brånemark first found this osseointegration in 1977 and it has been verified by light microscopy (Brånemark, 1977), radiography (Albrektsson et al., 1981), transmission electron microscopy (Albrektsson et al., 1981), scanning electron microscopy (Albrektsson et al., 1981), Auger electron spectroscopy (McQueen et al., 1982), and energy-dispersive analysis of x-rays (Albrektsson et al., 1981). The amount of osseointegration of an implant is dependent upon the surface area of implant-bone contact. The maximal load that these implants can withstand is determined by the surface area that is osseointegrated (Lorenzo, 2002). The parameters that contribute to the surface area of implant-tissue contact are length and diameter since most implants are cylindrical (Van Roekel, 1989; Block and Hoffman, 1995). The process of osseointegration in humans requires from four to six months depending on the site of implant placement (Roberts, 1990).

For an endosseous implant to be successful, it is necessary to have primary stability at initial placement as well as stability once functional stresses are applied whether they are from orthodontic forces or due to prosthetic replacement. Different forces in direction and amount are subjected to an implant when it is used for orthodontic anchorage compared to those for prosthetic replacement. Endosseous implants used for prosthetic purposes are subject to vertical loads with intermittent forces estimated in kilograms. Endosseous implants that are used for orthodontic anchorage receive continuous force loads which are much lower and are mostly directed in a horizontal direction (Favero et al., 2002). Another difference in implant applications is that those used for orthodontic anchorage are temporary devices and used early in treatment unless they will also serve the dual role of replacing missing teeth following orthodontic treatment. While endosseous implants have proven themselves extremely useful for providing anchorage, their size typically limits their use in fully dentate individuals to the palate or distal to the most posterior molar (Roberts et al., 1996). Endosseous implants also require a second surgical procedure to be removed and they can be quite costly to the patient.

Mini-Screw Anchorage

In the past several years the use of mini-screws, also referred to mini-implants, micro-screws, or Temporary Anchorage Devices (TADs) as skeletal anchorage to aid in correcting malocclusions has become more popular. In a recent survey, eighty percent of respondents said they had at least one active case involving TADs in their practice (Buschang, 2008). TADs have received great attention from the orthodontic community because of the potential advantages they offer over conventional endosseous implants. TADs are smaller in size, easier to place, do not need a second surgical procedure for removal, cause less patient trauma, offer reduced risk as well as reduced cost, and offer potential for immediate loading. Their smaller size also allows a greater number of implant sites and more indications for better treatment (Lin and Liou, 2003). Possibly the greatest benefit is that TADs are not dependent on patient compliance and provide the ability to apply a continuous force whether that be elastic chain, springs, closing loops, or simply maintain anchorage to utilize whatever mechanic is suitable to the patient's particular need.

Gainsforth and Higley (1945) attempted to use vitallium screws in dogs at the University of Iowa in the 1940's. The prompt loosening of all screws and peri-implant infection at all sites was found and the researchers concluded screw use was unwarranted at that time. Despite Gainsforth and Higley's attempts nearly 40 years earlier, Creekmore (1983) is generally credited with suggesting the possibility of obtaining orthodontic anchorage through the use of small screws inserted in the alveolar process.

Safe and effective utilization of mini-screws in orthodontic therapy has been shown in numerous case reports in orthodontic literature. These reports have shown dramatic treatment results and success which is in sharp contrast to the results of Gainsforth and Higley. After 12 weeks of orthodontic force application using TADS and coil springs, mandibular third premolars were intruded 4.5 mm in beagle dogs (Ohmae

2001). Umemori (1999) documented the intrusion of mandibular molars to close an anterior openbite in two human subjects using TADs. Sassouni (1969) demonstrated that patients with anterior openbites are frequently characterized by longer vertical dimensions, an increase in the development of the maxillary posterior dentoalveolar structure, and a steep mandibular plane. To reduce the anterior facial height a counterclockwise mandibular rotation is needed, and therefore close skeletal anterior openbites, often require orthognathic surgical treatment (Lawry, 1990). Umemori (1999) and colleagues used TADS and observed molar intrusion of up to 5 mm in their patients along with a resultant counterclockwise rotation of the mandibular plane and correction of these open-bite malocclusions in an attempt to treat these patients without surgery. TADs have also been placed in the zygomatic area to successfully treat similar malocclusions with the intrusion of the maxillary posterior teeth and resultant counterclockwise mandibular rotation (Erverdi et al., 2004). Park et al. (2001) documented treatment of bialveolar protrusion requiring extraction of both the maxillary and mandibular first premolars using TADS for anchorage. The TADs were inserted into the buccal alveolar bone between the maxillary second premolars and first molars. A class I molar and canine relationship was achieved in 18 months of treatment and cephalometric superimposition demonstrated a bodily retraction of the maxillary anterior teeth along with no mesial movement of the maxillary posterior teeth showing no anchorage loss. These case reports show anchorage control offered by TADs in situations that would conventionally require surgical intervention or strict patient compliance with the use of headgear, elastics, or bite blocks. In fact, in a study comparing anchorage loss with TADs versus a transpalatal arch and headgear Yao (2008) found greater incisor retraction and less anchorage loss of the maxillary first molar with TADs.

Most TADs on the market today are fabricated from titanium alloy. They are available in numerous lengths and diameters as well as with differing head configurations for attachment to individual teeth or fixed appliances. The diameter of available screws varies from 1 mm to 2.3mm (Costa, 1998; Miyawaki, 2003). Narrow screws provide ease of insertion between roots with reduced risk of root contact (Melsen, 2005). However, the drawback of such narrow screws is the potential for fracture, which is closely related to screws of small diameter (Dalstra et al., 2004). A higher failure rate was also found for 1.0mm mini-screws (Miyawaki 2003). Screw strength is optimized by utilizing a slightly tapered conical shape and solid head with a screwdriver slot (Melsen, 2005). Melsen (2005) also states that "If stability depends on insertion into trabecular bone, a longer screw is needed, but if cortical bone will provide enough stability, a shorter screw can be chosen." This would lead one to conclude that if more of the screw is in cortical bone a shorter screw could be used. Using a shorter mini-screw would allow the clinician to place them in more areas with less worry about root damage caused by screw contact on insertion. Concern of root damage is the number one reason that orthodontists do not place their own mini-screws according to a survey in 2008 (Buschang).

Root contact involving mini-screws was recently studied by Kadioglu et al. (2008). This study included 10 patients with a treatment plan that inloved extraction of two maxillary first premolars. Before the premolars were removed, two mini-screws were placed on each patient and the first maxillary premolar roots were tipped into the mini-screws using tipping springs with a standardized force. Half the teeth were allowed to remain in contact for 4 weeks and the other half 8 weeks. In 5 patients the screws were then removed and in 5 patients the springs were removed and the teeth were allowed to move back. The roots were then allowed to recover for 4 or 8 weeks. The teeth were then removed and examined with scanning electron microscopy. Although there was some evidence of resorption it was found that the dentin surface was not denuded and that the affected areas were fully covered by collagen fibers. This study concluded that teeth put into contact with mini-screws show swift repair and almost complete healing within a few weeks after removal of the screw or orthodontic force.

Currently, mini-screws are being placed by general dentists, oral surgeons, periodontists, and orthodontists. Many clinicians recommend that orthodontists place mini-screws themselves. The orthodontist is ultimately the person that will be utilizing the mini-screw and therefore knows exactly where it should be placed. Melsen (2005) suggests that TADs be placed in attached gingiva under local anesthesia following the application of 0.02% chlorhexidine to the surgical area. Melsen also suggests a pilot hole 0.2-0.3 mm thinner than the screw should be used, if necessary, and inserted to a depth no greater than 2-3 mm and use a manual screwdriver for insertion since it provided a better tactile feel if a root has been contacted and damage can be minimized. Specific screw length selection is not given, but Melsen (2005) states “A transcortical screw can be used for added stability in edentulous areas, where trabecular bone is usually scarce.” Freudenthaler (2001) provided another reference to bi-cortical mini-screw placement in which he described mandibular molar protraction in a preliminary report. Brettin (2008) compared 1.5 mm diameter surgical fixation screws placed both monocortically and bicortically in maxillary and mandibular samples obtained from human cadavers and subjected them to tangential force application. Brettin's research had clearly shown that screws placed bicortically (placed in both the buccal and lingual cortical plates) were far more resistant to force application than those placed monocortically (placed in buccal cortical plate alone). Morarend found in his master's thesis at the University of Iowa that 1.5mm bicortical screws to be more resistant than 2.5 mm monocortical (Morarend, 2006). Woodall's thesis concluded that the anchorage resistance offered by miniscrews placed at 90 degrees to the alveolar bone was, on average, greater than the anchorage resistance offered by screws placed at 30 and 60 degrees (Woodall, 2009).

Immediate loading of mini-screws is commonly recommended in the literature (Freudenthaler et al., 2001; Kyung et al., 2003; Melsen and Costa, 2000). However, some others suggest waiting two weeks to allow soft tissue healing prior to loading (Liou et al., 2004; Park et al., 2001). In both situations, successful treatment outcomes have been achieved. For a practicing orthodontist, the convenience of immediate loading cannot be overlooked as it saves the patient an extra visit.

The primary stability of TADs is believed to result from a mechanical interlock with the bone. This differs from traditional endosseous implants, which depend on osseointegration after a waiting period for bone healing. If a load is placed upon an endosseous implant prior to osseointegration histological analysis reveals that a layer of fibrous tissue becomes interposed between the implant and the surrounding bone (Majzoub et al., 1999). TADs have been found to provide stable anchorage for orthodontic tooth movement, but unlike osseointegrated endosseous implants, the TADs did not remain absolutely stationary throughout orthodontic treatment (Liou 2004). After nine months of treatment, the mobility of 16 screws was assessed and all were found to exhibit no mobility. Although clinically there was no detectable mobility, a cephalometric superimposition immediately post-insertion to nine months revealed the screws tipped forward 0.4 mm at the screw head. This movement was attributed to compression of the interposed fibrous tissue layer that develops following immediate loading by Liou and colleagues. This compression continues until the threads of the screw become mechanically locked into the surrounding bone. Park et al. (2006) suggests that unlike endosseous implants, slight mobility with a TAD does not represent failure. Even though slight mobility is a risk factor for failure, if not overloaded the screw may function as needed.

Forces used to move teeth can range from approximately 0.3 to 4 N depending upon the desired tooth movement, so TADs probably receive highly variable loads depending on treatment choices (Ren, 2003). Studies and case reports have documented treatment success with TADs loaded from 70 to 200 grams to achieve tooth translation (Cheng, 2004; Park, 2002), 150 grams for tooth intrusion (Ohmae, 2001; Park, 2003) 50 grams for single impacted canine extrusion (Park, 2004). A headgear effect was obtained with forces of 500 to 600 grams (Lin and Liou, 2003). Huja (2005) found that maximal force loads of 388.3 N were obtained when loaded in an axial direction but this axial loading is not representative of the direction which orthodontic forces are applied and the authors suggests that torsional force application should be avoided.

Success rates of mini-screws have been reported to be in the range of 50% to 91% (Cheng, 2003 and 2004; Miyawaki, 2003; Tseng, 2006). Generally, success has been recognized as the ability for a TAD to sustain anchorage loads during orthodontic treatment in the absence of inflammation and mobility. Miyawaki et al. (2003) evaluated a total of 134 titanium screws in a retrospective study and found that factors associated with mini-screw failure included peri-implant tissue inflammation and a high mandibular plane angle. The authors suggest that the thicker buccal cortical bone of low mandibular plane individuals offers increased mechanical interdigitation between the screw and cortical bone which is an important determinant in the stability for mini-screws to be used as orthodontic anchorage. The study found that there was no significant association between the success rate and any of the following variables: screw length, kind of placement surgery, immediate loading, location of implant, age, gender, crowding of teeth, anterior posterior jaw relationship, controlled periodontitis, and temporomandibular disorder symptoms. The study concluded that no difference existed in the 1-year success rate of screws 1.5 mm or 2.3 mm in diameter, but the success rate of these screws were significantly greater than screws 1.0 mm in diameter.

Insertion torque upon placement of mini-screws is, like many other factors, not agreed upon yet. There have been only a few studies focused on evaluating maximum insertion torque as a factor related to the ultimate success of mini-screws used for orthodontic anchorage. Motoyoshi (2006) conducted clinical research to determine a placement torque for mini-screws that would result in improved success rates. One hundred and twenty-four titanium mini-screws were placed with a success rate of 85.5%. No significant difference in success rate existed between the maxilla and mandible placements, right and left placements, gender or patient age. The success rate for implants with maximum insertion torques greater than 5Ncm and less than 10Ncm was significantly higher than those screws placed at torques above or below that range.

Recommended implant placement torque (IPT) for clinically placed 1.6mm diameter mini-implants was 5-10 Ncm. Another clinical study was conducted by Motoyoshi (2007) looked at the effect of cortical thickness and placement torque on the stability of orthodontic mini-implants. Computer tomography was used to assess the cortical thickness and then eighty-seven, 1.6mm wide and 8mm long implants were placed in thirty-two patients. They achieved 87.4% success rate and found that there was significantly more failure when the cortical bone thickness was less than 1mm. Also, they achieved a 100% success rate for the implants that were placed with a maximum insertion torque of 8-10 Ncm. A similar animal study by Yu-Yu Su (2009) was conducted to compare self-tapping and self-drilling orthodontic implants. After pre-drilling, fifty-four implants were placed in vitro in pig ilia. Insertion torque and lateral displacement from lateral loading were measured. Results found that even though self-tapping implants generally had lower insertion torques, they both exhibited similar resistance to lateral forces. Wilmes (2009) made the assumption that maximal insertion torque would be a reliable method to determine whether a mini-implant has primary stability. He came to this conclusion after reviewing the above cited articles. Given this assumption, Wilmes proceeded to investigate ways to increase insertion torque by lowering the predrilling diameter and increasing the insertion depth.

There is not agreement whether controlling maximium insertion torque will raise the success rate of orthodontic mini-implants. There may be other clinical factors, such as, mandibular plane inclination, function, oral hygiene, etc., that may be present along with torque variations that may be the real cause for clinical success or failure. Limited evidence exists to measure maximum insertion torque of orthodontic mini-implants and their resistance to applied force in human cadaver jaws. Our study hopes to evaluate maximal insertion torque in a controlled human in vitro study to determine whether placement torque does affect mini-implant success.

MATERIALS AND METHODS

Cadaver Study

Sample

The maxillae and mandibles of human cadavers were obtained from the University of Iowa, Department of Anatomy and Cell Biology Deeded Body Program. Vital statistics of the cadavers were not available. Fully dentate and partially-dentate specimens were considered acceptable. Fully edentulous or partially-dentate specimens with visible, severely atrophic alveolar ridges were excluded. Maxillary specimens were dissected superior to the maxillary sinus to avoid damage to maxillary alveolar bone and tooth roots and extended distal to the maxillary tuberosity. Mandibular specimens were dissected approximately halfway up the ascending ramus. All maxillae and mandibles were subsequently hemisected and soft tissue was carefully removed and stored in 10% buffered formalin solution.

The site for placement of screws was in the area between the first and second premolars in both the maxilla and mandible. Twenty four maxillary halves and twenty four mandibular halves were selected that met the inclusion criteria. In the event that either the first or second premolars were missing, the adjacent first or second premolar was utilized as a reference for its location based upon average tooth size.

Screw Insertion

A total of 96 commercially available titanium screws (KLS Martin L.P., Jacksonville, FL)(Figure B1) typically used for rigid internal fixation during oral and maxillofacial surgery were placed in the 48 hemisected maxillary and mandibular specimens. All screws used were 1.5 mm x 11 mm long screws (KLS Martin L.P., Jacksonville, FL, #25-675-11) which are manufactured from titanium alloy (Ti-6Al-4V). Two screws were placed between first and second premolars, one coronally positioned and the other more apical (Figure B3). Screws were inserted to a depth of 6 mm. Insertion of the coronally positioned screw was placed four millimeters apical to the maximal height of the interproximal crestal bone (Figure B3). The apically positioned screw was inserted 5.5 millimeters apical to the coronally positioned screw (Figure B3). The coronal distance was selected to ensure that all screws would have adequate bone and proper root divergence for placement without root contact. The apical distance was selected so that mini-screws would not be placed in the mental foramen or maxillary sinus areas, yet maintaining adequate separation from the coronally positioned screw. Pilot holes were placed with the manufacturer's recommended non-tapered, 1.1mm diameter twist drill (Figure B2) for 1.5 mm screws (KLS Martin L.P., Jacksonville, FL, #25-452-15).All screws were placed by a single operator with a manual digital torque screwdriver (Check-line Instruments by Electromatic, Cedarhurst, NY, Model DID-4) (Figure B4) with a milled insert by University of Iowa's bioengineering department (KLS Martin L.P., Jacksonville, FL, blade #25-483-97) (Figure B5). Screws were inserted at 90 degrees to the bone surface at the area of insertion. The digital torque screwdriver was set to measure maximum insertion torque to the nearest tenth Ncm(Table A3). After verification of satisfactory screw placement, the most distal portion of each bony specimen was embedded in buff laboratory stone to a depth of 1.0 inches and allowed to harden for twenty-four hours (Figure B).

Force Application

Each mini-screw was subjected to tangential force application oriented perpendicular to placement of the mini-screw and parallel to the occlusal plane (Figure B13). This mimics the force placed on a mini-screw if used for retraction of anterior teeth. A Zwick Instron Diametral Materials Testing Machine (Zwick GmbH & Co model 1445, Ulm, Germany) was used which incorporates a force transducer attached to a crosshead and is linked to a computer for recording of data (Figure B9). A customized X-Y-Z table with mounting device was fabricated to rigidly fixate each stone block and cadaver specimen during testing (Figures B10, B11). A customized grip was designed and machined from stainless steel to fit between the threads of each mini-screw (Figure B12). The custom grip was attached to the force transducer and oriented in a vertical position (Figures B12). The custom X-Y-Z table allowed for movement in three planes of space to ensure that the force was parallel to the occlusal plane (Figures B13). Following orientation of the occlusal plane, the custom grip was attached to each mini-screw.

A crosshead speed of 0.05 mm per second was applied parallel to the occlusal plane. Similar crosshead speed was used by Huja et al. (2005) in axial pullout studies of mini-screws. Displacement of the system was measured for approximately 1.5 mm, but only the first 0.60mm of movement was investigated. This amount of displacement was selected to represent the amount of movement that would result in a clinically mobile mini-screw and potential failure.

Screw Mobility Observation

Following force application, all assessments of mobility and whether the screw was bent or not was made independently by two individuals and if there was disagreement each one was examined together until a consensus had been reached (Table A1).

Cortical Bone Thickness Measurement

Each screw was removed and the bony specimens were sectioned mesial and distal to each mini-screw insertion site to allow visualization and measurement of both buccal and lingual cortical bone thickness. The specimens were sectioned with a diamond disk and a laboratory handpiece. Buccal plate, lingual plate, and total alveolar bone width was measured by a single observer with a sharp, fine-tip digital caliper (Table A2). Each measurement was made twice at screw insertion sites and the average of the two measurements was recorded.

Overview of Statistical Methods

Spearman's rank correlation test was used to evaluate whether there was an apparent increasing or decreasing relationship between maximum insertion torque of mini-screws, anchorage resistance, and bone thickness. The following is an approximate guide for interpreting the strength of the relationship between two variables, based on the absolute value of the Spearman's rank correlation coefficient:

i) ±1= perfect correlation,

ii) ±0.8=strong correlation,

iii) ±0.5=moderate correlation,

iv) ±0.2=weak correlation,

v) ±0.00=no correlation.

A paired-sample t-test and the nonparametric Wilcoxon signed-rank test were used to compare maximum insertion torque, bone thickness and anchorage resistance between coronally-positioned and apically-positioned mini-screws in the maxilla and the mandible or between mini-screws placed in the maxilla versus mini-screws placed in the mandible.

Additionally, one-way ANOVA with post-hoc Tukey-Kramer's test was used to determine whether there was a significant difference in anchorage resistance for screws placed with maximum insertion torque of less than 5Ncm, between 5-10Ncm and greater than 10Ncm. The Tukey-Kramer's test is used when sample sizes differ among groups.

All tests employed a 0.05 level of statistical significance. Statistical analyses were carried out with the statistical package SAS® System version 9.1(SAS Institute Inc, Cary, NC, USA).

RESULTS

Assessment of correlation between maximum insertion torque and anchorage resistance for all screws

Assessment of correlation between maximum insertion torque and anchorage resistance at each deflection measurement was performed using Spearman's rank correlation test. The analysis indicated that there was a significantly increasing relationship between maximum insertion torque of mini-screws and anchorage resistance at each deflection ranging from 0.01 to 0.60 (except for at deflection=0.02, p=0.0602). Coefficients ranged from 0.20 to 0.51, which indicated there was a weak to moderate association between the two variables.

Assessment of correlation between maximum insertion torque and anchorage resistance for screws within maxillary bone

Assessment of correlation between maximum insertion torque of maxillary mini-screws and anchorage resistance at each deflection was performed using Spearman's rank correlation test. The analysis indicated that there was a significantly increasing relationship between maximum insertion torque of maxillary mini-screws and anchorage resistance at each deflection ranging from 0.01 to 0.60. Coefficients ranged from 0.33 to 0.69, which indicated there was a weak to moderate association between the two variables.

Assessment of correlation between maximum insertion torque and anchorage resistance for screws within mandibular bone

Assessment of correlation between maximum insertion torque and anchorage resistance at each deflection measurement was performed using Spearman’s rank correlation test. No statistically significant correlation was found between maximum insertion torque of mandible mini-screws and anchorage resistance at each deflection measurement ranging from 0.01 to 0.60 ($p>0.05$ in each instance).

Assessment of correlation between bone thickness and anchorage resistance for all screws

Assessment of correlation between buccal cortical bone thickness and anchorage resistance at each deflection was performed using Spearman’s rank correlation test. The analysis indicated that there was no significantly relationship between bone thickness and anchorage resistance at each deflection measurement ranging from 0.01 to 0.60 ($p>0.05$ in each instance).

Assessment of correlation between bone thickness and anchorage resistance for screws within maxillary bone

Assessment of correlation between buccal cortical bone thickness and anchorage resistance of mini-screws placed in the maxilla at each deflection was performed using Spearman’s rank correlation test. No statistically significant correlation was found between buccal cortical bone thickness and anchorage resistance at each deflection measurement ranging from 0.01 to 0.60 ($p>0.05$ in each instance).

Assessment of correlation between bone thickness

and anchorage resistance for screws

within mandibular bone

Assessment of correlation between buccal cortical bone thickness and anchorage resistance of mini-screws placed in the mandible at each deflection measurement was performed using Spearman's rank correlation test. No statistically significant correlation was found between buccal cortical bone thickness and anchorage resistance at each deflection measurement ranging from 0.01 to 0.60 ($p>0.05$ in each instance).

Assessment of correlation between bone thickness and

maximum insertion torque for all screws

Assessment of correlation between maximum insertion torque and buccal cortical bone thickness at each deflection measurement was performed using Spearman's rank correlation test. The analysis indicated that there was a significantly increasing relationship between maximum insertion torque of mini-screws and buccal cortical bone thickness at each deflection measurement ranging from 0.00 to 0.60 ($p<0.00001$ in each instance). A coefficient of 0.53 at each of the deflections (0.00-0.60) indicated there was a moderate association between the two variables.

Assessment of correlation between bone thickness and

maximum insertion torque for screws

within maxillary bone

Assessment of correlation between maximum insertion torque of maxillary mini-screws and buccal cortical bone thickness at each deflection measurement was performed using Spearman's rank correlation test. No statistically significant correlation was found between maximum insertion torque of maxillary mini-screws and buccal cortical bone thickness at each deflection measurement ranging from 0.00 to 0.60 ($p>0.05$ in each instance).

Assessment of correlation between bone thickness and maximum insertion torque for screws within mandibular bone

Assessment of correlation between maximum insertion torque of mandible mini-screws and bone thickness at each deflection was performed using Spearman's rank correlation test. The analysis indicated that there was a significantly increasing relationship between maximum insertion torque of mandible mini-screws and buccal cortical bone thickness at each deflection ranging from 0.00 to 0.60 ($p<0.00001$ in each instance). A coefficient of 0.61 at each of deflections (0.00-0.60) indicated there was a moderate association between the two variables ($p>0.05$ in each instance).

Comparisons of maximum insertion torque between coronally-positioned and apically-positioned screws in maxillary bone

A nonparametric Wilcoxon signed-rank test was used to compare maximum insertion torque of mini-screws placed coronally and those placed apically within the maxilla. The analysis showed no significant difference in maximum insertion torque between coronally-positioned and apically-positioned mini-screws in the maxilla at each deflection ranging from 0.00 to 0.60 ($p=0.6582$ for each instance).

Comparisons of maximum insertion torque between coronally-positioned and apically-positioned screws in mandibular bone

A paired-sample t-test was used to compare maximum insertion torque of mini-screws placed coronally and those placed apically within the mandible. The analysis showed no significant difference in maximum insertion torque between coronally-positioned and apically-positioned mini-screws in the mandible was found at each deflection ranging from 0.00 to 0.60 (p=0.6991 for each instance).

Comparisons of bone thickness between coronally-positioned and apically-positioned screws in maxillary bone

A paired-sample t-test was used to compare buccal bone cortical thickness of mini-screws placed coronally and those placed apically within the maxilla. The analysis showed no significant difference in buccal bone cortical thickness between coronally-positioned and apically-positioned mini-screws in the maxilla at each deflection ranging from 0.00 to 0.60 (p=0.4048 for each instance).

Comparisons of bone thickness between coronally-positioned and apically-positioned screws in mandibular bone

A nonparametric Wilcoxon signed-rank test was used to compare buccal bone cortical thickness of mini-screws placed coronally and those placed apically within the mandible. The analysis showed no significant difference in buccal bone cortical thickness between coronally-positioned and apically-positioned mini-screws in the mandible at each deflection ranging from 0.00 to 0.60 (p=0.2266 for each instance).

Comparisons of anchorage resistance between coronally-positioned and apically-positioned screws in maxillary bone

Based on a paired-sample t-test, no significant difference in anchorage resistance between coronally-positioned and apically-positioned mini-screws in the maxilla was found at each deflection ranging from 0.01 to 0.60 (p>0.05 for each instance).

Comparisons of anchorage resistance between coronally-positioned and apically-positioned screws in mandibular bone

Based on a paired-sample t-test, there was a significant difference in anchorage resistance between coronally-positioned and apically-positioned mini-screws in the mandible at each deflection ranging from 0.01 to 0.37. The data showed that mean anchorage resistance of apically-positioned mini-screws placed in the mandible was significantly greater than that observed for the coronally-positioned mini-screws in each instance. No significant difference was found at each deflection ranging from 0.38 to 0.60 (p>0.05 in each instance).

Comparisons of maximum insertion torque between screws placed in the maxilla and screws placed in the mandible

Based on a paired-sample t-test, there was a significant difference in maximum insertion torque between mini-screws placed in the maxilla and mini-screws placed in the mandible at each deflection ranging from 0.00 to 0.60 ($p<0.0001$ in each instance). The data showed that mean maximum insertion torque of mini-screws placed in the mandible was significantly greater than that placed in the maxilla (mean maximum torque difference between the two groups =4.21; std=5.15 for all instances).

Comparisons of bone thickness between screws placed in the maxilla and screws placed in the mandible

Based on a paired-sample t-test, there was a significant difference in buccal cortical bone thickness between mini-screws placed in the maxilla and mini-screws placed in the mandible at each deflection ranging from 0.00 to 0.60 ($p<0.0001$ in each instance). The data showed that mean buccal cortical bone thickness of mini-screws placed in the mandible was significantly greater than that placed in the maxilla (mean bone thickness difference between the two groups=0.56; std=0.77 for all instances).

Comparisons of anchorage resistance between screws placed in the maxilla and screws placed in the mandible

Based on a paired-sample t-test, there was a significant difference in anchorage between mini-screws placed in the maxilla and mini-screws placed in the mandible at each deflection ranging from 0.20 to 0.60 ($p<0.05$ in each instance). The data showed that mean anchorage resistance of mini-screws placed in the mandible was significantly greater than that placed in the maxilla in each instance. No significant difference was found at each deflection ranging from 0.01 to 0.19.

Comparisons of anchorage resistance for screws placed with maximum insertion torque of less than 5Ncm, between 5-10Ncm and greater than 10Ncm

At each deflection, there were 45 measurements obtained for less than 5Ncm, 36 measurements for 5-10Ncm, and 15 measurements for greater than 10Ncm. Between deflections ranging from 0.01 and 0.11, results of one-way ANOVA revealed no significant effect for mini-screws placed with 3 different maximum insertion torque groups ($p>0.05$ for each instance). Moreover, there was no significant difference in anchorage resistance for screws placed with maximum insertion torque of less than 5Ncm, between 5-10Ncm and greater than 10Ncm.

Between deflections ranging from 0.12 and 0.33, results of one-way ANOVA revealed a significant effect for mini-screws placed with 3 different maximum insertion torque groups ($p<0.05$ for each instance). The post-hoc Tukey-Kramer's test showed that mean anchorage resistance for mini-screws placed with maximum insertion torque of less than 5Ncm was significantly lower than 5-10Ncm. However, no significant difference was found between less than 5Ncm and greater than 10Ncm, as well as between 5-10Ncm and greater than 10Ncm.

Between deflections ranging from 0.34 and 0.60, results of one-way ANOVA revealed a significant effect for mini-screws placed with 3 different maximum insertion torque groups ($p<0.05$ for each instance). The post-hoc Tukey-Kramer's test showed that mean anchorage resistance for screws placed with maximum insertion torque of less than

5Ncm was significantly lower than those observed for 5-10Ncm and greater than 10Ncm. No significant difference was found between 5-10Ncm and greater than 10Ncm.

DISCUSSION

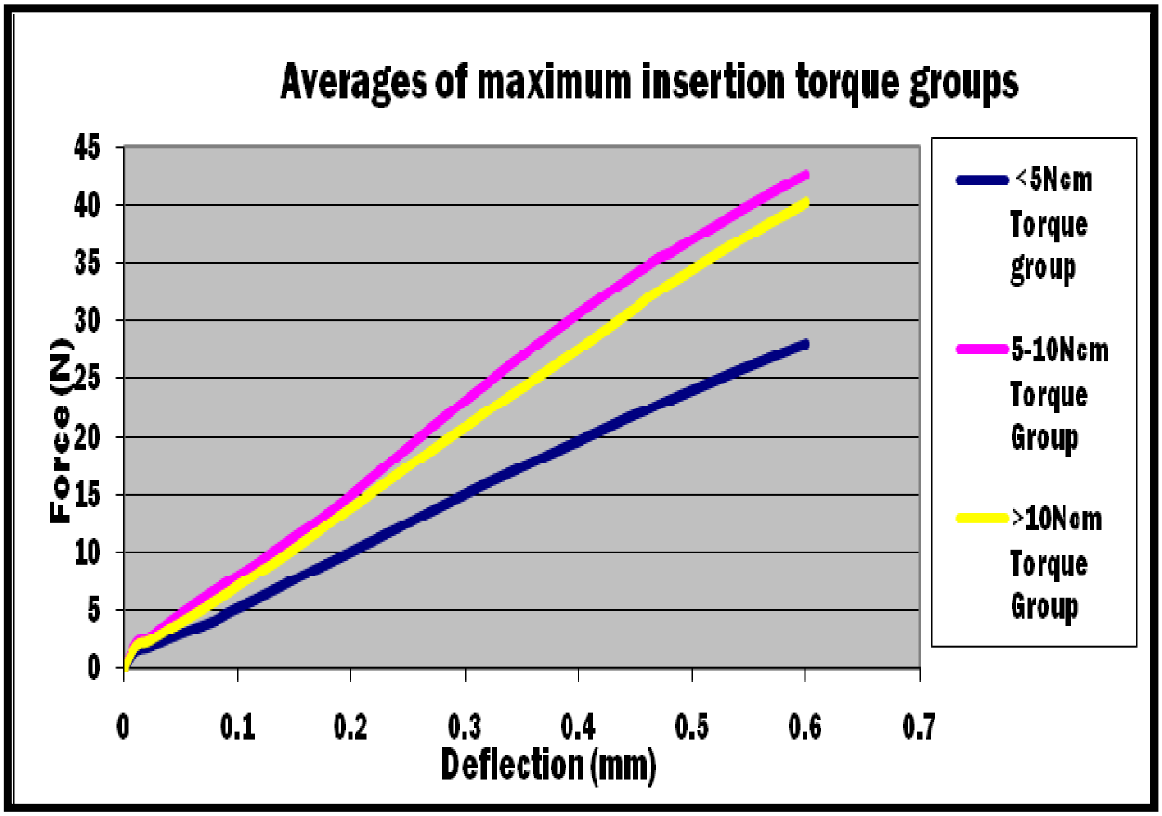
The question we were hoping to answer in this study was whether differences in maximum insertion torque results in differences in mini-screw anchorage resistance. Although clinical studies have been conducted to investigate maximum insertion torque of mini-screws (Motoyoshi, 2006 and 2007), we wanted to isolate torque from other variables that may co-exist in an in vivo study. Through this cadaver study, we found that mini-screws placed with higher insertion torque displayed higher anchorage resistance. This correlation held true when the statistical analysis was limited to the maxillary bone, but not when it was limited to the mini-screws placed in the mandibular bone. This may imply that increasing the maximum insertion torque can make mini-screws more resistant to applied force, but only to a certain point. Since the maximum insertion torque of mini-screws in mandibular bone is higher, there may be a maximum insertion torque, at which, increasing the torque gives no additional benefit to resisting force.

Analysis was conducted to see if there was a correlation between the buccal cortical bone thickness and maximum insertion torque. At each deflection measurement, there was a significantly increasing relationship between maximum insertion torque of mini-screws and buccal cortical bone thickness. An unexpected finding was that correlations were found between increased maximum insertion torque and increased anchorage resistance, as well as, between increased maximum insertion torque and increased buccal cortical bone thickness, but no correlation was found between increased buccal cortical bone thickness and increased anchorage resistance.

We compared mini-screws placed in the apical position to those placed in the coronal position for all three variables (maximum insertion torque, bone thickness and anchorage resistance). No significant differences were found, except one. There was a significant difference in anchorage resistance between coronally-positioned and apically-positioned mini-screws in the mandible at each deflection ranging from 0.01mm to 0.37mm. The data showed that mean anchorage resistance of apically-positioned mini-screws placed in the mandible was significantly greater than that observed for the coronally-positioned mini-screws in each instance. In similar studies by Brettin(2008) and Morarend(2009), no difference was found between apical and coronal positions. Woodall (2009) found that in the mandible with 90 degree screws at deflections between 0.05mm and 0.06mm, the apically-positioned screw was more resistant to force. Our study's findings may appear to promote placing orthodontic mini-screws in the apical position when being inserted in the mandible, but other clinical factors should be weighed. The clinician should consider a location that is in attached gingiva, because this position limits the chances of peri-implant inflammation and possibly eliminates the risk factor of screw mobility (Melsen, 2005; Miyawaki, 2003). Also, in the more coronal position the screw is easier for the patient to clean and closer to the center of resistance. The key point here may be to place the orthodontic mini-screw as apically as possible without encroaching on unattached gingiva or sacrificing optimal mechanics.

Comparisons were also conducted to investigate whether mini-screws placed in the maxilla had any differences when compared to mini-screws placed in the mandible. Data showed that mean maximum insertion torque of mini-screws placed in the mandible was significantly greater than that placed in the maxilla. Similarly, mean buccal cortical bone thickness of mini-screws placed in the mandible was significantly greater than that placed in the maxilla. This pattern held true when looking at anchorage resistance. For deflections ranging from 0.20mm to 0.60mm mean anchorage resistance of mini-screws placed in the mandible was significantly greater than that placed in the maxilla, but for deflections ranging from 0.01mm to 0.19mm there was no significant difference. The quality and quantity of a patient's bone likely influences anchorage potential (Huja et al., 2005). Previous research has indicated that mandibular bone is subject to significant torsion and flexure due to muscular pull and masticatory function while maxillary bone receives primarily compressive forces (Atkinson, 1964; Hylander, 1981). The added forces and function on the lower jaw cause the mandible to develop thicker cortical bone when compared to the maxilla. Our research found higher maximum insertion torque and anchorage resistance in the mandible versus the maxilla, so the assumption is that bone quality and quantity is higher in the lower jaw.

Motoyoshi (2006) recommended implant placement torque for 1.6mm mini-implants to be between 5Ncm and 10Ncm. He came to this conclusion after conducting clinical research that found a higher percentage of TADs were successful within this maximum insertion torque range. We felt it would be valuable to group our data into similar groups to compare findings. In our study, forty-five mini-screws had maximum insertion torque measurements less than 5Ncm, thirty-six were in the range of 5Ncm to 10Ncm and the remaining fifteen mini-screws fell into the group that measured greater than 10Ncm. No significant differences were found between any of the groups between deflections ranging from 0.01mm to 0.11mm. When we look at deflections ranging from 0.12mm to 0.33mm, mean anchorage resistance for screws placed with less than 5Ncm torque was significantly lower than the screws placed with torques between 5-10Ncm. As deflection ranges move into 0.34mm to 0.60mm, we still see that the anchorage resistance for the less than 5Ncm group is significantly lower than those observed for the 5-10Ncm group, as well as, the greater than 10Ncm. Our findings appear to support Motoyoshi's placement recommendations, as far as, obtaining a minimum of 5Ncm of maximum insertion torque. As for limiting the maximum insertion torque to 10Ncm, our analysis does not reinforce this claim. Other factors may come into play in a clinical study that may validate keeping the maximum insertion torque below 10Ncm. For example, in an in vivo situation, higher insertion torques may over heat the bone and cause screw failure (Adell et al., 1981; Albrektsson et al., 1986) or possibly strip or crush the bone upon insertion, which will interferes with the mechanical "locking" and stability of the screw. Another viable reason for more failures at higher torques in clinical situations is that sights that tend to have higher maximum insertion torques (i.e., posterior mandible) may also have other characteristics that lead to screw failure , such as, higher masticatory forces, limited access for oral hygiene and a more difficult location for screw placement (Miyawaki, 2003). As we discussed earlier, quality and quantity of bone can effect the amount of anchorage resistance a particular site can achieve (Huja et al., 2005). In the less than 5Ncm group, the decreased ability to resist forces is likely due to failure of the thinner cortical plate.



GraphC1 : Means of mini-screws torque groups vs. deflection

Application of these findings to a clinical environment should be explored. It would be unrealistic to expect an orthodontist to invest in an expensive torque measuring driver to place TADs and even more unreasonable to expect the clinician to replace a screw that appears sound, because it did not register the appropriate maximum insertion torque. One idea we entertained was the use of a driver which gives the doctor an indication (i.e. click) that the screw had reached 5Ncm of torque and then another indication that 10Ncm was achieved. If 5Ncm of maximum insertion torque was not reached then the mini-screw could be replaced with a mini-screw of larger diameter or a different jaw location could be chosen, if possible. On the other hand, if the insertion torque exceeded 10 Ncm the mini-screw could be removed and a pilot hole placed to relieve the insertion resistance. Another application could be designing TADs for specific placement sites with the thought that with varying the screw design (i.e. length, diameter) the maximum insertion torque could be controlled. For example, if the placement of screws in the posterior region of the mandible consistently produces maximum insertion torque greater than 10 Ncm, a mini-screw with a smaller diameter and shorter length may be recommended.

Limitations of this study should be discussed. Since this is an in-vitro study, biologic changes which occur with osseous loading could not be examined. Unlike traditional endosseous implants which depend on a waiting period for bone healing and osseointegration, the primary stability of orthodontic mini-screws (TADs) is thought to be result from mechanical retention of screw in bone (Costa, 1998 and Melsen, 2000). The ability of TADs to be mechanically retained allows for an in-vitro study without consideration of needing to allow healing or biologic adaptation to occur. This study provides an indication of anchorage in the case of immediate loading following mini-screw placement. Additionally, the age and systemic health of each of the cadavers was unknown. No bone density testing was performed and this variable may affect screw retention. The effect of the chemicals used in preservation of the bone is unknown. In this study it was assumed that all samples would be affected equally and therefore the effect minimized. There was a relatively small sample size and therefore variation in bone density or quality between samples might be magnified.

The use of temporary anchorage devices has opened up endless possibilities in the field of orthodontics. TADs are allowing the clinician increased control of tooth movement, more predictable mechanics and less need to rely on patient compliance. These benefits do not come without some trial and error. Clinicians have reported a wide range of success rates and orthodontists have yet to settle on a standard placement protocol. Many factors play a role in the success or failure of TADs and with continued research hopefully we can control these factors and make the use of TADs extremely predictable. The results of our study do not provide any hard and fast rules for TAD placement, but hopefully offers directions that will be added to, discussed and trigger future research that will continue to develop protocols for more successful and predictable TAD placement.

CONCLUSION

- In vitro, the anchorage resistance offered by mini-screws placed with higher maximum insertion torque was, on average, greater than the anchorage resistance offered by mini-screws placed at lower maximum insertion torques. This difference was statistically significant in the deflection ranges of 0.01mm to 0.06mm in the maxilla and mandible.

- In vitro, there was a significantly increasing relationship between maximum insertion torque of mandibular mini-screws and buccal cortical bone thickness.

- In vitro, mean anchorage resistance of apically positioned mini-screws placed in the mandible was significantly greater than that observed for coronally-positioned mini-screws at each deflection rangeing from 0.01mm to 0.37mm.

- In vitro, mean maximum insertion torque of mini-screws placed in the mandible was significantly greater than those placed in the maxilla at all deflection ranging from 0.00mm to 0.60mm.

- In vitro, mean buccal cortical bone thickness of mini-screws placed in the mandible was significantly greater than those placed in the maxilla at all deflection ranged from 0.00mm to 0.60mm.

- In vitro, mean anchorage resistance of mini-screws placed in the mandible was significantly greater than those placed in the maxilla at all deflection ranged from 0.20mm to 0.60mm.

- In vitro, mean anchorage resistance for screws placed with maximum insertion torque of less than 5Ncm was significantly lower than those placed with maximum insertion torque between 5Ncm and 10Ncm at deflections ranging from 0.12mm to 0.60mm.

- In terms of maximizing anchorage resistance, we recommend placement of TADs with maximum insertion torque of greater than 5Ncm.

APPENDIX A-TABLES

Table A1: Mini Screw Mobility and Observation

Quadrant	Screw #	Location	Mobility	Bent
Mandibular Right	1	coronal	Mobile	Bent
Mandibular Right	2	apical	Not Mobile	Bent
Mandibular Left	3	coronal	Not Mobile	Bent
Mandibular Left	4	apical	Not Mobile	Bent
Mandibular Right	5	coronal	Not Mobile	Bent
Mandibular Right	6	apical	Not Mobile	Bent
Mandibular Left	7	coronal	Not Mobile	Bent
Mandibular Left	8	apical	Mobile	Bent
Maxillary Right	9	coronal	Not Mobile	Bent
Maxillary Right	10	apical	Mobile	Bent
Maxillary Left	11	coronal	Mobile	Not Bent
Maxillary Left	12	apical	Mobile	Not Bent
Maxillary Right	13	coronal	Mobile	Bent
Maxillary Right	14	apical	Mobile	Not Bent
Maxillary Left	15	coronal	Mobile	Bent
Maxillary Left	16	apical	Not Mobile	Bent
Maxillary Right	17	coronal	Not Mobile	Bent
Maxillary Right	18	apical	Not Mobile	Bent
Mandibular Left	19	coronal	Not Mobile	Bent
Mandibular Left	20	apical	Not Mobile	Bent
Mandibular Right	21	coronal	Not Mobile	Bent
Mandibular Right	22	apical	Not Mobile	Bent
Maxillary Left	23	coronal	Mobile	Not Bent
Maxillary Left	24	apical	Not Mobile	Not Bent
Maxillary Right	25	coronal	Mobile	Bent
Maxillary Right	26	apical	Mobile	Not Bent
Maxillary Left	27	coronal	Not Mobile	Bent
Maxillary Left	28	apical	Not Mobile	Bent
Mandibular Right	29	coronal	Not Mobile	Bent

Table A1: Mini Screw Mobility and Observation (cont.)

Quadrant	**Screw #**	**Location**	**Mobility**	**Bent**
Mandibular Right	30	apical	Not Mobile	Bent
Mandibular Right	31	coronal	Not Mobile	Bent
Mandibular Right	32	apical	Not Mobile	Bent
Maxillary Right	33	coronal	Mobile	Not Bent
Maxillary Right	34	apical	Mobile	Not Bent
Maxillary Left	35	coronal	Mobile	Bent
Maxillary Left	36	apical	Mobile	Not Bent
Maxillary Left	37	coronal	Not Mobile	Bent
Maxillary Left	38	apical	Not Mobile	Bent
Maxillary Right	39	coronal	Mobile	Bent
Maxillary Right	40	apical	Mobile	Bent
Maxillary Left	41	coronal	Mobile	Not Bent
Maxillary Left	42	apical	Mobile	Not Bent
Maxillary Left	43	coronal	Not Mobile	Bent
Maxillary Left	44	apical	Not Mobile	Bent
Maxillary Left	45	coronal	Not Mobile	Bent
Maxillary Left	46	apical	Not Mobile	Bent
Maxillary Right	47	coronal	Not Mobile	Bent
Maxillary Right	48	apical	Not Mobile	Bent
Maxillary Right	49	coronal	Mobile	Bent
Maxillary Right	50	apical	Not Mobile	Bent
Maxillary Right	51	coronal	Mobile	Not Bent
Maxillary Right	52	apical	Mobile	Not Bent
Mandibular Right	53	coronal	Not Mobile	Bent
Mandibular Right	54	apical	Not Mobile	Bent
Mandibular Right	55	coronal	Not Mobile	Not Bent
Mandibular Right	56	apical	Not Mobile	Bent
Mandibular Left	57	coronal	Not Mobile	Bent

Table A1: Mini Screw Mobility and Observation (cont.)

Quadrant	Screw #	Location	Mobility	Bent
Mandibular Left	58	apical	Not Mobile	Bent
Mandibular Right	59	coronal	Not Mobile	Bent
Mandibular Right	60	apical	Not Mobile	Bent
Mandibular Left	61	coronal	Not Mobile	Bent
Mandibular Left	62	apical	Not Mobile	Bent
Mandibular Left	63	coronal	Not Mobile	Bent
Mandibular Left	64	apical	Not Mobile	Bent
Mandibular Left	65	coronal	Not Mobile	Bent
Mandibular Left	66	apical	Not Mobile	Bent
Maxillary Left	67	coronal	Mobile	Bent
Maxillary Left	68	apical	Not Mobile	Not Bent
Mandibular Left	69	coronal	Not Mobile	Bent
Mandibular Left	70	apical	Not Mobile	Bent
Mandibular Left	71	coronal	Not Mobile	Bent
Mandibular Left	72	apical	Not Mobile	Bent
Mandibular Left	73	coronal	Not Mobile	Bent
Mandibular Left	74	apical	Not Mobile	Bent
Maxillary Right	75	coronal	Not Mobile	Not Bent
Maxillary Right	76	apical	Not Mobile	Bent
Maxillary Right	77	coronal	Mobile	Bent
Maxillary Right	78	apical	Mobile	Not Bent
Maxillary Right	79	coronal	Not Mobile	Bent
Maxillary Right	80	apical	Mobile	Bent
Mandibular Right	81	coronal	Not Mobile	Bent
Mandibular Right	82	apical	Not Mobile	Bent
Mandibular Left	83	coronal	Not Mobile	Bent
Mandibular Left	84	apical	Not Mobile	Bent
Mandibular Right	85	coronal	Not Mobile	Bent

Table A1: Mini Screw Mobility and Observation (cont.)

Quadrant	Screw #	Location	Mobility	Bent
Mandibular Right	86	apical	Not Mobile	Bent
Maxillary Left	87	coronal	Mobile	Bent
Maxillary Left	88	apical	Mobile	Bent
Mandibular Right	89	coronal	Not Mobile	Bent
Mandibular Right	90	apical	Not Mobile	Bent
Maxillary Left	91	coronal	Mobile	Bent
Maxillary Left	92	apical	Mobile	Bent
Mandibular Left	93	coronal	Not Mobile	Bent
Mandibular Left	94	apical	Not Mobile	Bent
Mandibular Right	95	coronal	Not Mobile	Bent
Mandibular Right	96	apical	Not Mobile	Bent

Table A2: Bone Thickness Measurements

Quadrant	Screw #	Buccal	Lingual	Alveolar Width
Mandibular Right	1	2.01	2.36	8.51
Mandibular Right	2	2.23	2.32	9.6
Mandibular Left	3	1.51	5.08	18.63
Mandibular Left	4	1.8	4.3	13.45
Mandibular Right	5	2.11	2.07	11.48
Mandibular Right	6	2.8	2.62	11.48
Mandibular Left	7	1.84	2.44	12.23
Mandibular Left	8	1.36	1.03	11.44
Maxillary Right	9	2.01	2.08	9.86
Maxillary Right	10	2.62	2.14	9.85
Maxillary Left	11	1.14	2.6	9.36
Maxillary Left	12	0.87	2.94	9.77
Maxillary Right	13	1.31	1.04	8.33
Maxillary Right	14	1.44	0.91	9.08
Maxillary Left	15	0.7	1.27	7.44
Maxillary Left	16	0.9	0.96	7.56
Maxillary Right	17	1.72	1.26	8.08
Maxillary Right	18	1.39	1.41	7.2
Mandibular Left	19	1.79	1.37	7.35
Mandibular Left	20	1.53	1.65	8.33
Mandibular Right	21	1.73	2.75	9.03
Mandibular Right	22	2.05	3.52	9.51
Maxillary Left	23	0.97	1.27	8.02
Maxillary Left	24	0.87	1.06	5.95
Maxillary Right	25	1.41	1.92	9.1
Maxillary Right	26	1	1.69	8.96
Maxillary Left	27	1.27	0.93	6.6

Table A2: Bone Thickness Measurements (cont.)

Quadrant	**Screw #**	**Buccal**	**Lingual**	**Alveolar Width**
Maxillary Left	28	1.14	0.96	6.48
Mandibular Right	29	2.04	6.97	14.8
Mandibular Right	30	2.13	3.49	13.88
Mandibular Right	31	1.93	2.33	10.93
Mandibular Right	32	1.91	3.22	11.64
Maxillary Right	33	0.88	1.65	6.81
Maxillary Right	34	1.49	0.93	6.35
Maxillary Left	35	1.59	1.28	10.25
Maxillary Left	36	2	2.14	10.16
Maxillary Left	37	1.63	1.94	7.84
Maxillary Left	38	1.69	1.53	7.43
Maxillary Right	39	2.03	1.77	6.74
Maxillary Right	40	1.45	1.93	6.25
Maxillary Left	41	1.31	1.3	8.8
Maxillary Left	42	1.14	1.35	10.03
Maxillary Left	43	2.01	1.21	12.82
Maxillary Left	44	2.44	1.58	12.63
Maxillary Left	45	1.12	1.31	10.13
Maxillary Left	46	1.71	2.1	10.14
Maxillary Right	47	2.02	1.83	7.7
Maxillary Right	48	1.65	2.02	7.15
Maxillary Right	49	0.84	1.13	8.07
Maxillary Right	50	1.15	1.23	8.09
Maxillary Right	51	2.79	1.42	7.9
Maxillary Right	52	2.32	1.68	7.81
Mandibular Right	53	2.12	2.48	11.74
Mandibular Right	54	2.37	2.28	12.04

Table A2: Bone Thickness Measurements (cont.)

Quadrant	Screw #	Buccal	Lingual	Alveolar Width
Mandibular Right	55	1.69	2.09	9.36
Mandibular Right	56	1.9	1.03	9.29
Mandibular Left	57	1.03	3.14	8.53
Mandibular Left	58	1.35	2.56	9.42
Mandibular Right	59	1.15	2.3	7.72
Mandibular Right	60	1.85	2.27	8.5
Mandibular Left	61	1.86	1.97	7.18
Mandibular Left	62	2.17	2.31	8.93
Mandibular Left	63	1.6	1.94	6.95
Mandibular Left	64	1.82	2.16	7.79
Mandibular Left	65	1.87	2.52	6.35
Mandibular Left	66	2.68	2.68	10.1
Maxillary Left	67	2.02	1.84	6.36
Maxillary Left	68	2.32	1.78	7.16
Mandibular Left	69	1.92	2.93	11.26
Mandibular Left	70	2.14	3.14	12.18
Mandibular Left	71	1.02	2.38	7.73
Mandibular Left	72	1.58	2.78	8.97
Mandibular Left	73	2.35	2.02	7.43
Mandibular Left	74	1.52	2.97	7.53
Maxillary Right	75	2.75	2.87	11.27
Maxillary Right	76	2.04	3.19	11.47
Maxillary Right	77	1.29	1.6	10.54
Maxillary Right	78	1.99	1.68	10.05
Maxillary Right	79	1.26	2.62	8.9
Maxillary Right	80	1.47	1.38	8.97
Mandibular Right	81	3.37	2.82	8.02

Table A2: Bone Thickness Measurements (cont.)

Quadrant	**Screw #**	**Buccal**	**Lingual**	**Alveolar Width**
Mandibular Right	82	2.66	3.06	9.21
Mandibular Left	83	2.72	3.57	11.55
Mandibular Left	84	2.23	2.92	11.29
Mandibular Right	85	3.55	3.15	9.68
Mandibular Right	86	4.18	4.1	9.99
Maxillary Left	87	1.11	2.21	8.35
Maxillary Left	88	2.34	2.2	8.03
Mandibular Right	89	3.44	2.84	9.96
Mandibular Right	90	1.85	1.86	10.14
Maxillary Left	91	2.11	2.12	9.01
Maxillary Left	92	2.8	1.94	7.72
Mandibular Left	93	2.91	3.36	8.2
Mandibular Left	94	3.02	3.16	9.71
Mandibular Right	95	2.42	3.03	8.48
Mandibular Right	96	2.93	2.28	9.33

Table A3: Maximum Insertion Torque Measurements

Quadrant	Screw #	Location	Torque (Ncm)
Mandibular Right	1	coronal	7.9
Mandibular Right	2	apical	9.7
Mandibular Left	3	coronal	5
Mandibular Left	4	apical	5.3
Mandibular Right	5	coronal	5.8
Mandibular Right	6	apical	7.6
Mandibular Left	7	coronal	3.4
Mandibular Left	8	apical	2.8
Maxillary Right	9	coronal	5.8
Maxillary Right	10	apical	6.4
Maxillary Left	11	coronal	2.6
Maxillary Left	12	apical	0
Maxillary Right	13	coronal	2.5
Maxillary Right	14	apical	0
Maxillary Left	15	coronal	2.5
Maxillary Left	16	apical	3.7
Maxillary Right	17	coronal	3.6
Maxillary Right	18	apical	3.8
Mandibular Left	19	coronal	5.8
Mandibular Left	20	apical	3.5
Mandibular Right	21	coronal	4.6
Mandibular Right	22	apical	5.6
Maxillary Left	23	coronal	2
Maxillary Left	24	apical	4
Maxillary Right	25	coronal	3.6
Maxillary Right	26	apical	2.1
Maxillary Left	27	coronal	6.5

Table A3: Maximum Insertion Torque Measurements (cont.)

Quadrant	Screw #	Location	Torque (Ncm)
Maxillary Left	28	apical	6.9
Mandibular Right	29	coronal	7.3
Mandibular Right	30	apical	10.1
Mandibular Right	31	coronal	10.4
Mandibular Right	32	apical	11.9
Maxillary Right	33	coronal	2.5
Maxillary Right	34	apical	2.5
Maxillary Left	35	coronal	3.2
Maxillary Left	36	apical	2.7
Maxillary Left	37	coronal	9.7
Maxillary Left	38	apical	5.3
Maxillary Right	39	coronal	3.2
Maxillary Right	40	apical	4.1
Maxillary Left	41	coronal	2
Maxillary Left	42	apical	2.6
Maxillary Left	43	coronal	3.7
Maxillary Left	44	apical	5.8
Maxillary Left	45	coronal	5.7
Maxillary Left	46	apical	22.5
Maxillary Right	47	coronal	7.1
Maxillary Right	48	apical	5.6
Maxillary Right	49	coronal	3.5
Maxillary Right	50	apical	4.6
Maxillary Right	51	coronal	3.8
Maxillary Right	52	apical	3.6
Mandibular Right	53	coronal	10.6
Mandibular Right	54	apical	13
Mandibular Right	55	coronal	6.8
Mandibular Right	56	apical	2.7

Table A3: Maximum Insertion Torque Measurements (cont.)

Quadrant	Screw #	Location	Torque (Ncm)
Mandibular Left	57	coronal	4.5
Mandibular Left	58	apical	4.5
Mandibular Right	59	coronal	4.5
Mandibular Right	60	apical	4.2
Mandibular Left	61	coronal	9.5
Mandibular Left	62	apical	7.8
Mandibular Left	63	coronal	12.5
Mandibular Left	64	apical	6.7
Mandibular Left	65	coronal	24.2
Mandibular Left	66	apical	23.5
Maxillary Left	67	coronal	8.2
Maxillary Left	68	apical	9.2
Mandibular Left	69	coronal	9
Mandibular Left	70	apical	5.6
Mandibular Left	71	coronal	3.2
Mandibular Left	72	apical	3
Mandibular Left	73	coronal	8
Mandibular Left	74	apical	10.2
Maxillary Right	75	coronal	2.1
Maxillary Right	76	apical	2.7
Maxillary Right	77	coronal	4.7
Maxillary Right	78	apical	2.7
Maxillary Right	79	coronal	5.8
Maxillary Right	80	apical	5.7
Mandibular Right	81	coronal	6.4
Mandibular Right	82	apical	6.9
Mandibular Left	83	coronal	6.9
Mandibular Left	84	apical	7.3
Mandibular Right	85	coronal	21.7

Table A3: Maximum Insertion Torque Measurements (cont.)

Quadrant	**Screw #**	**Location**	**Torque (Ncm)**
Mandibular Right	86	apical	24.3
Maxillary Left	87	coronal	4.8
Maxillary Left	88	apical	4
Mandibular Right	89	coronal	7.2
Mandibular Right	90	apical	5.2
Maxillary Left	91	coronal	5.8
Maxillary Left	92	apical	7.6
Mandibular Left	93	coronal	12.2
Mandibular Left	94	apical	15.5
Mandibular Right	95	coronal	12.4
Mandibular Right	96	apical	8.2

Table A4: Mean Force/ Deflection measurements for the less than 5Ncm Maximum Insertion Torque Group

Deflection (mm)	**Force (N)**	**Deflection (mm)**	**Force (N)**
0	0	0.38	18.77043
0.01	1.469091	0.39	19.23652
0.02	1.763636	0.4	19.66435
0.03	2.164222	0.41	20.13913
0.04	2.604	0.42	20.58609
0.05	2.988444	0.43	21.03478
0.06	3.364	0.44	21.50435
0.07	3.767778	0.45	21.93391
0.08	4.141111	0.46	22.34087
0.09	4.77	0.47	22.81391
0.1	5.238478	0.48	23.21913
0.11	5.70087	0.49	23.6487
0.12	6.166957	0.5	24.06609
0.13	6.683478	0.51	24.48348
0.14	7.184348	0.52	24.8887
0.15	7.709565	0.53	25.29739
0.16	8.187826	0.54	25.71304
0.17	8.667826	0.55	26.10609
0.18	9.133913	0.56	26.49565
0.19	9.612174	0.57	26.90609
0.2	10.08522	0.58	27.30435
0.21	10.58957	0.59	27.69391
0.22	11.06609	0.6	28.06783
0.23	11.58261		
0.24	12.07478		
0.25	12.59826		
0.26	13.10087		
0.27	13.59826		
0.28	14.10261		
0.29	14.58435		
0.3	15.08174		
0.31	15.5687		
0.32	16.0487		
0.33	16.49739		
0.34	16.96		
0.35	17.41913		
0.36	17.86261		
0.37	18.31652		

Table A5: Mean Force/ Deflection measurements for the 5Ncm to 10Ncm Maximum Insertion Torque Group

Deflection (mm)	Force (N)	Deflection (mm)	Force (N)
0	0	0.37	28.48865
0.01	2.172973	0.38	29.22811
0.02	2.566486	0.39	29.94378
0.03	3.275676	0.4	30.67676
0.04	4.041081	0.41	31.36432
0.05	4.765405	0.42	32.04973
0.06	5.433514	0.43	32.74811
0.07	6.112432	0.44	33.42703
0.08	6.758919	0.45	34.11676
0.09	7.407568	0.46	34.74378
0.1	8.03027	0.47	35.43784
0.11	8.607568	0.48	35.84
0.12	9.273514	0.49	36.46526
0.13	9.997838	0.5	37.05053
0.14	10.66811	0.51	37.66526
0.15	11.37297	0.52	38.22947
0.16	12.04541	0.53	38.82737
0.17	12.74162	0.54	39.40421
0.18	13.48973	0.55	39.98316
0.19	14.2227	0.56	40.52842
0.2	15.00541	0.57	41.08421
0.21	15.84432	0.58	41.62105
0.22	16.65946	0.59	42.13895
0.23	17.49622	0.6	42.62737
0.24	18.32432		
0.25	19.13514		
0.26	19.95027		
0.27	20.77622		
0.28	21.56324		
0.29	22.35459		
0.3	23.1373		
0.31	23.93297		
0.32	24.66378		
0.33	25.47676		
0.34	26.23568		
0.35	26.97514		
0.36	27.77297		
0.37	28.48865		

Table A6: Mean Force/ Deflection measurements for the greater than 10Ncm Maximum Insertion Torque Group

Deflection (mm)	Force (N)	Deflection (mm)	Force (N)
0	0	0.38	26.15467
0.01	1.882667	0.39	26.832
0.02	2.266667	0.4	27.54133
0.03	2.826667	0.41	28.23467
0.04	3.434667	0.42	28.93867
0.05	3.978667	0.43	29.62133
0.06	4.581333	0.44	30.34667
0.07	5.178667	0.45	31.008
0.08	5.818667	0.46	31.865
0.09	6.416	0.47	32.495
0.1	7.114667	0.48	33.155
0.11	7.744	0.49	33.76
0.12	8.384	0.5	34.37
0.13	8.976	0.51	34.99
0.14	9.642667	0.52	35.6
0.15	10.30933	0.53	36.195
0.16	11.024	0.54	36.78
0.17	11.712	0.55	37.37
0.18	12.46933	0.56	37.94
0.19	13.17867	0.57	38.53
0.2	13.888	0.58	39.035
0.21	14.56533	0.59	39.565
0.22	15.328	0.6	40.125
0.23	15.984		
0.24	16.69867		
0.25	17.41333		
0.26	18.10133		
0.27	18.76267		
0.28	19.48267		
0.29	20.13867		
0.3	20.77867		
0.31	21.47733		
0.32	22.21333		
0.33	22.84267		
0.34	23.54133		
0.35	24.176		
0.36	24.832		
0.37	25.488		

APPENDIX B – FIGURES

Figure B1: 1.5mm x 11.0mm titanium mini-screw (KLS Martin L.P.)

Figure B2: Pilot holes placed with 1.1mm diameter twist drilll

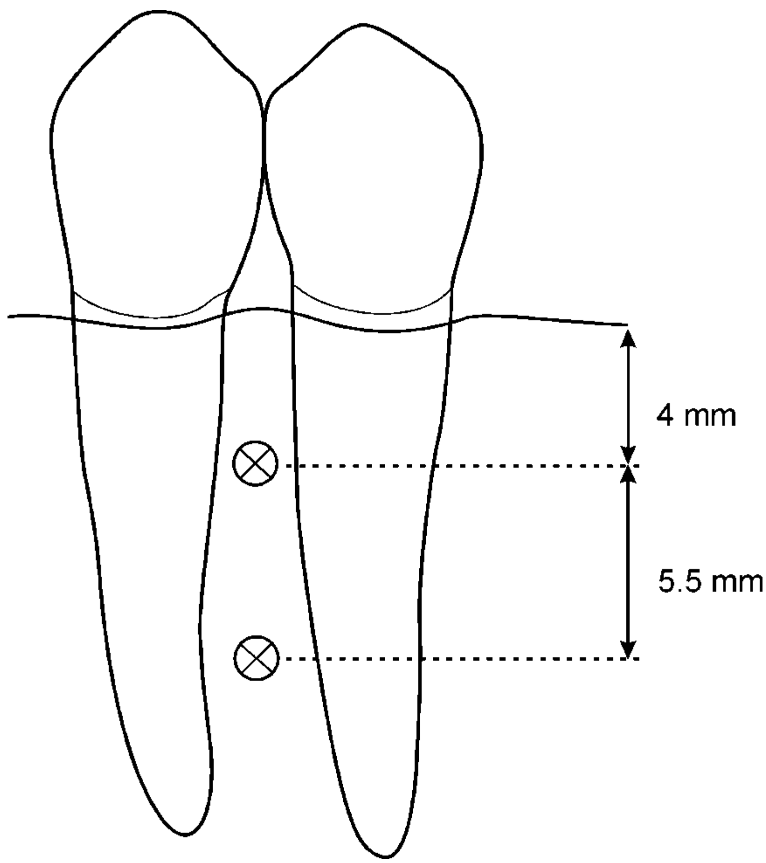


Figure B3: Representation of mini-screw insertion distances from crestal bone and adjacent mini-screws.

Figure B4: Digital Torque Screw Driver Model DID-4

Figure B5: Digital Torque screwdriver insert Model DID-4

Figure B6: Digital Torque screwdriver display Model DID-4

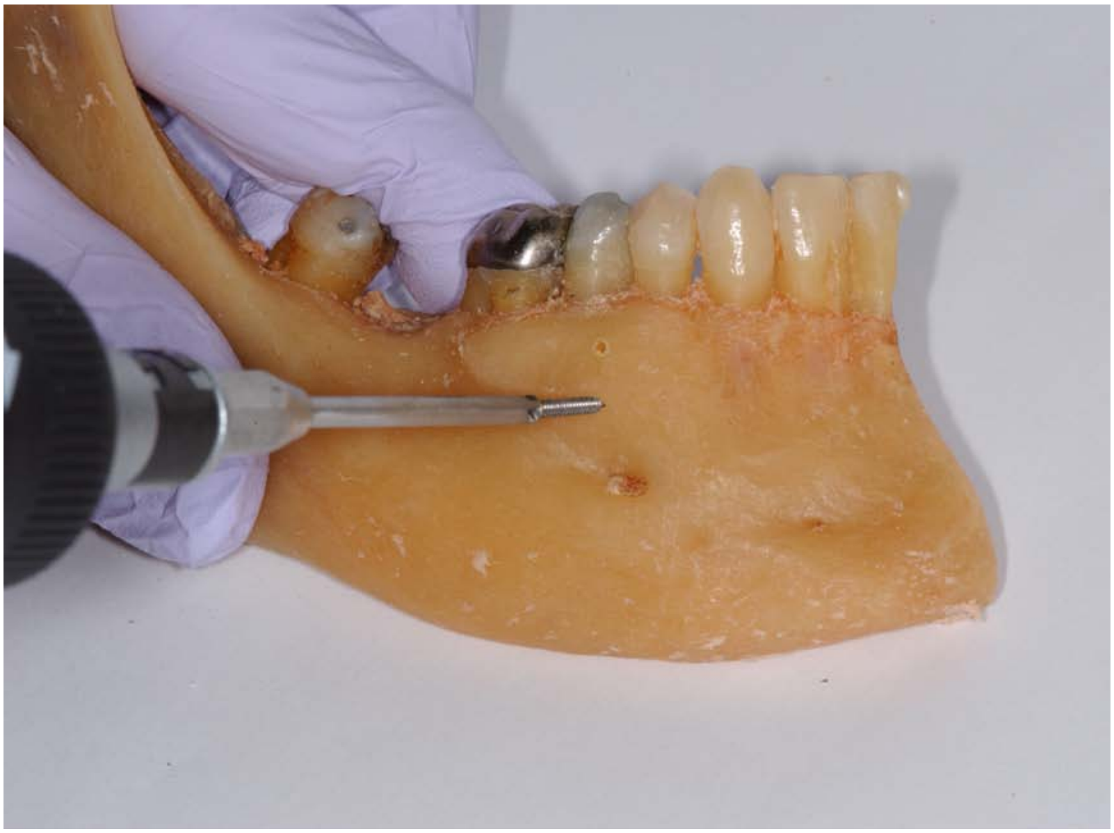


Figure B7: Mini-screw placement with digital torque screwdriver

Figure B8: Mini-screw insertion at 90 degrees

Figure B9: Zwick materials testing machine (Zwick GmbH & Co)

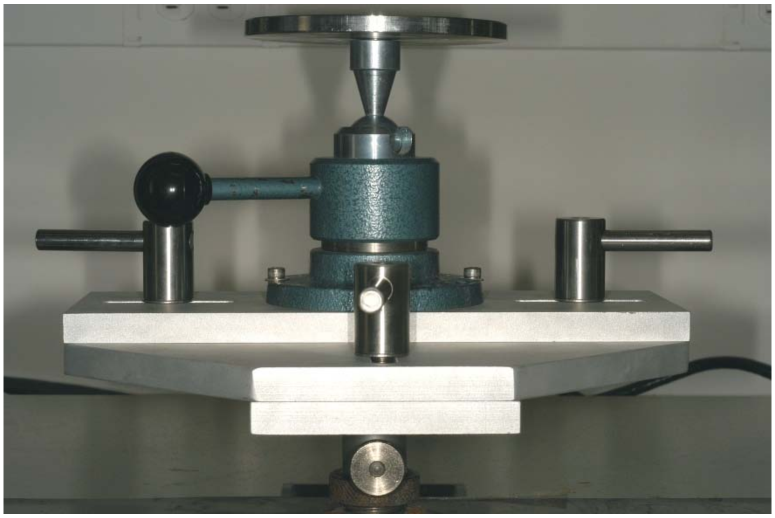


Figure B10: Customized X-Y-Z table

Figure B11: Customized X-Y-Z table, overhead view

Figure B12: Customized grip

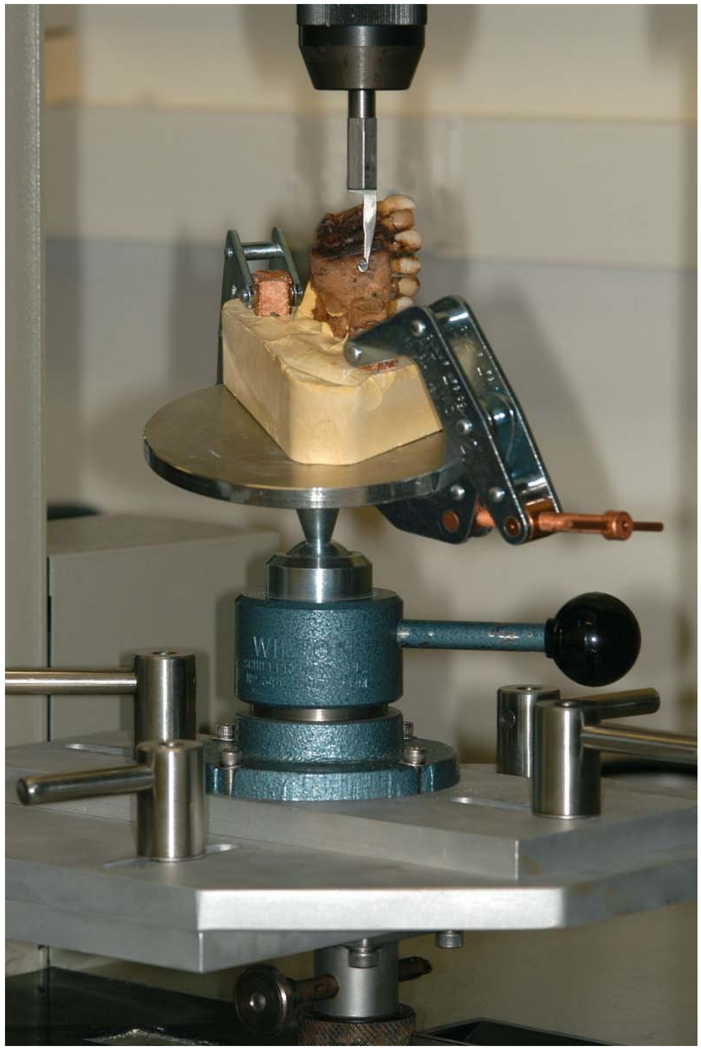
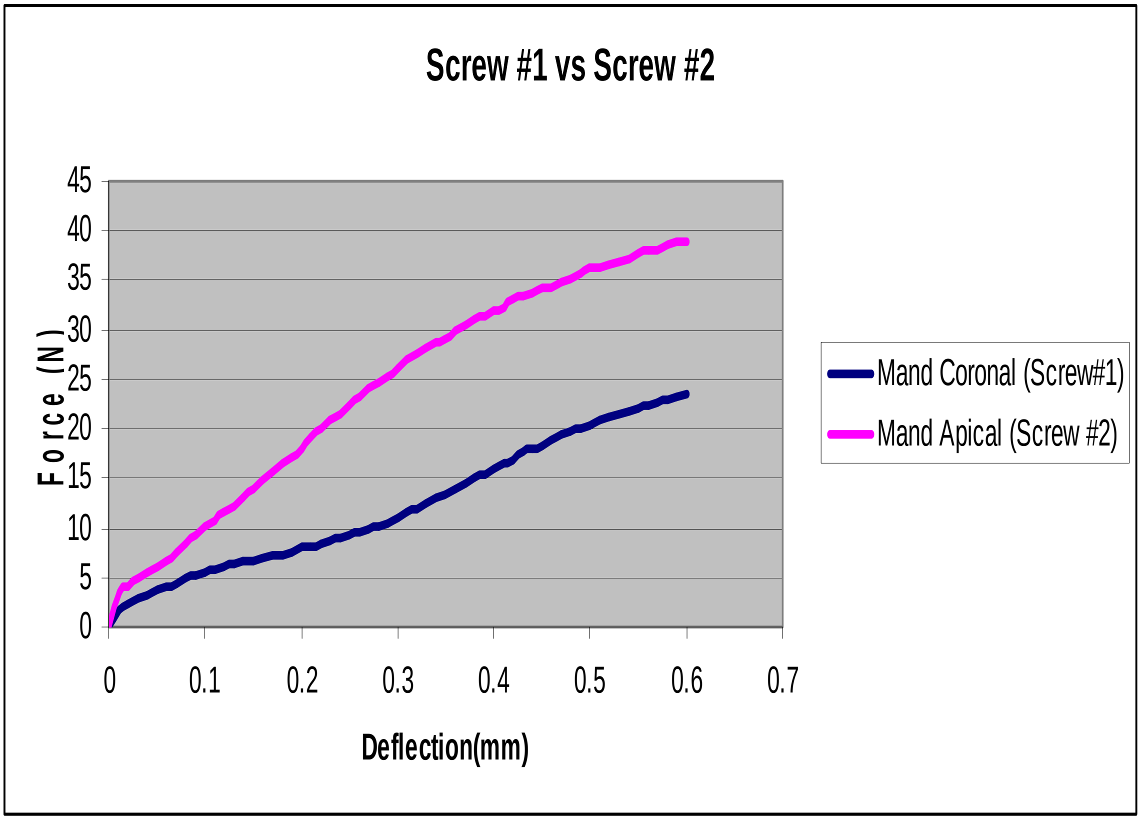
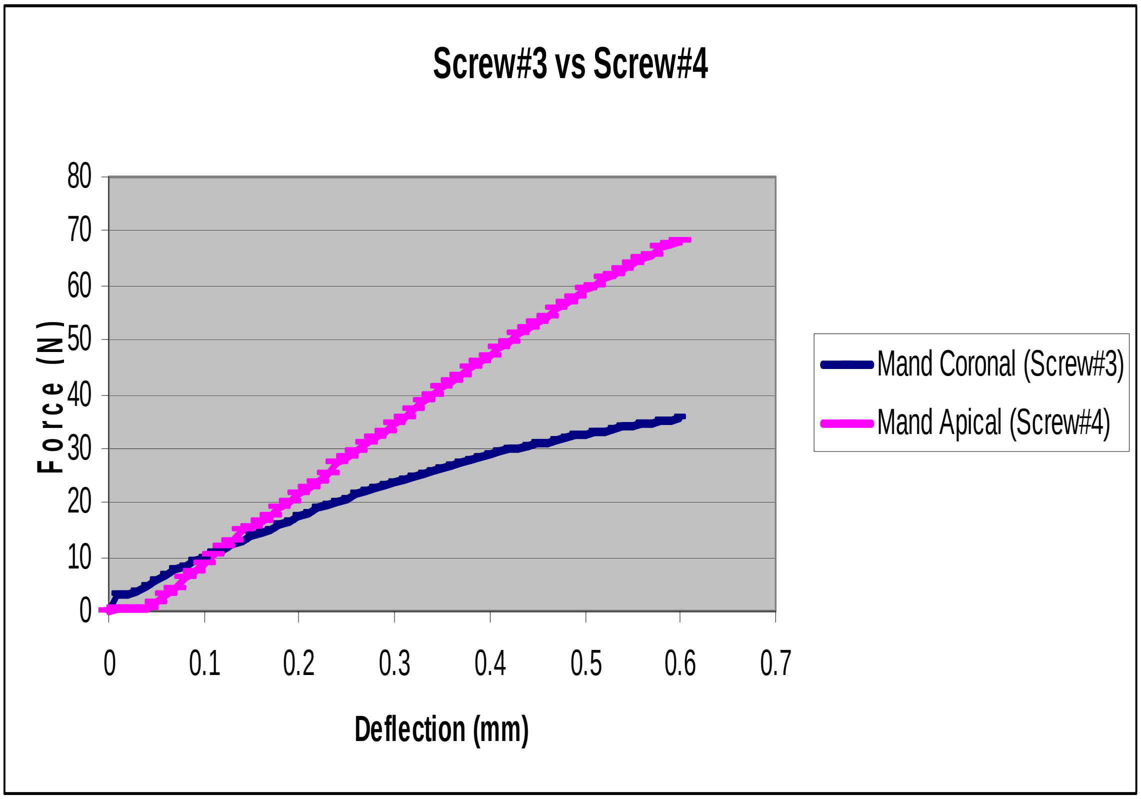


Figure B13: Specimen mounted on X-Y-Z table with custom grip parallel to occlusal plane

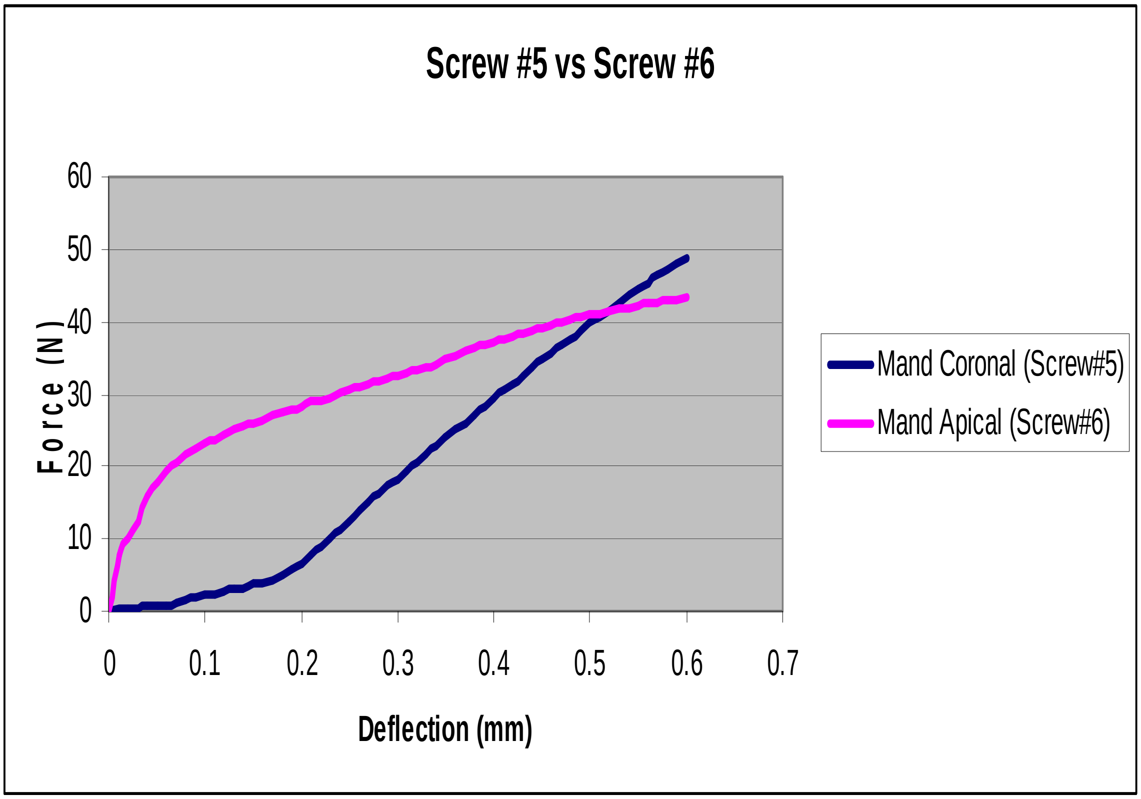
APPENDIX C – GRAPHS



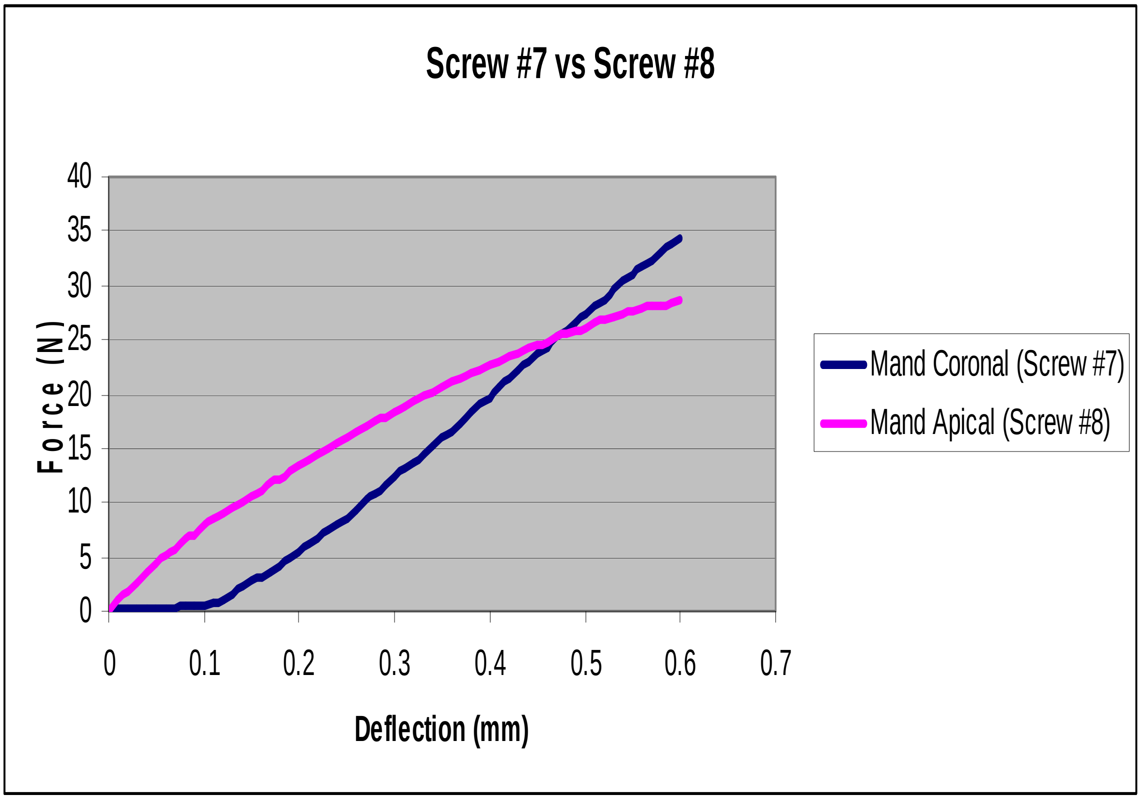
Graph C1: Force vs Deflection for screw #1 and screw #2 - mandible



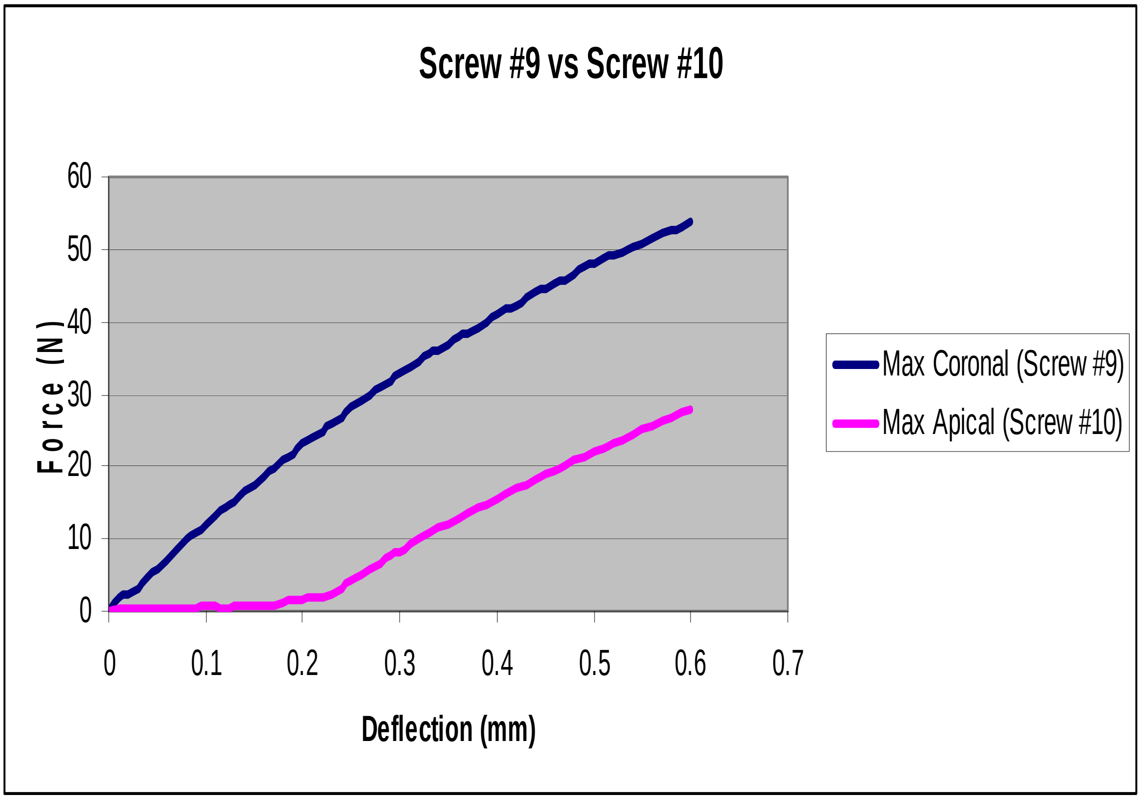
Graph C2: Force vs Deflection for screw #3 and screw #4 - mandible



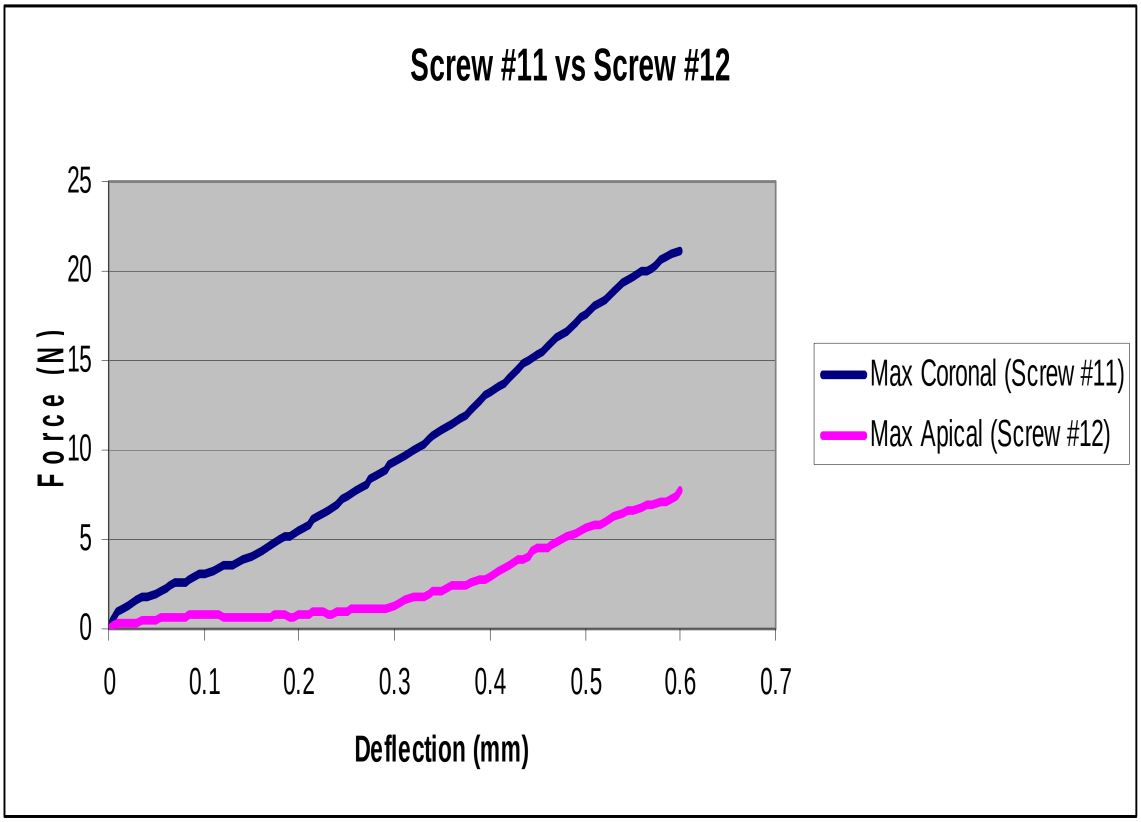
Graph C3: Force vs Deflection for screw #5 and screw #6 - mandible



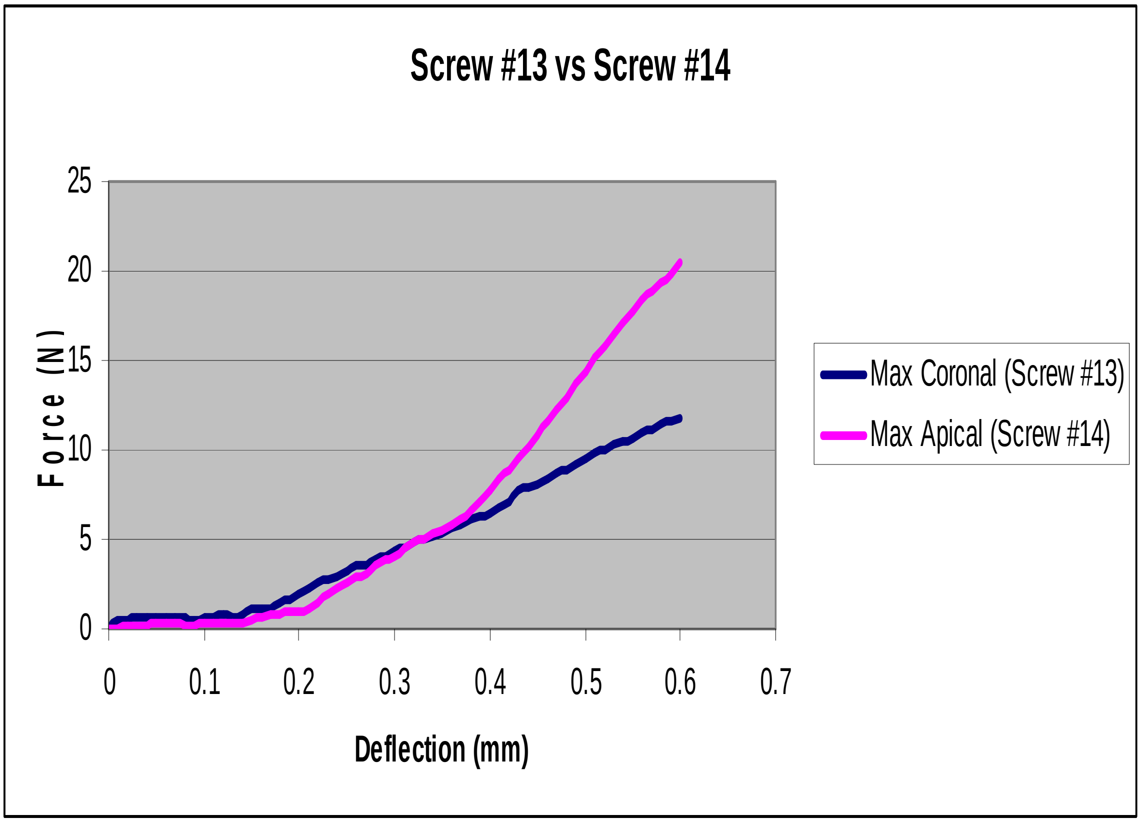
Graph C4: Force vs Deflection for screw #7 and screw #8 - mandible



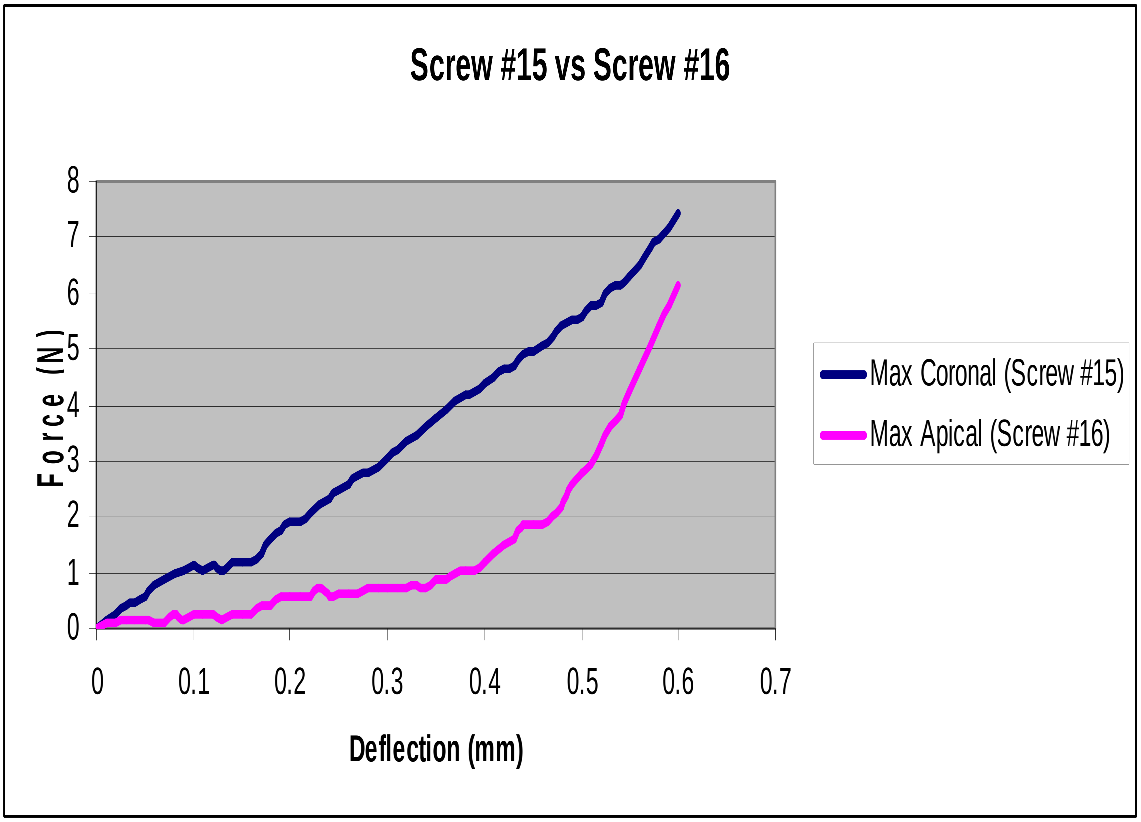
Graph C5: Force vs Deflection for screw #9 and screw #10 - maxilla



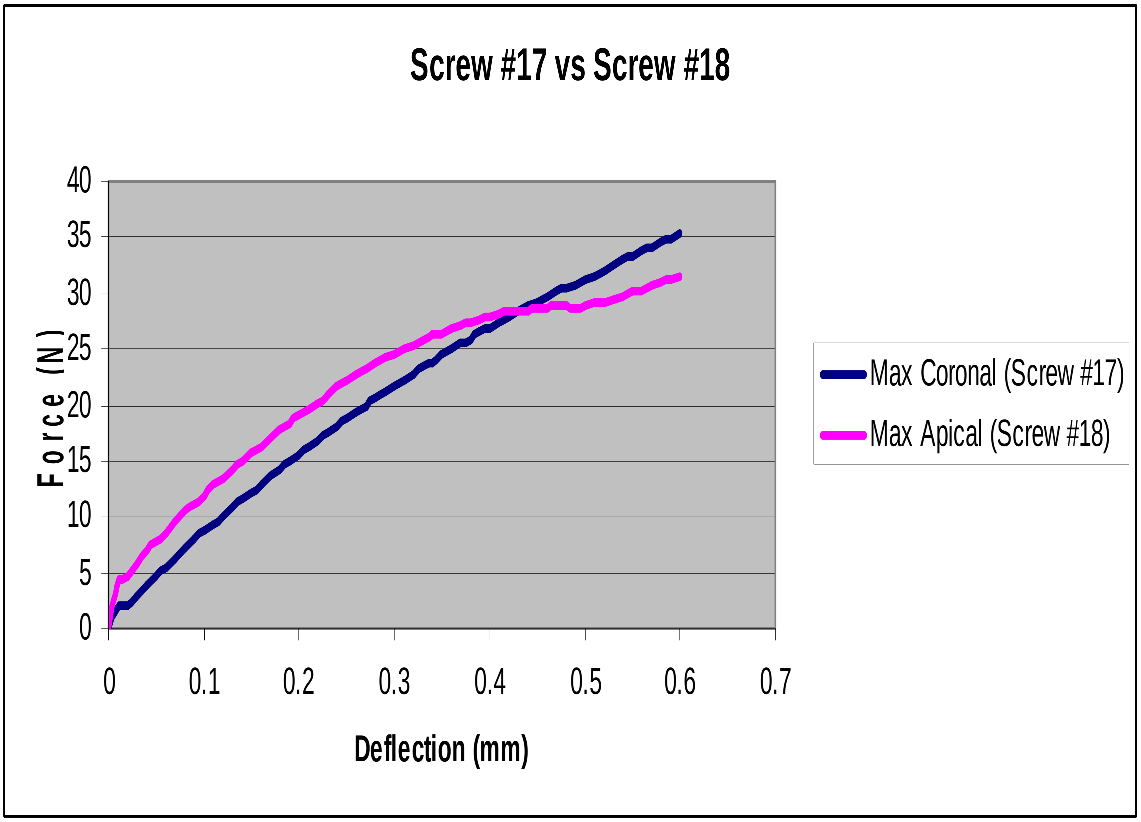
Graph C6: Force vs Deflection for screw #11 and screw #12 - maxilla



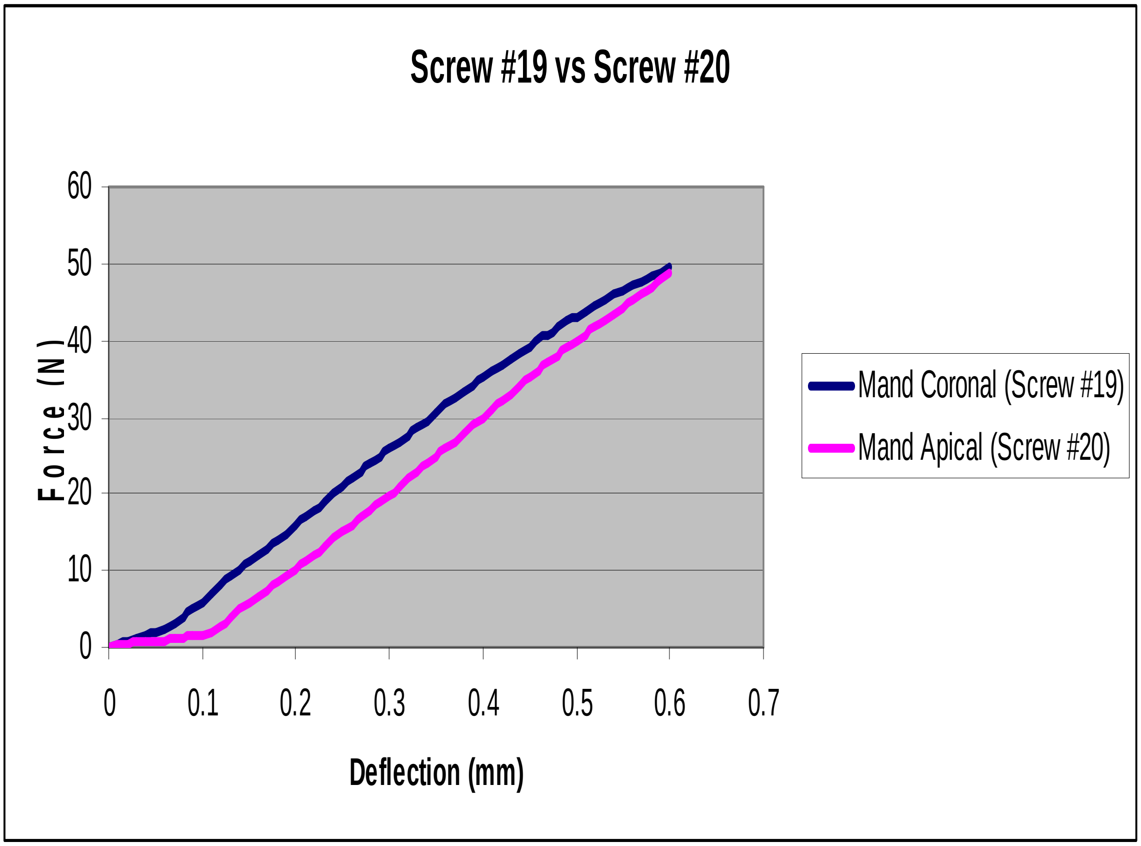
Graph C7: Force vs Deflection for screw #13 and screw #14 - maxilla



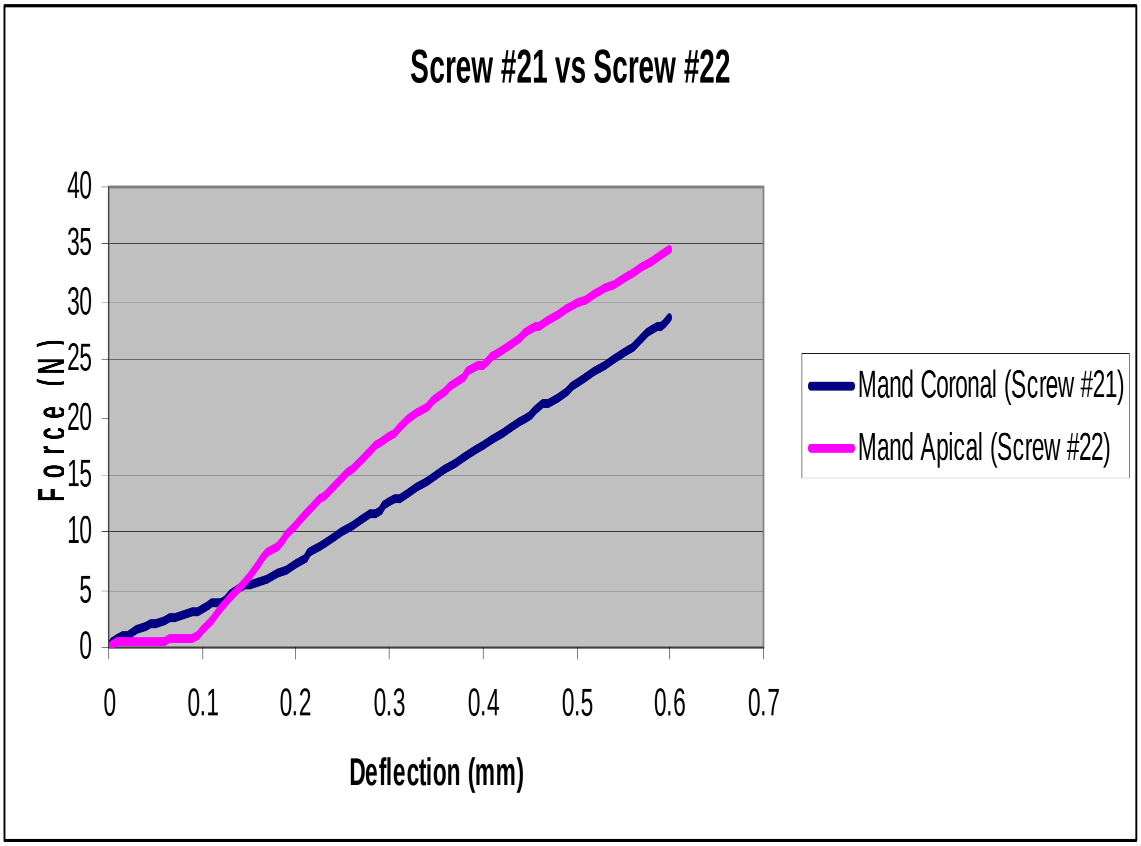
Graph C8: Force vs Deflection for screw #15 and screw #16 - maxilla



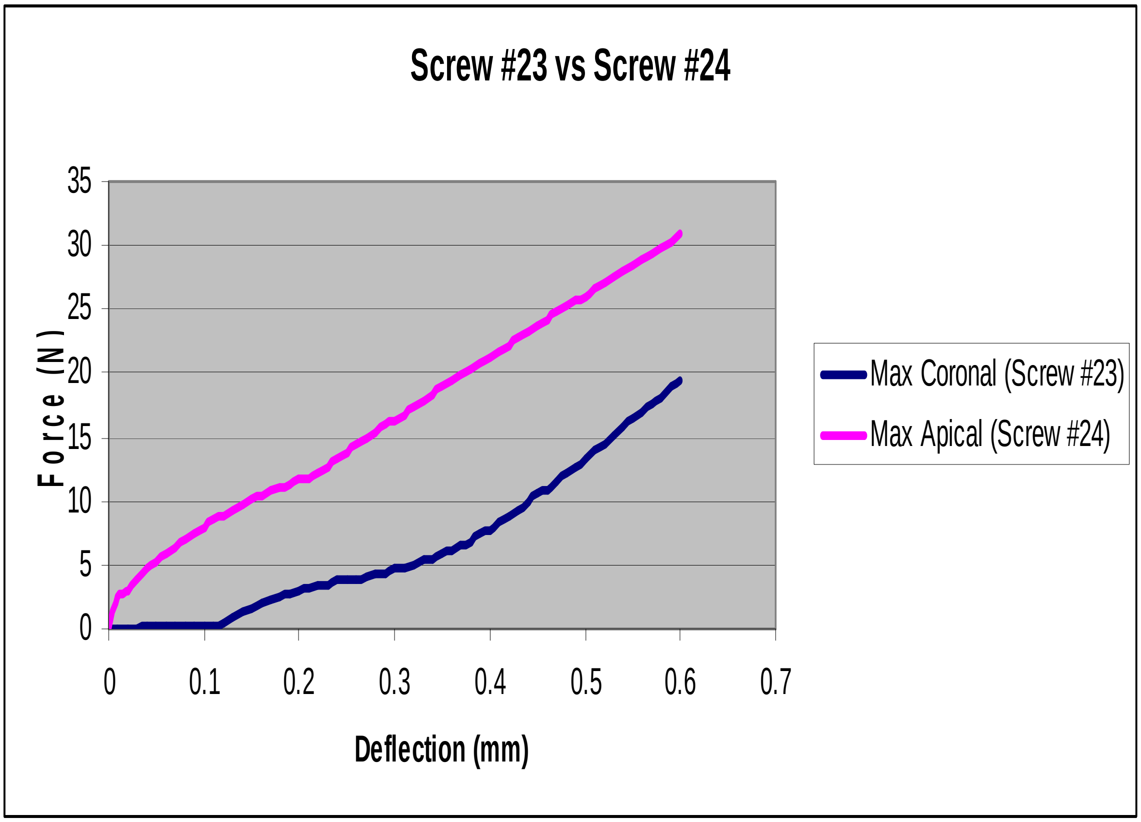
Graph C9: Force vs Deflection for screw #17 and screw #18 - maxilla



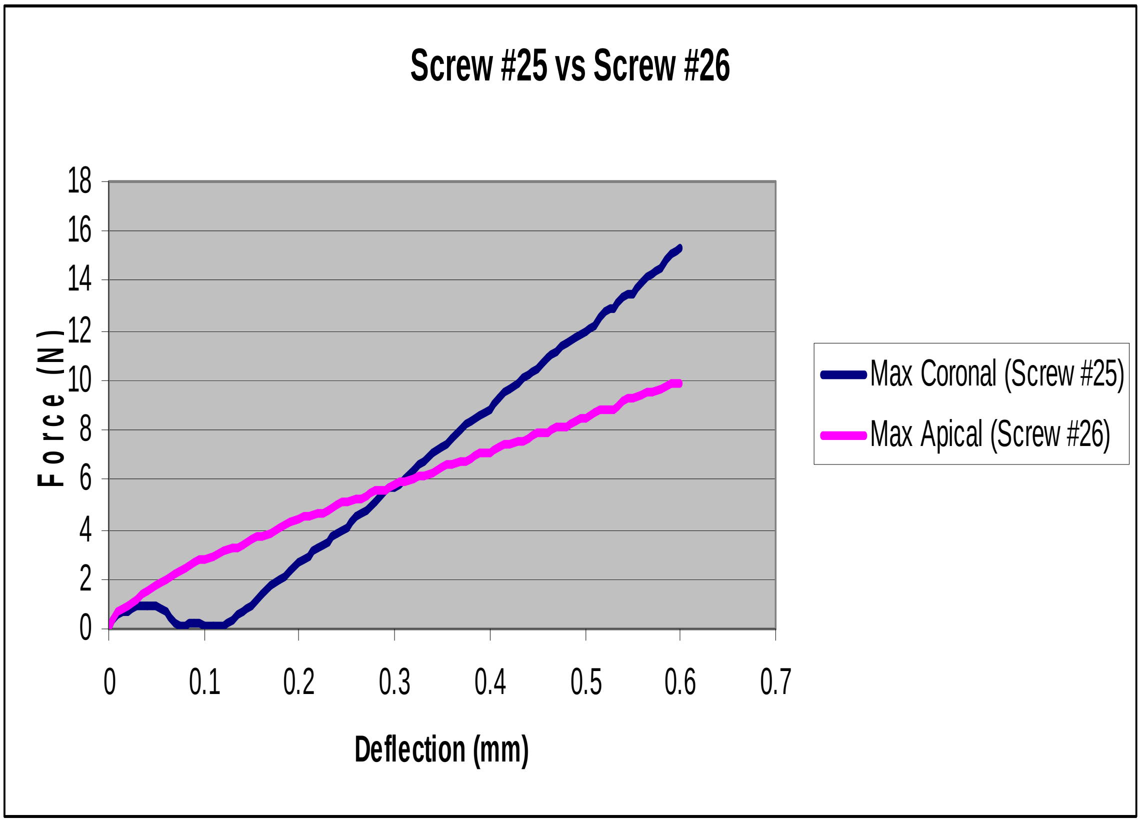
Graph C10: Force vs Deflection for screw #19 and screw #20 - mandible



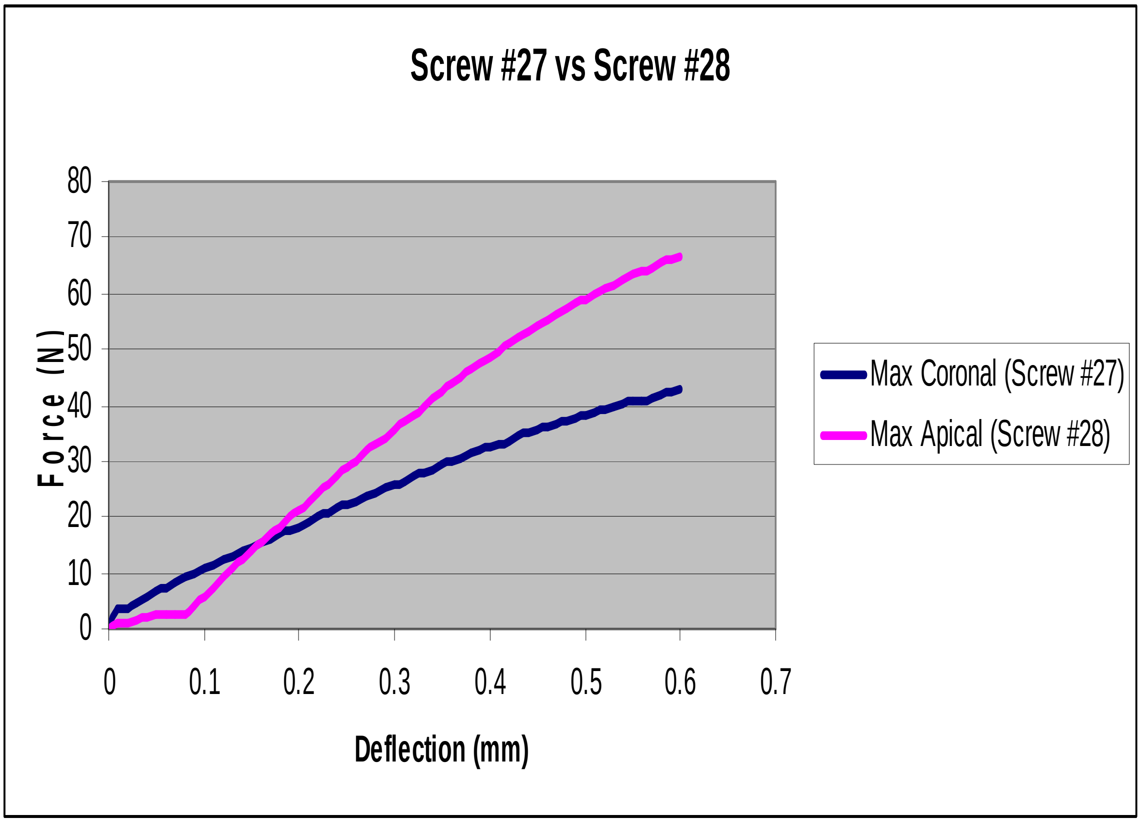
Graph C11: Force vs Deflection for screw #21 and screw #22 - mandible



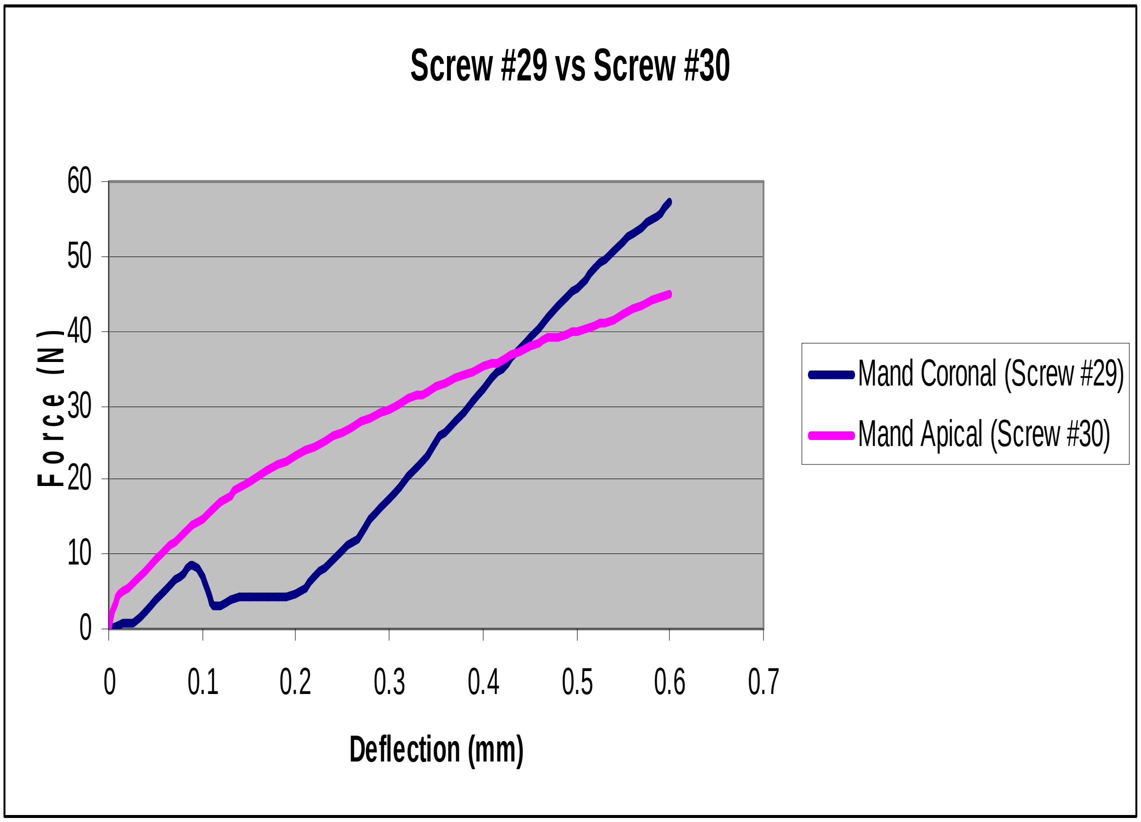
Graph C12: Force vs Deflection for screw #23 and screw #24 - maxilla



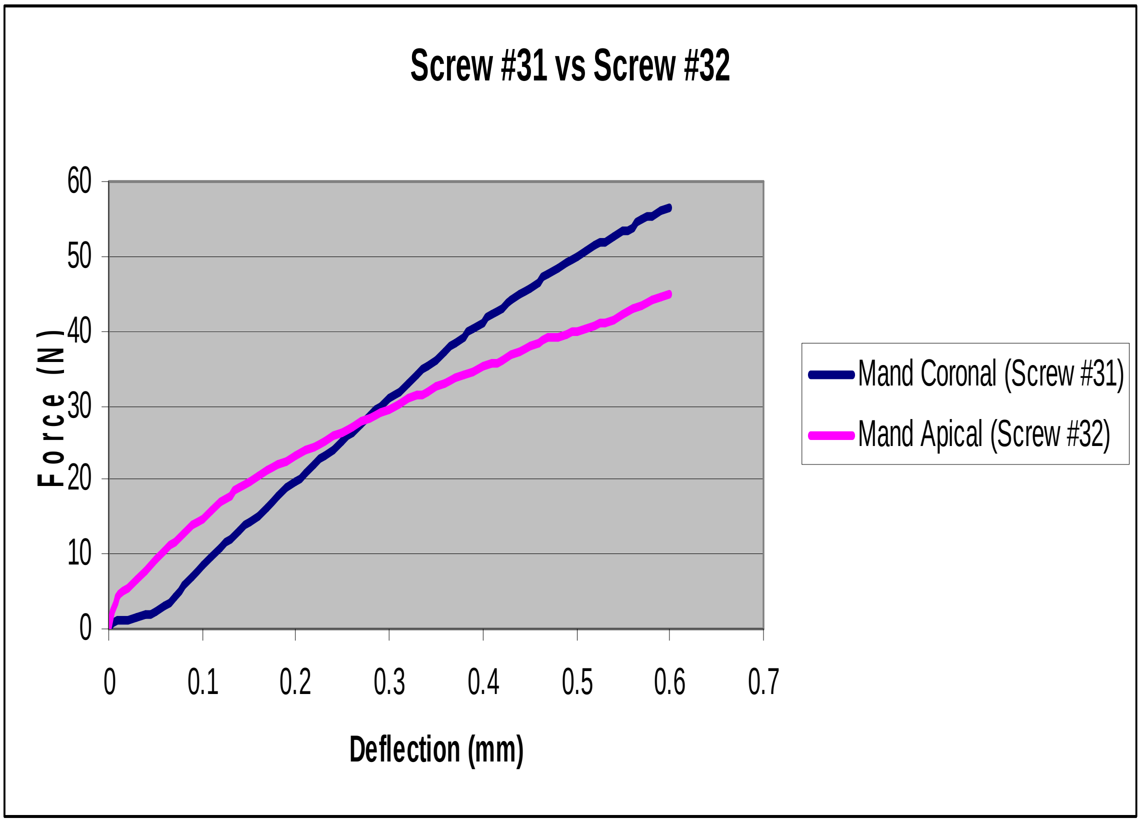
Graph C13: Force vs Deflection for screw #25 and screw #26 - maxilla



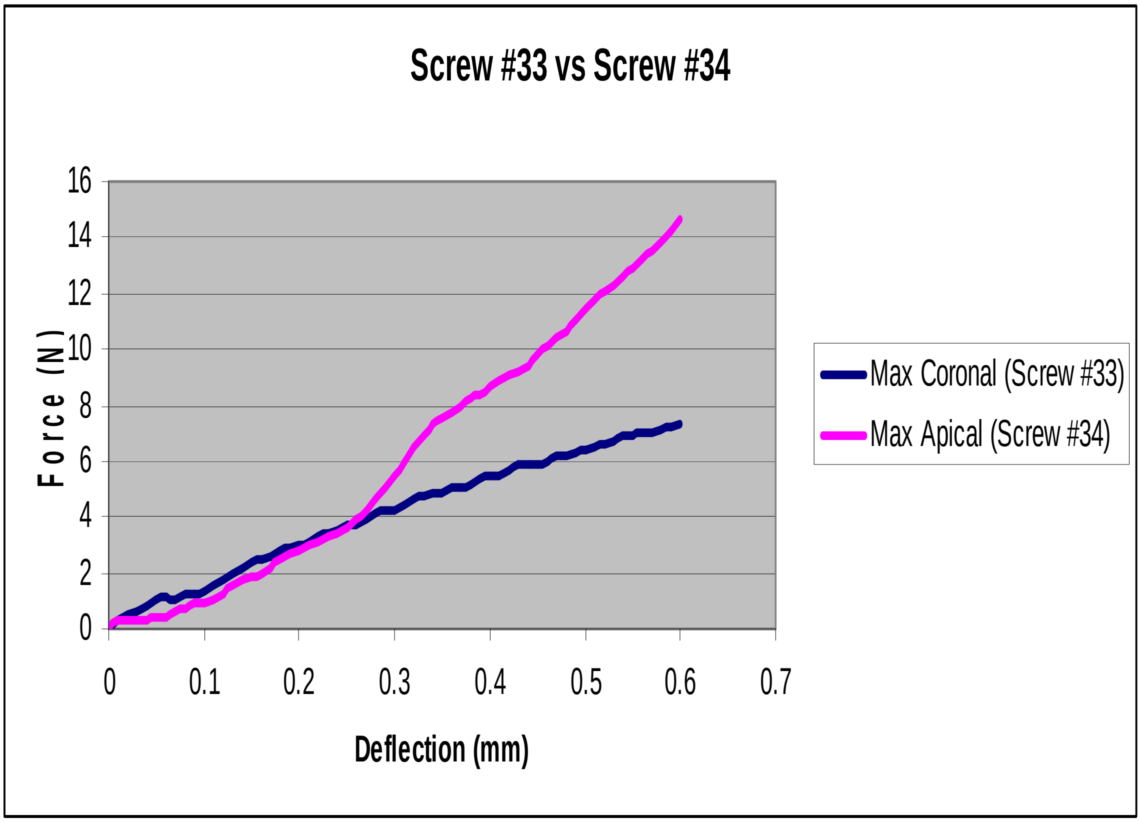
Graph C14: Force vs Deflection for screw #27 and screw #28 - maxilla



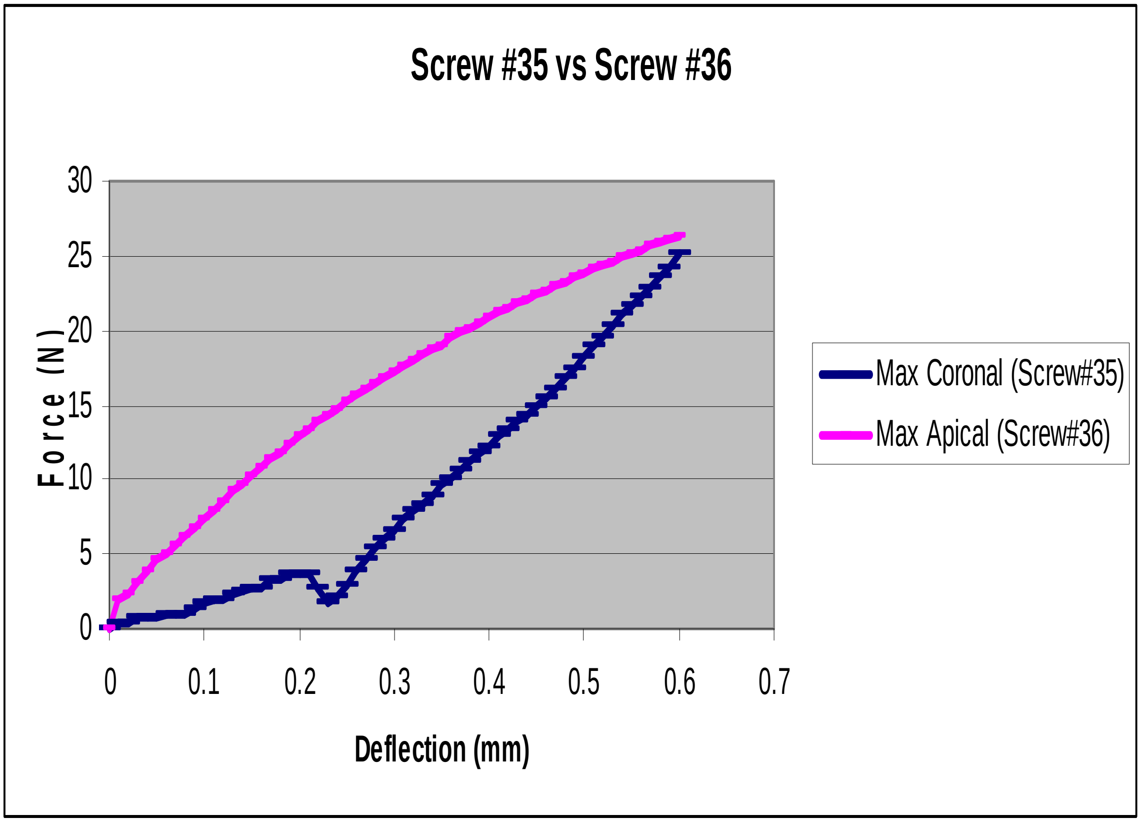
Graph C15: Force vs Deflection for screw #29 and screw #30 - mandible



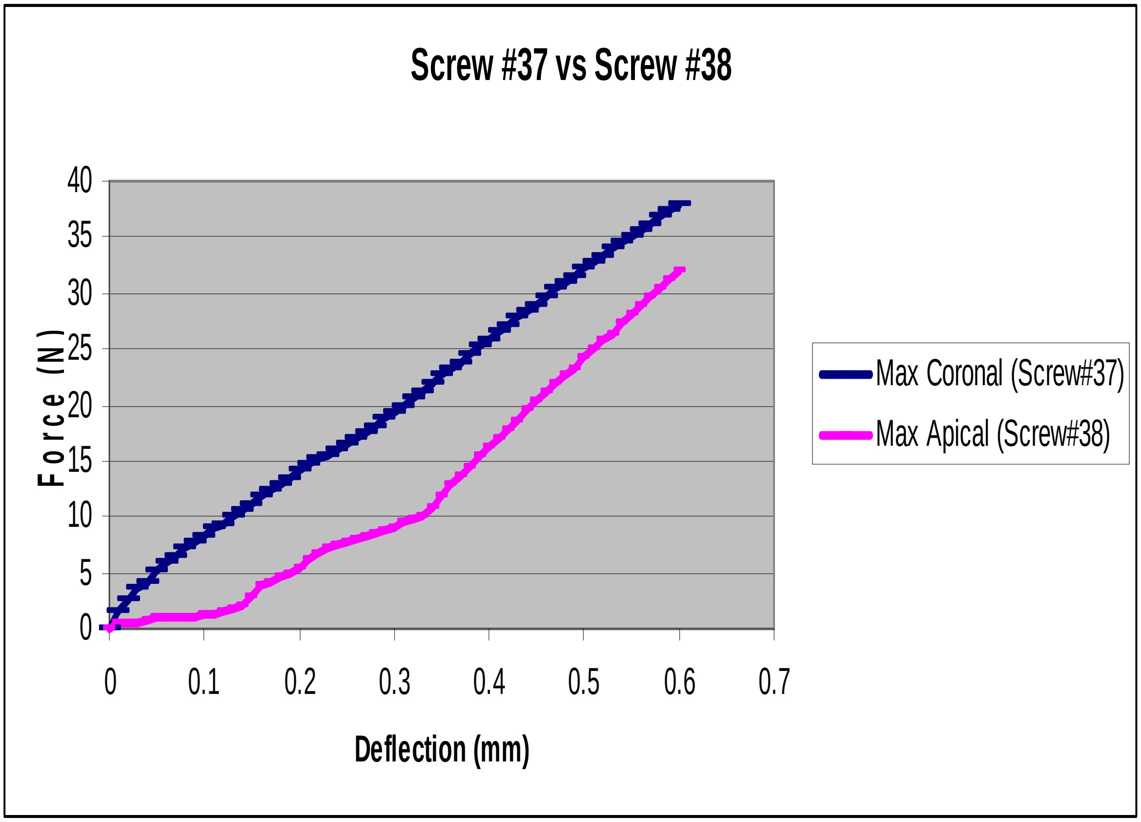
Graph C16: Force vs Deflection for screw #31 and screw #32 - mandible



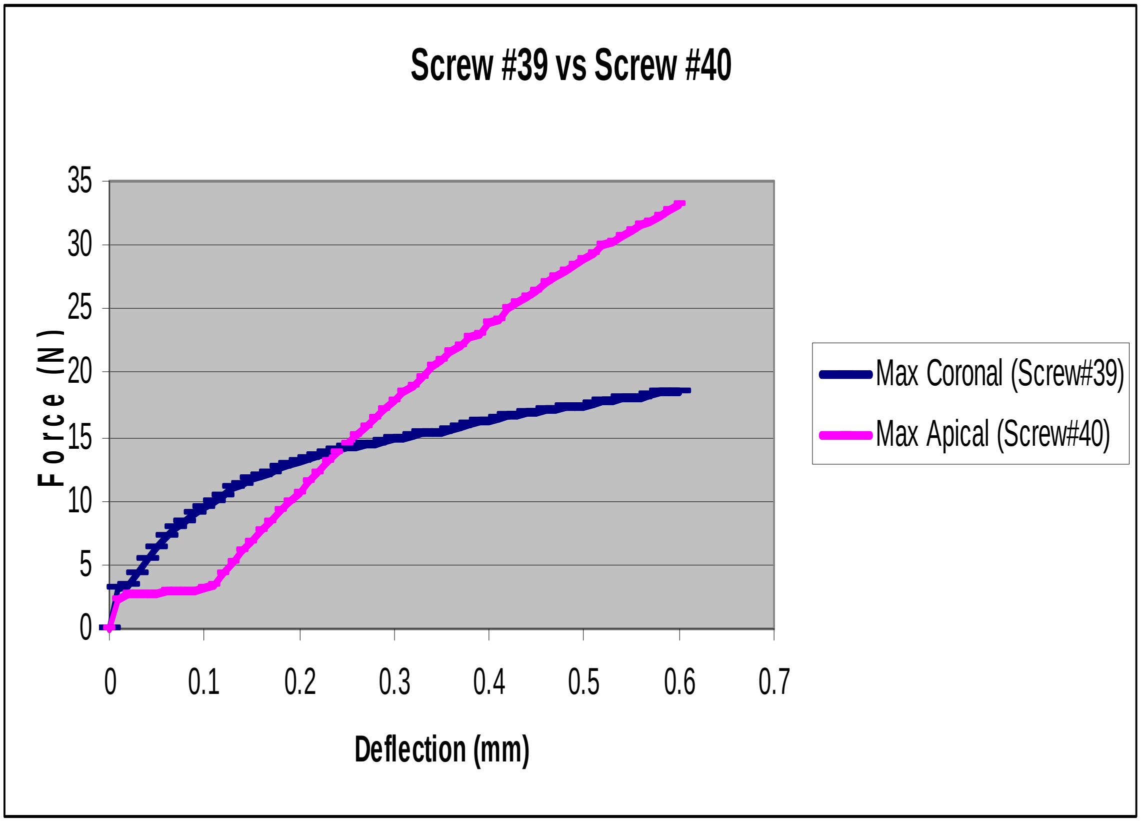
Graph C17: Force vs Deflection for screw #33 and screw #34 - maxilla



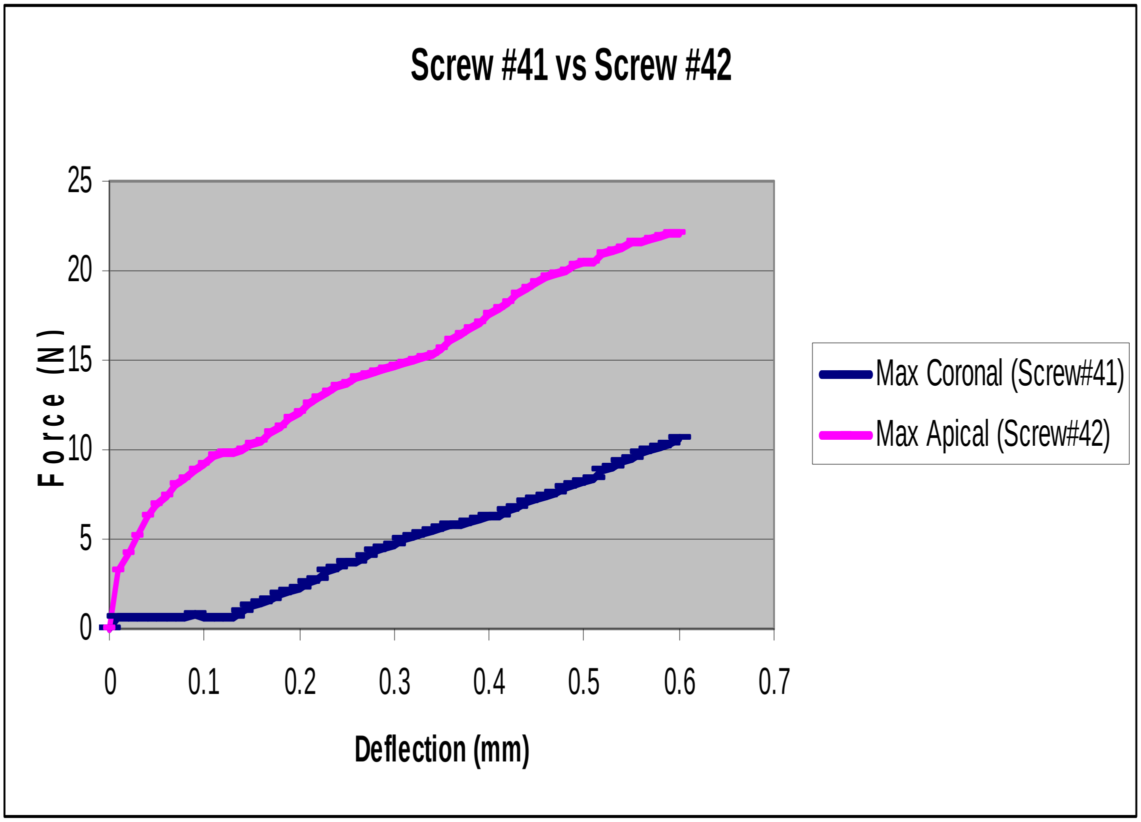
Graph C18: Force vs Deflection for screw #35 and screw #36 - maxilla



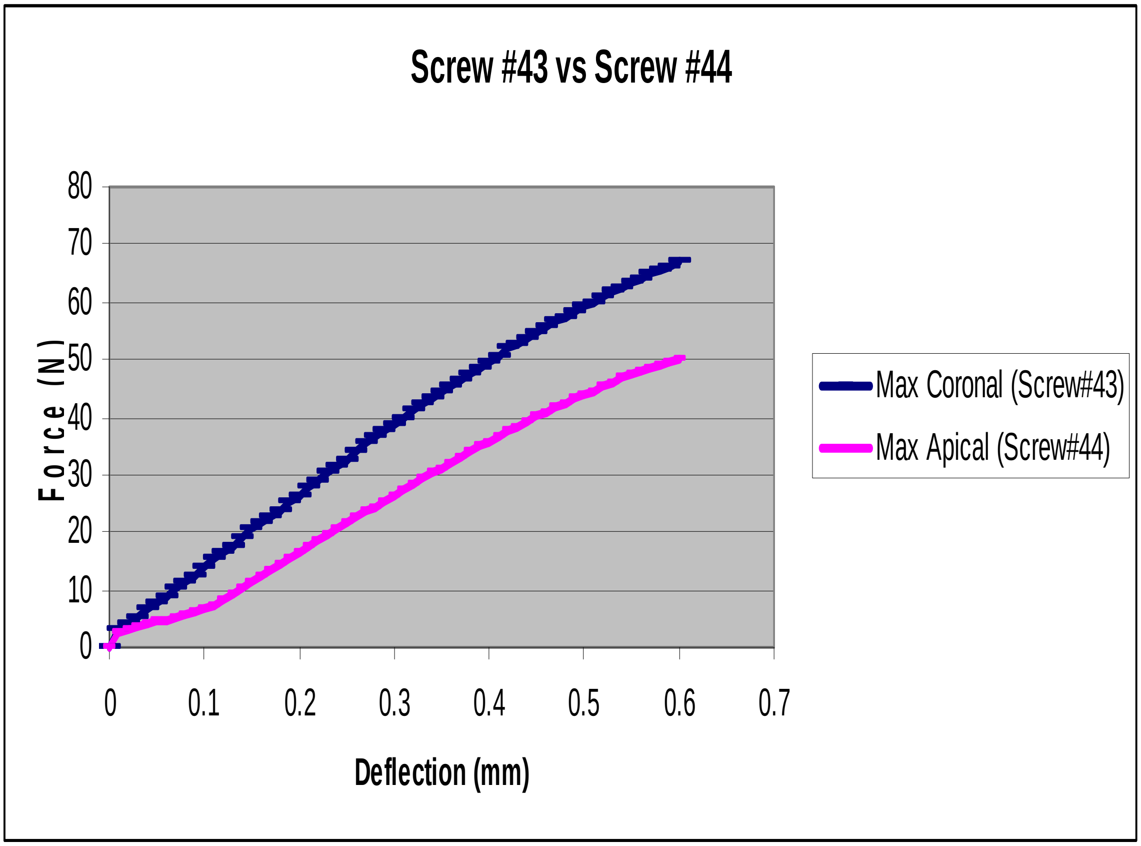
Graph C19: Force vs Deflection for screw #37 and screw #38 - maxilla



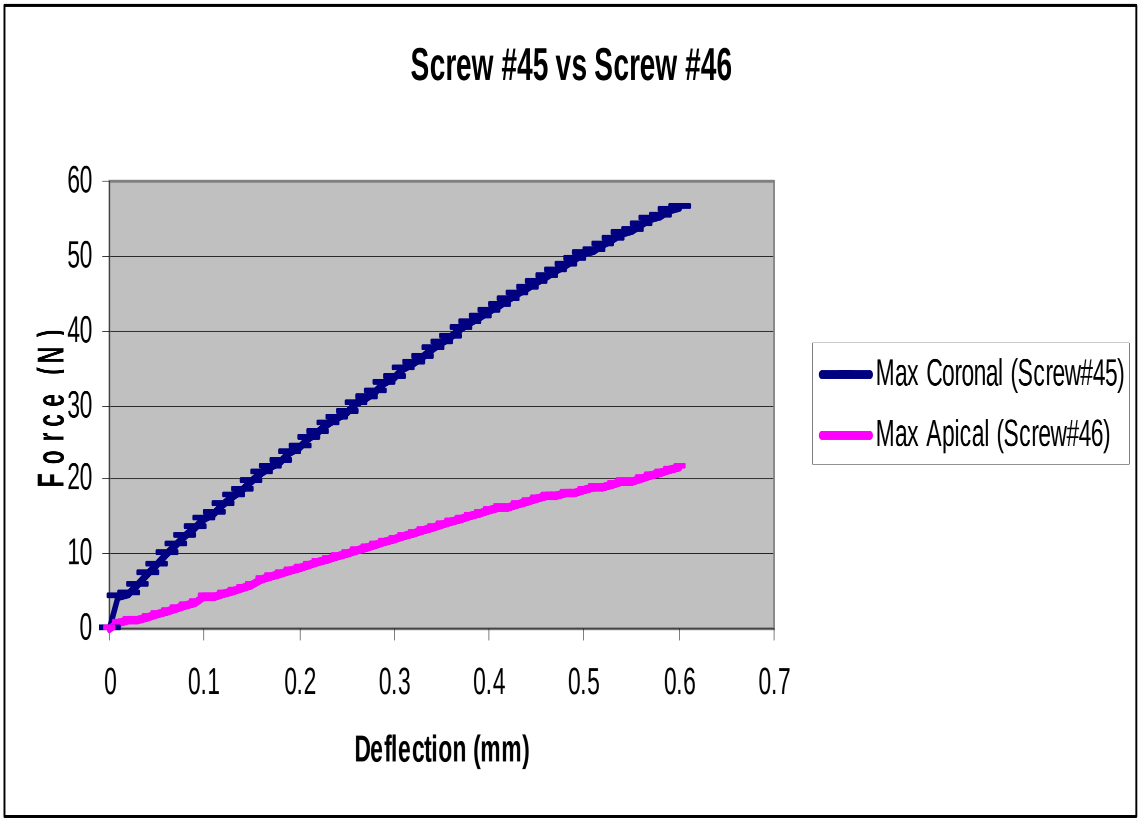
Graph C20: Force vs Deflection for screw #39 and screw #40 - maxilla



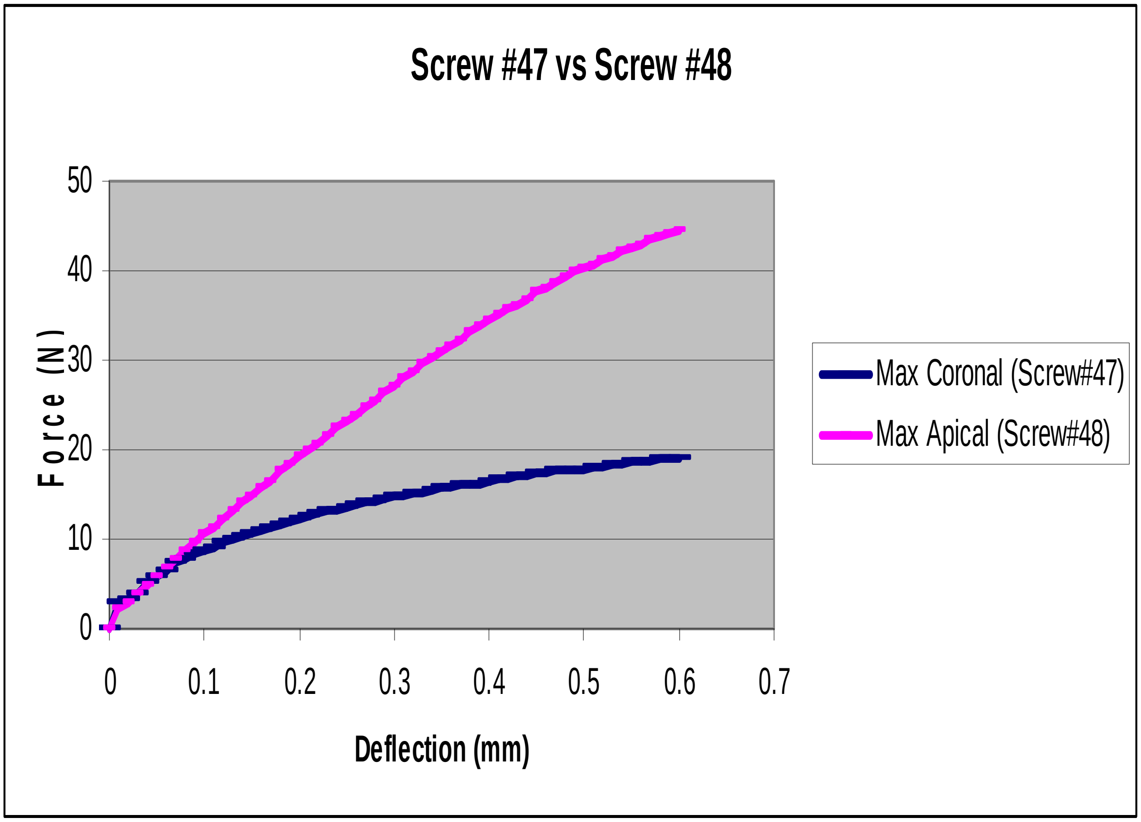
Graph C21: Force vs Deflection for screw #41 and screw #42 - maxilla



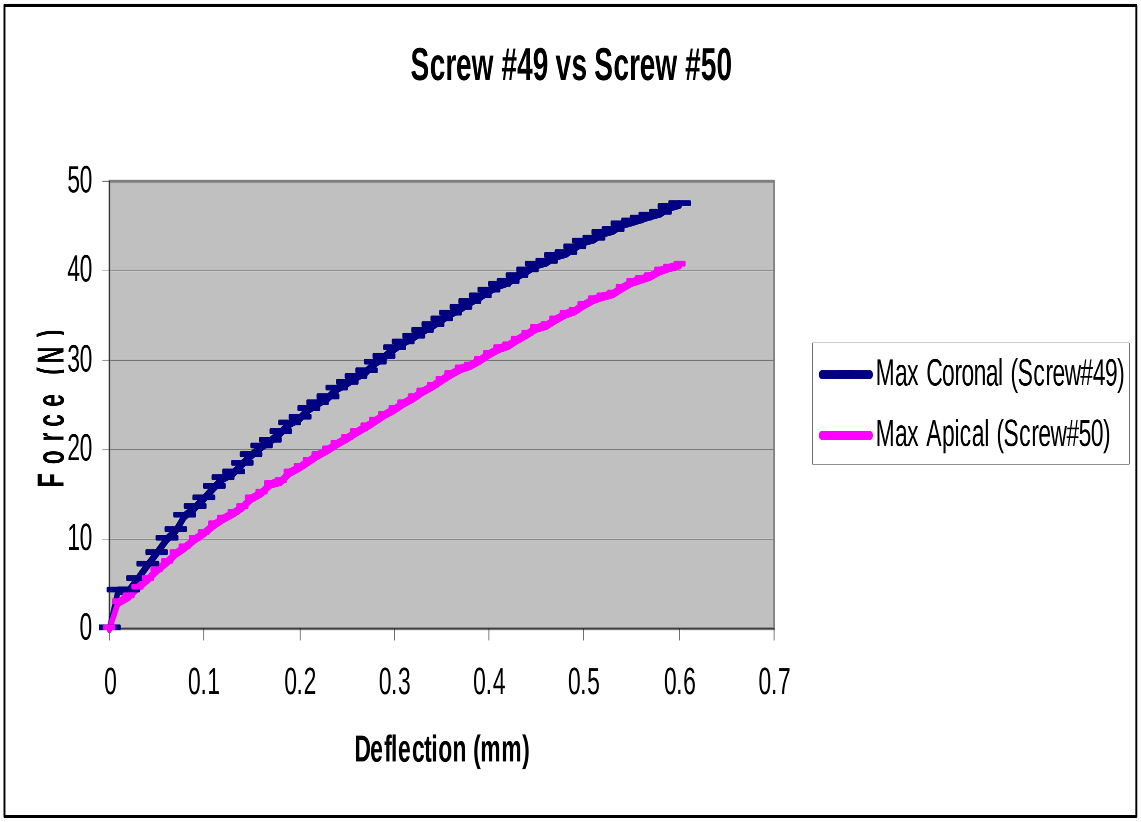
Graph C22: Force vs Deflection for screw #43 and screw #44 - maxilla



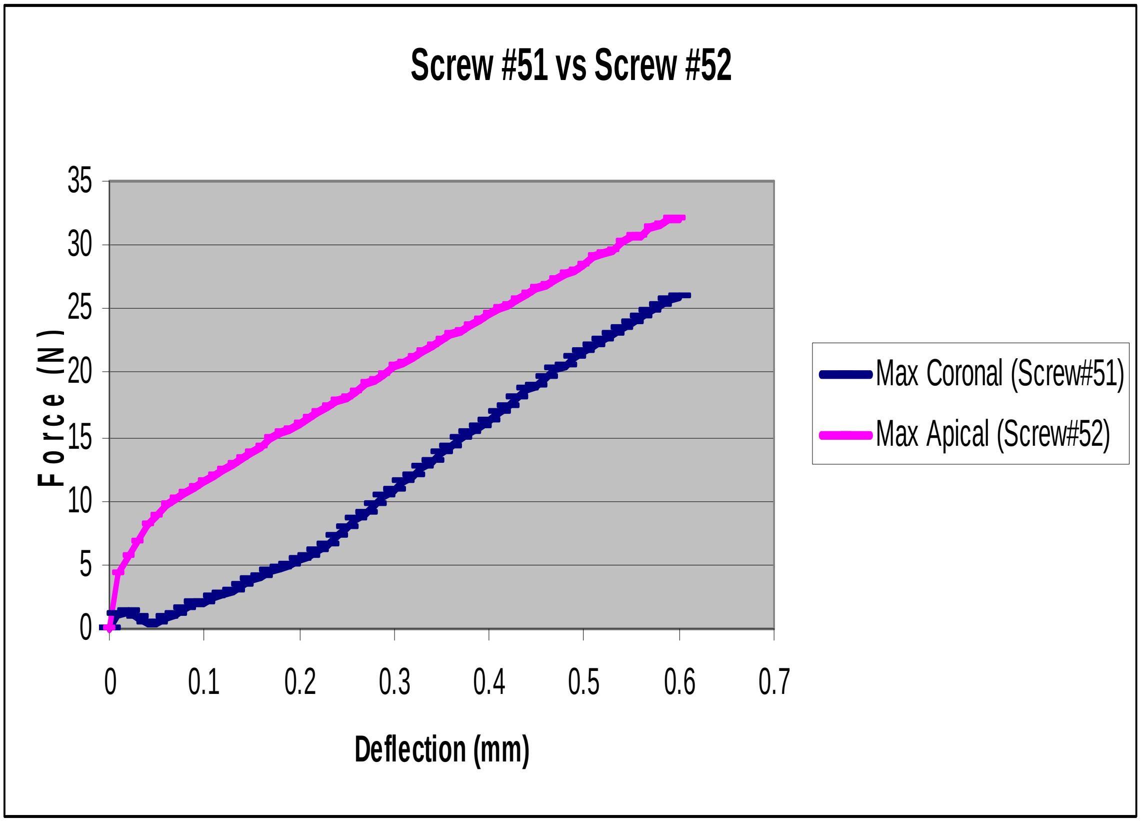
Graph C23: Force vs Deflection for screw #45 and screw #46 - maxilla



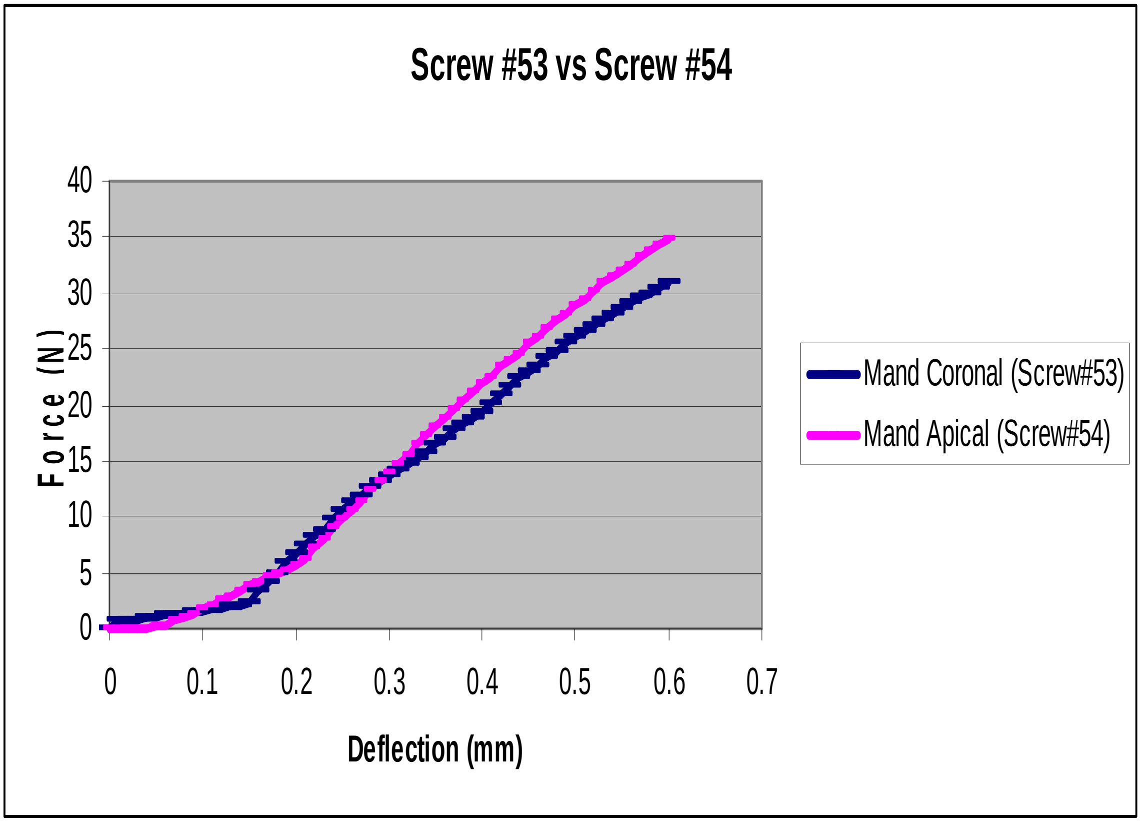
Graph C24: Force vs Deflection for screw #47 and screw #48 - maxilla



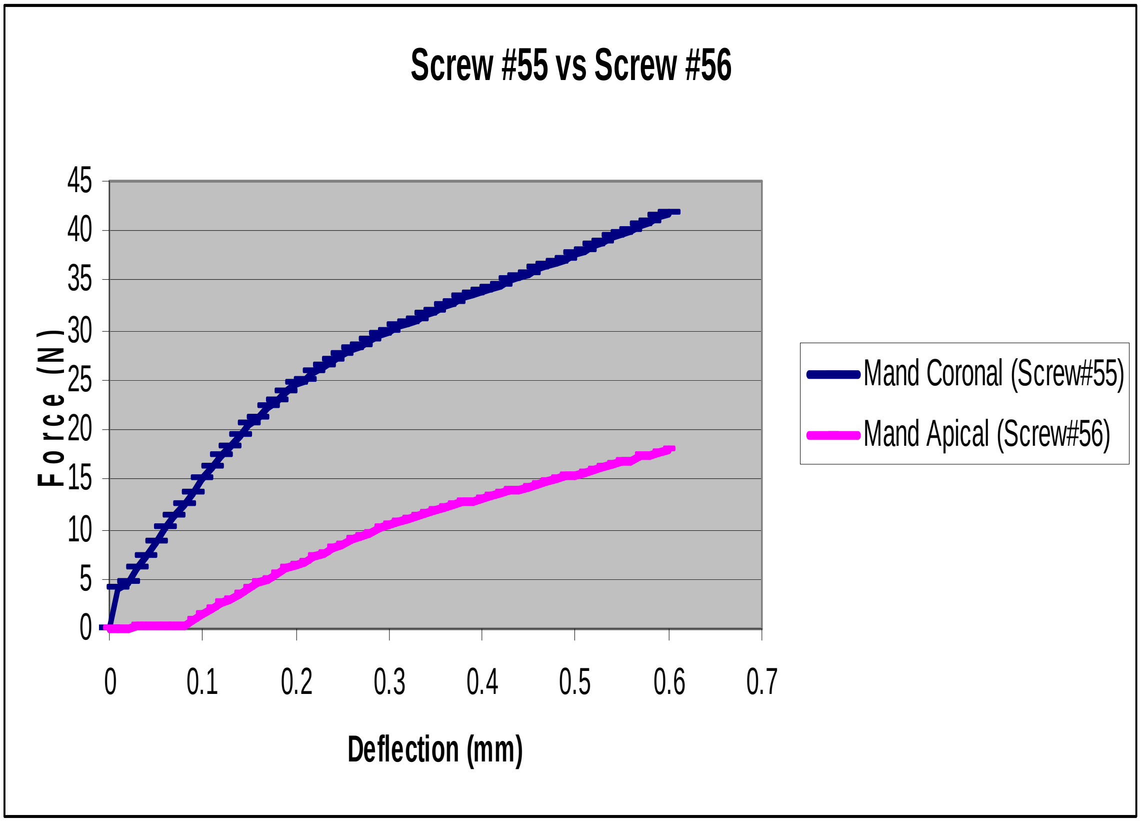
Graph C25: Force vs Deflection for screw #49 and screw #50 - maxilla



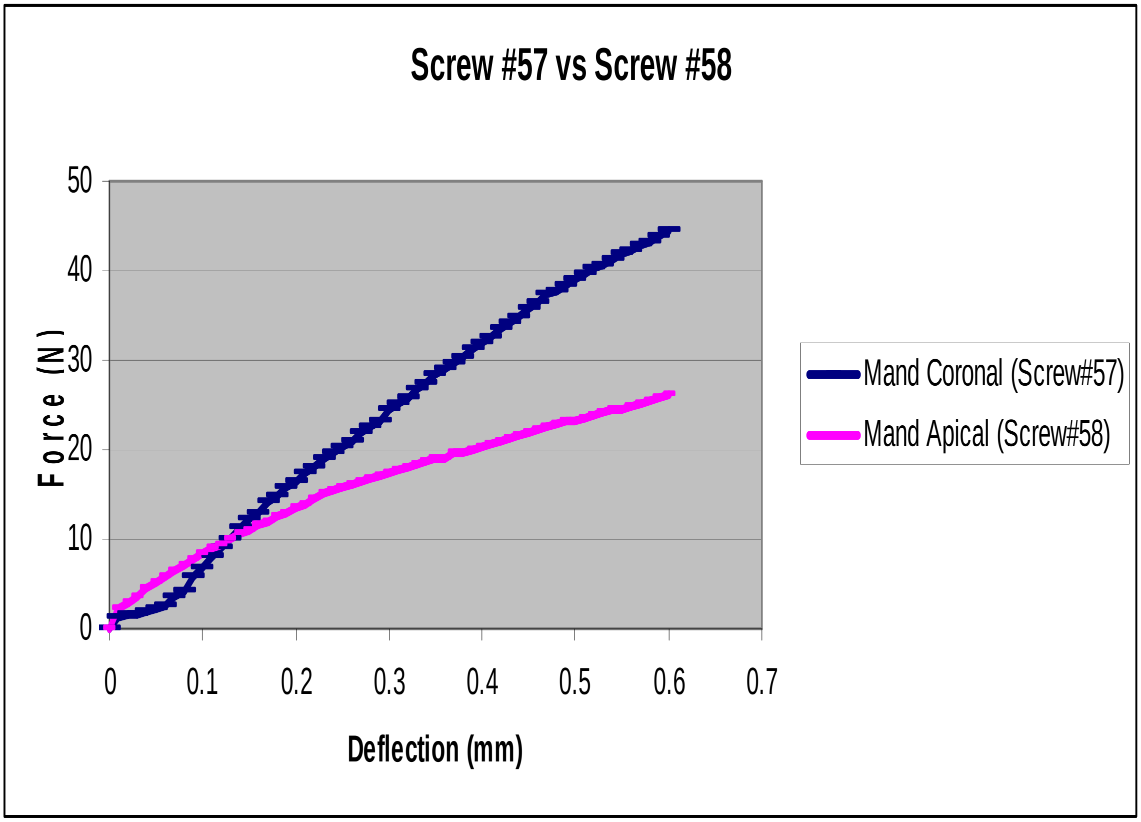
Graph C26: Force vs Deflection for screw #51 and screw #52 - maxilla



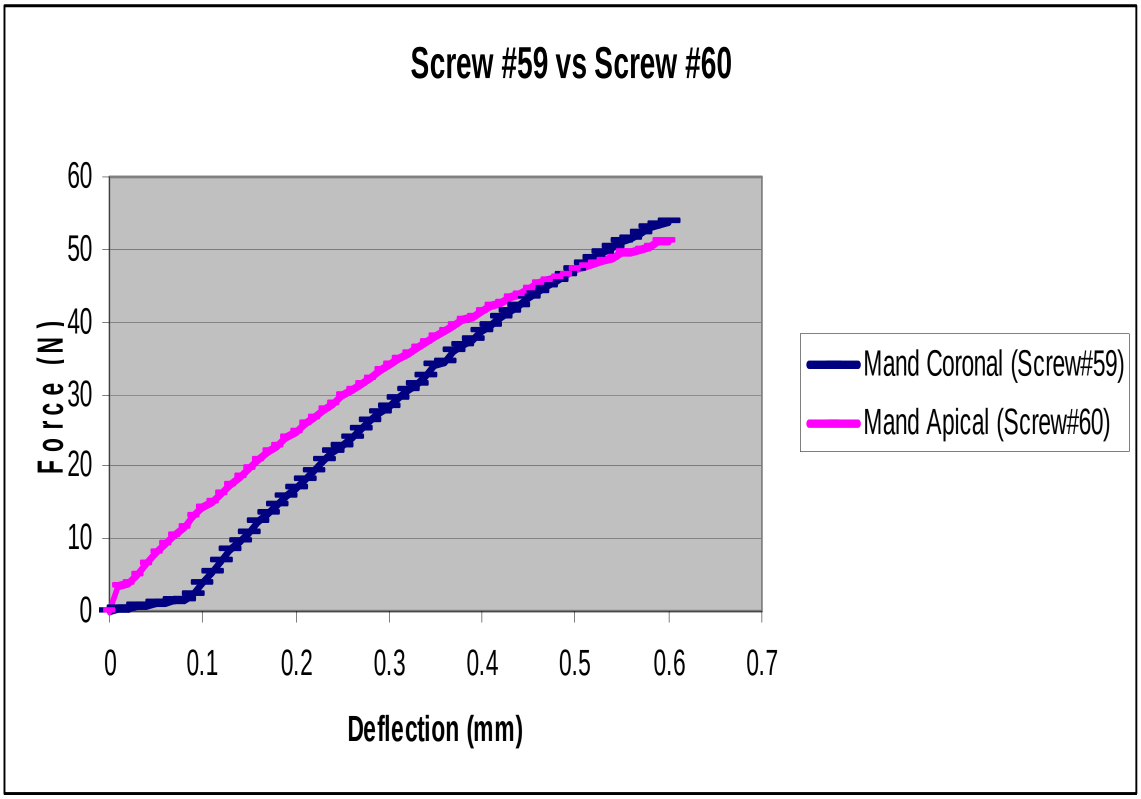
Graph C27: Force vs Deflection for screw #53 and screw #54 - mandible



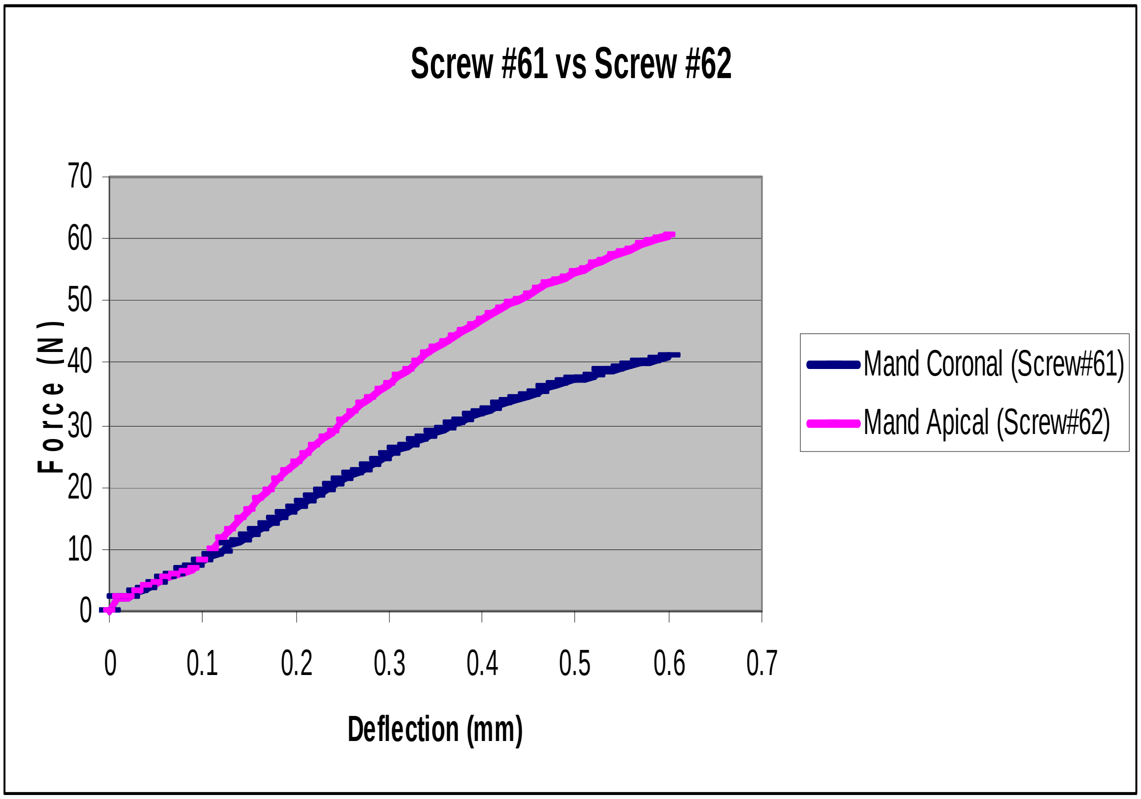
Graph C28: Force vs Deflection for screw #55 and screw #56 - mandible



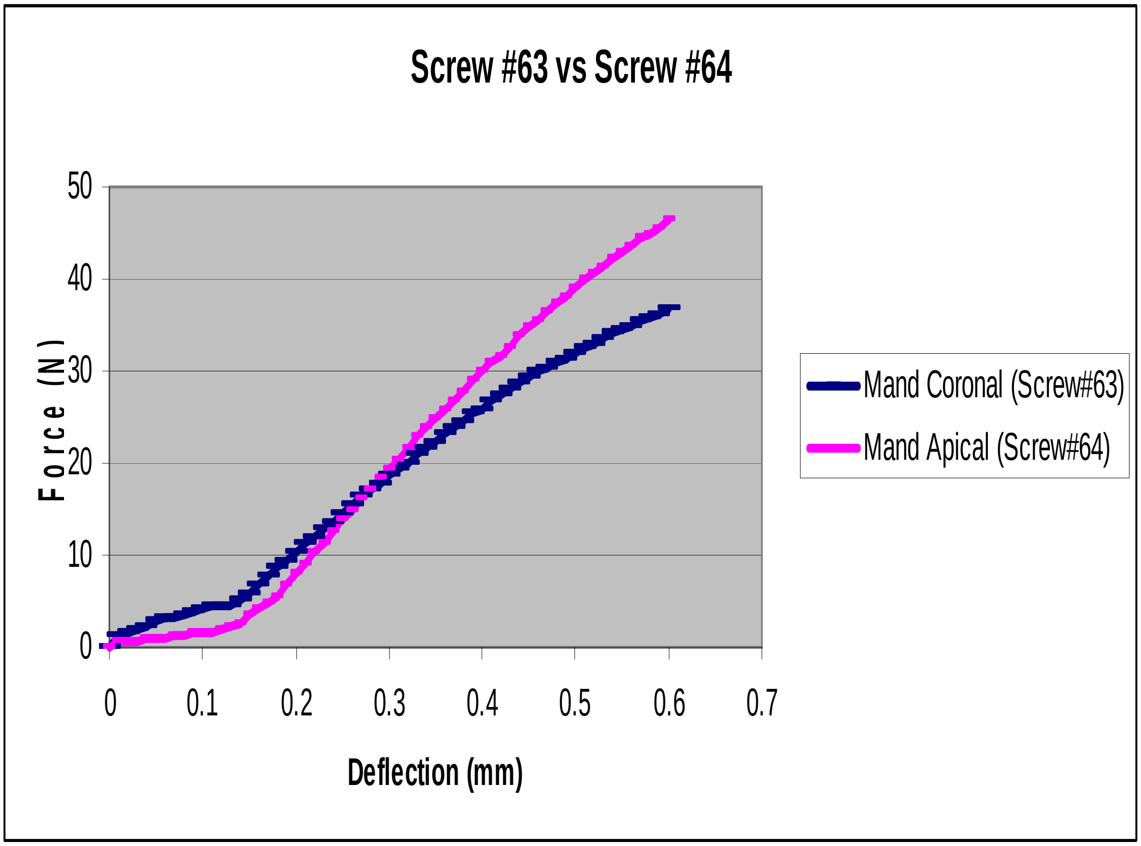
Graph C29: Force vs Deflection for screw #57 and screw #58 - mandible



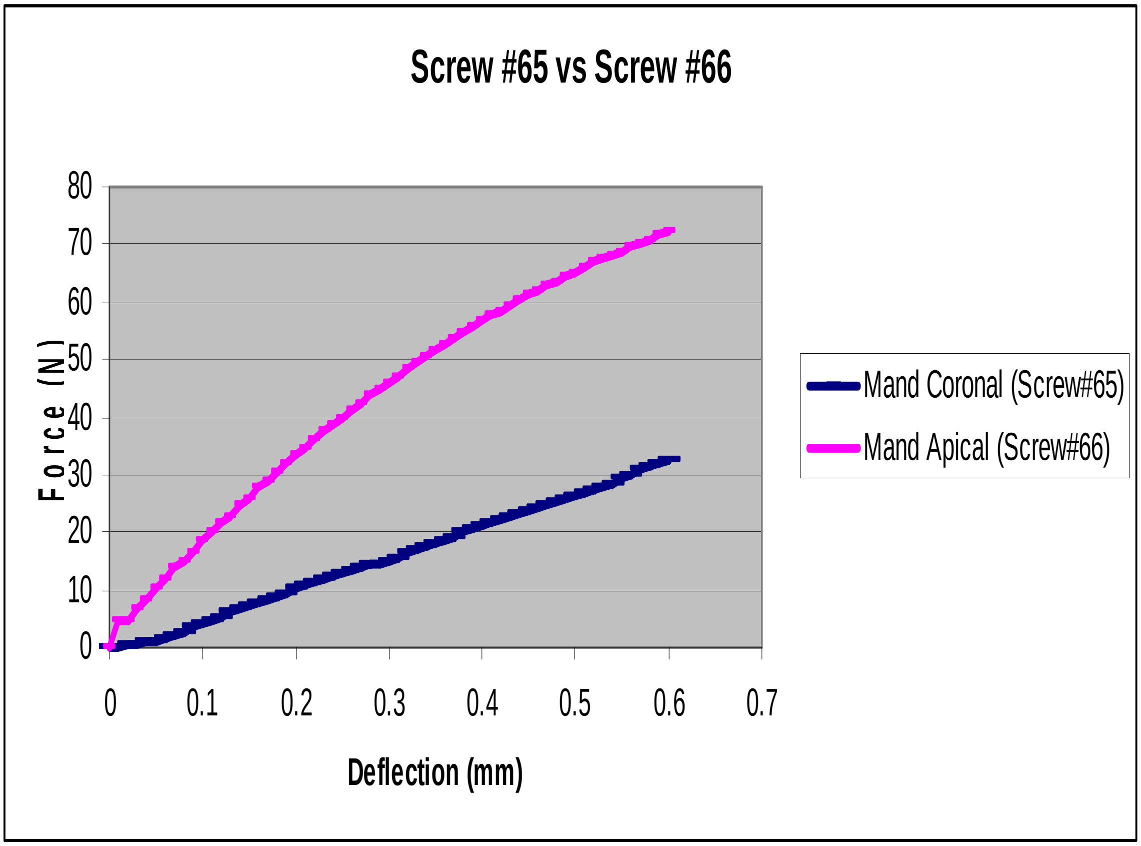
Graph C30: Force vs Deflection for screw #59 and screw #60 - mandible



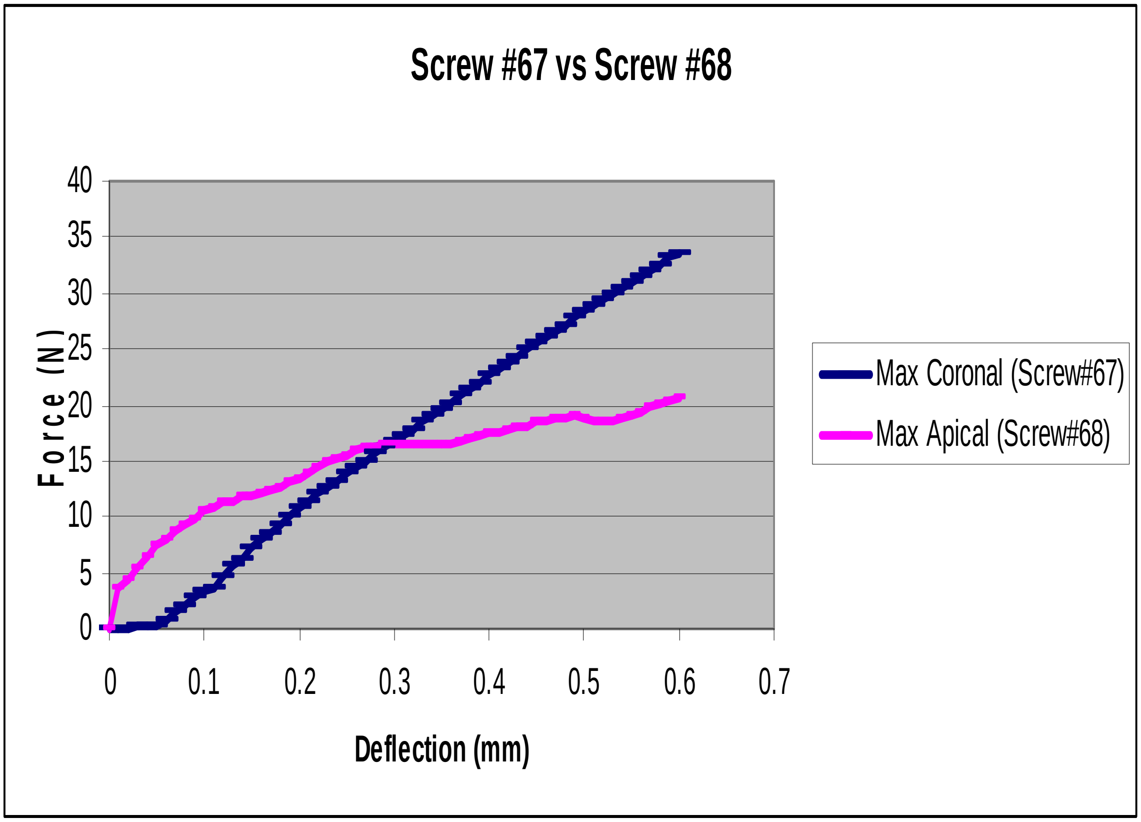
Graph C31: Force vs Deflection for screw #61 and screw #62 - mandible



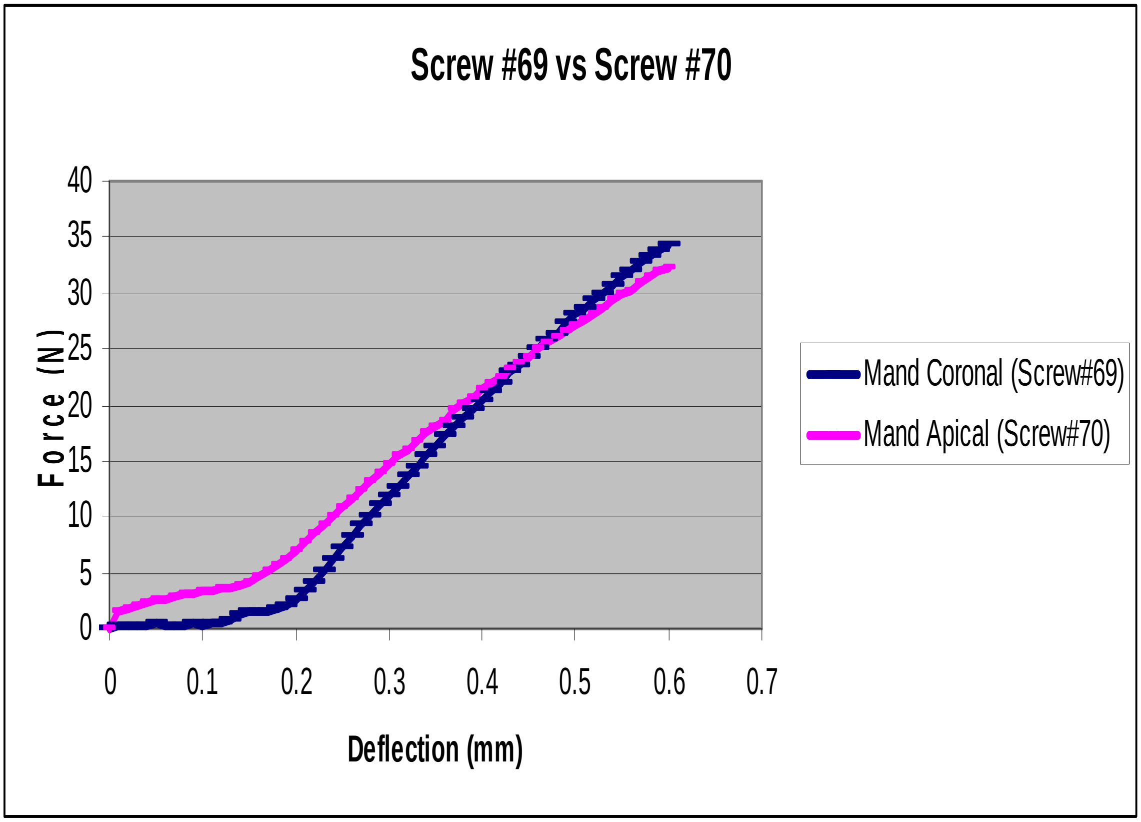
Graph C32: Force vs Deflection for screw #63 and screw #64 - mandible



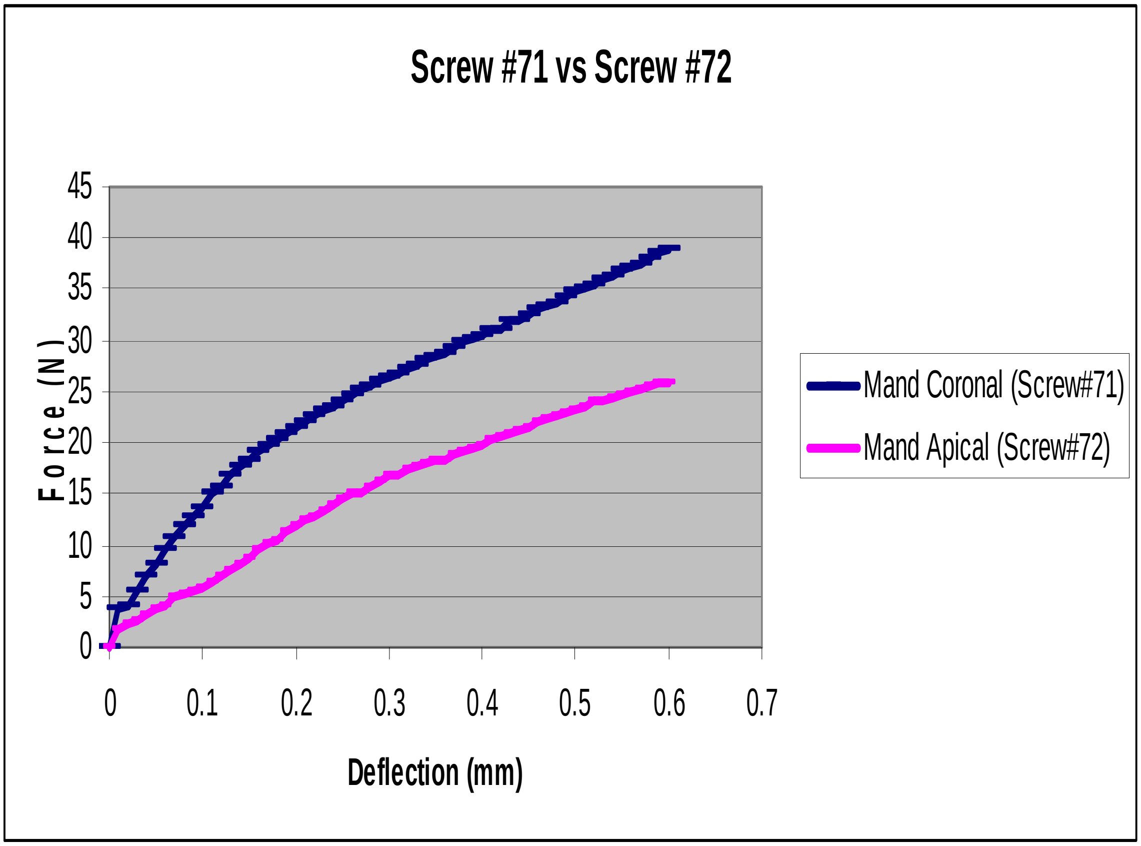
Graph C33: Force vs Deflection for screw #65 and screw #66 - mandible



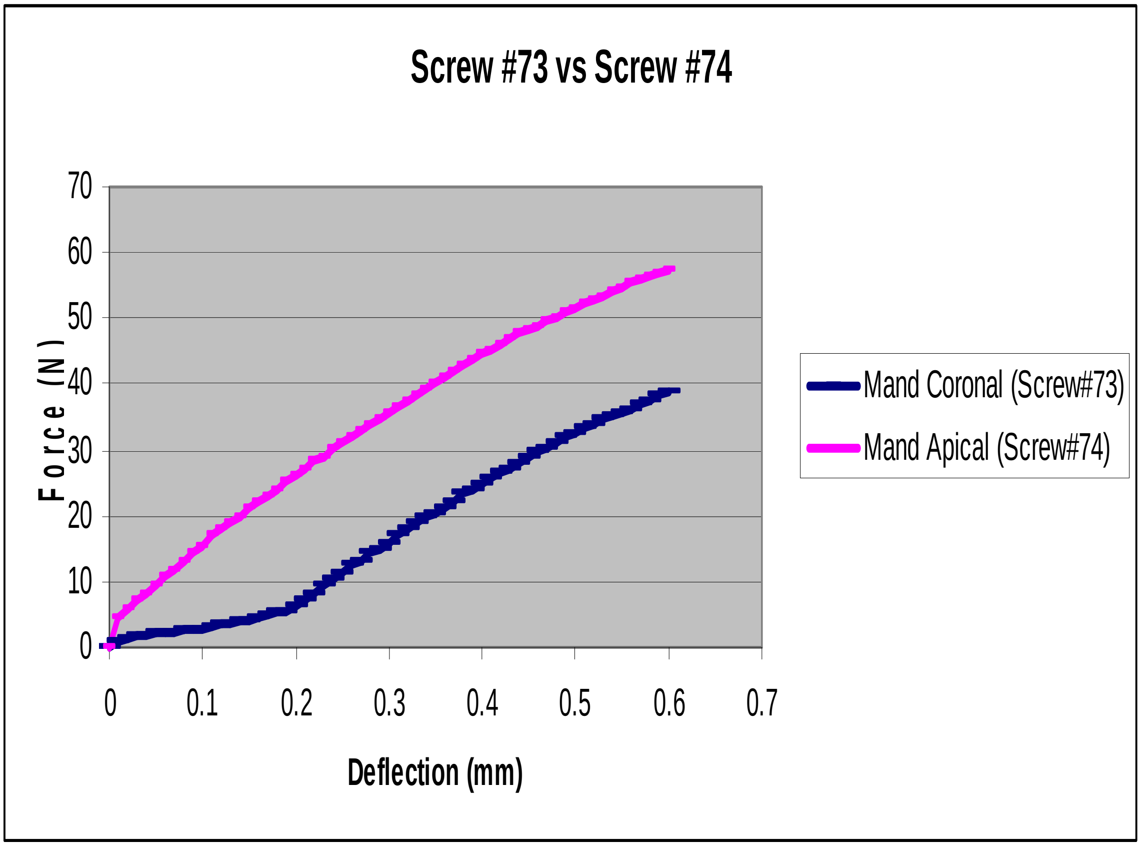
Graph C34: Force vs Deflection for screw #67 and screw #68 - maxilla



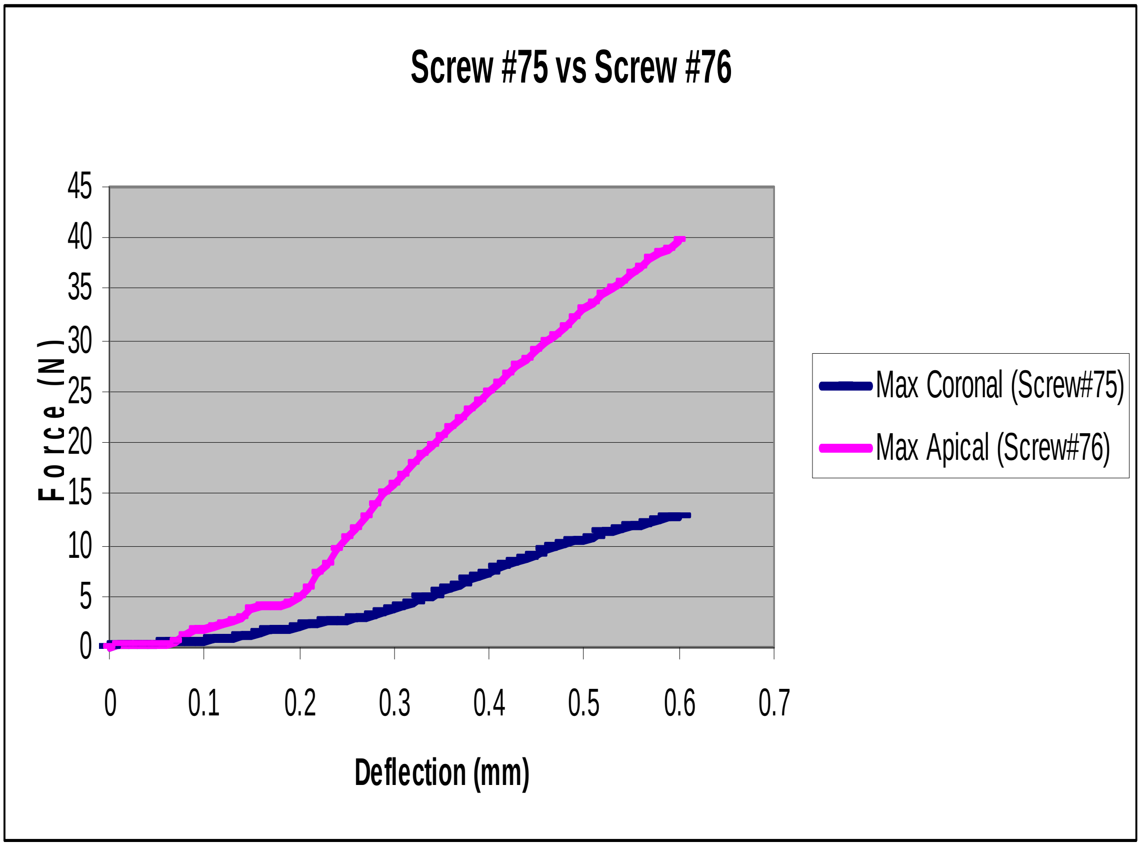
Graph C35: Force vs Deflection for screw #69 and screw #70 - mandible



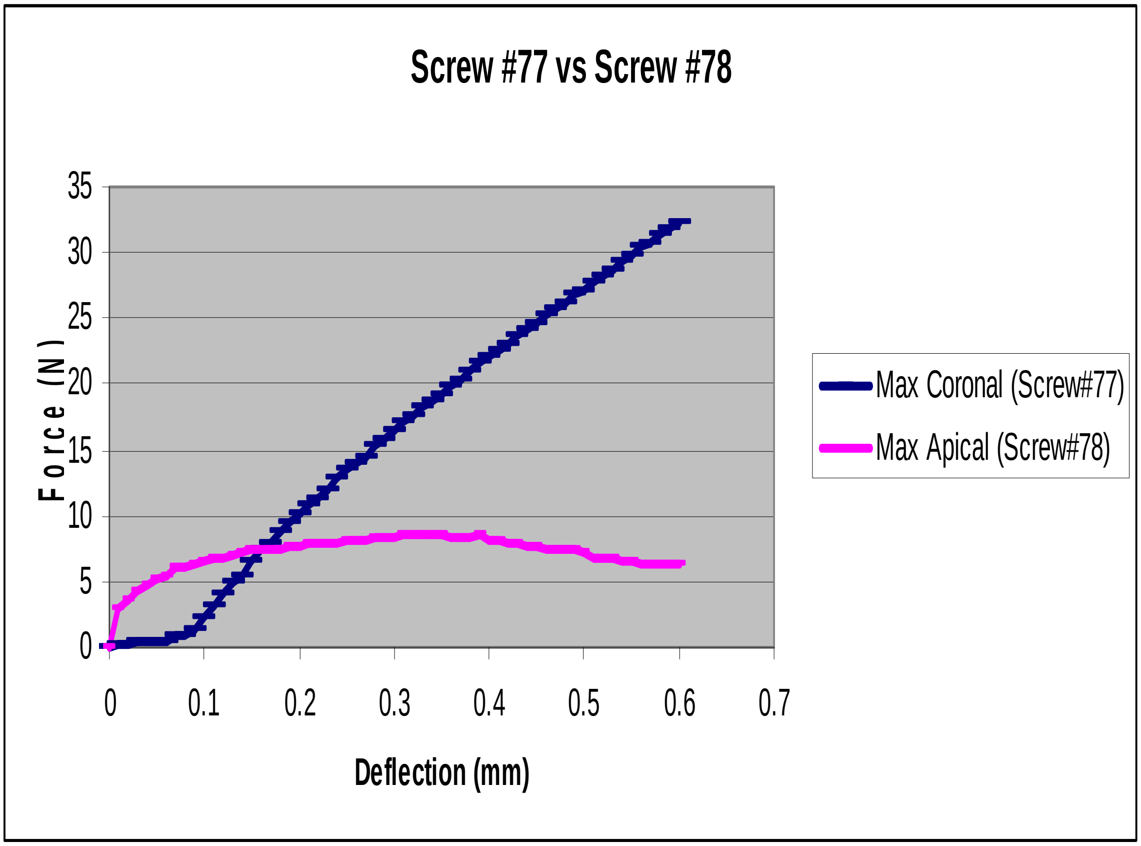
Graph C36: Force vs Deflection for screw #71 and screw #72 - mandible



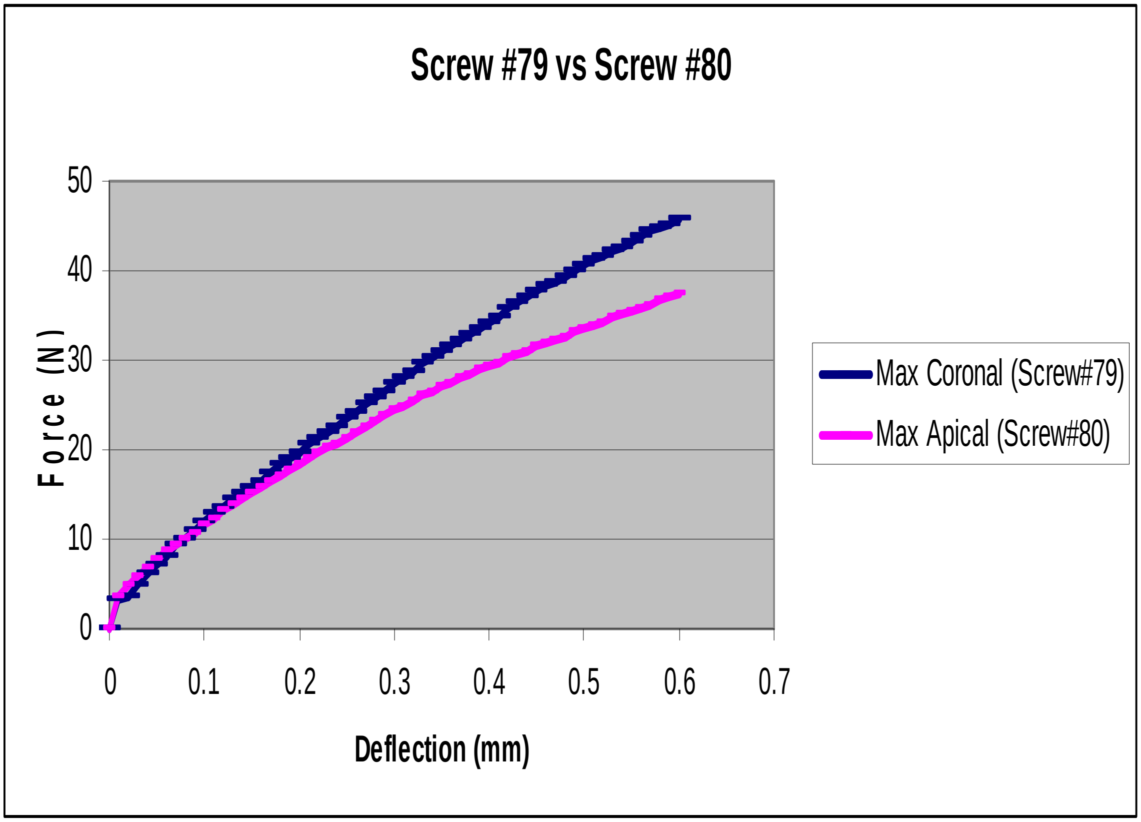
Graph C37: Force vs Deflection for screw #73 and screw #74 - mandible



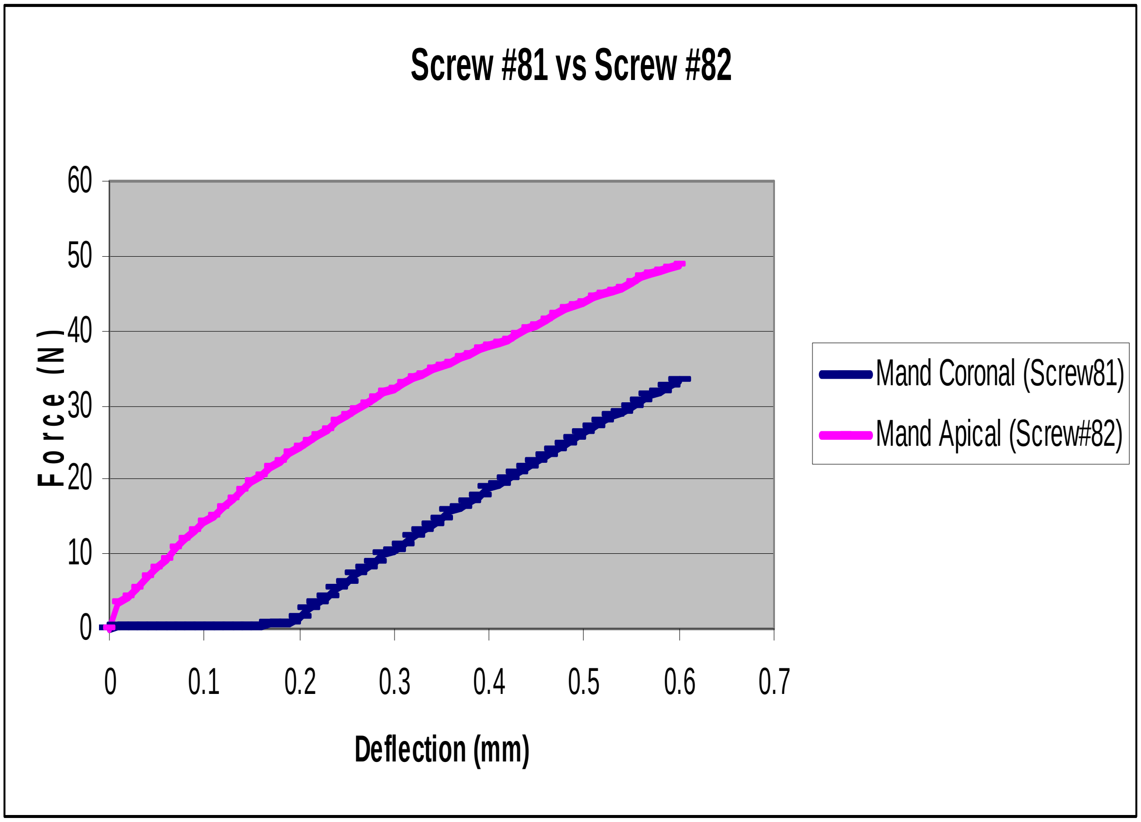
Graph C38: Force vs Deflection for screw #75 and screw #76 - maxilla



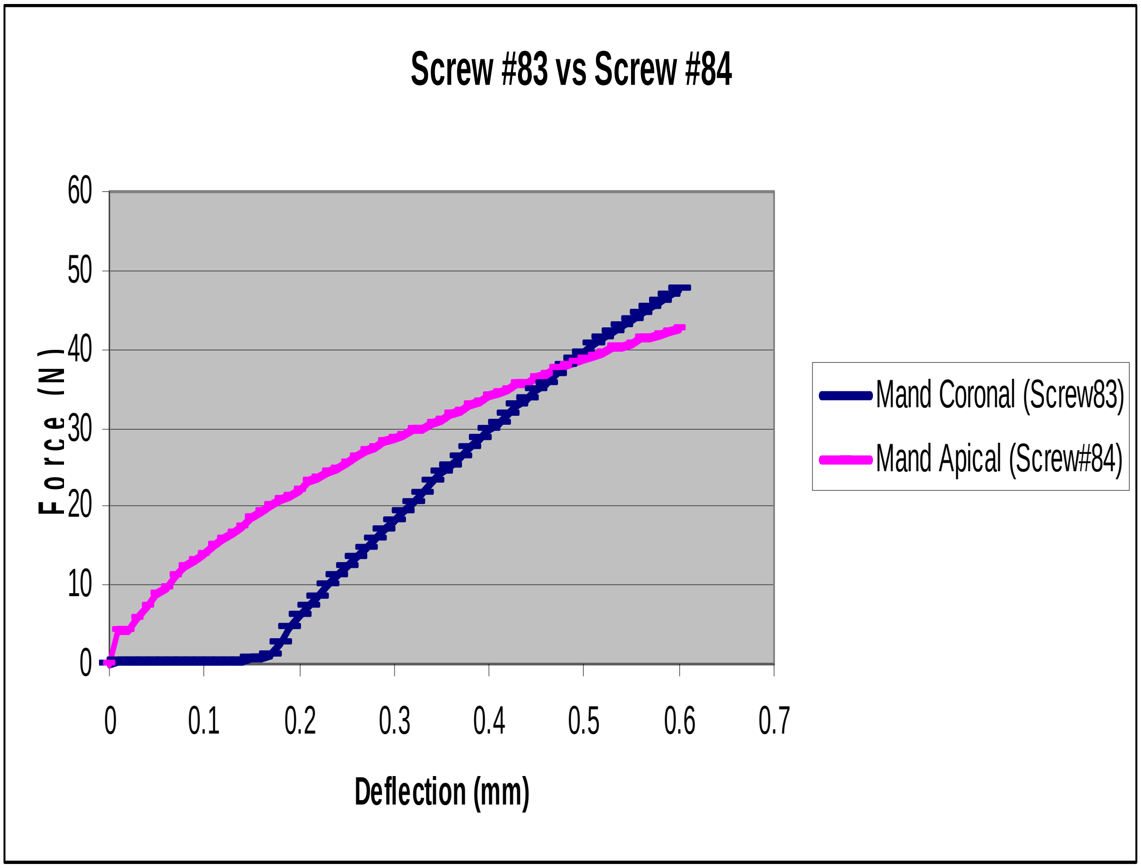
Graph C39: Force vs Deflection for screw #77 and screw #78 - maxilla



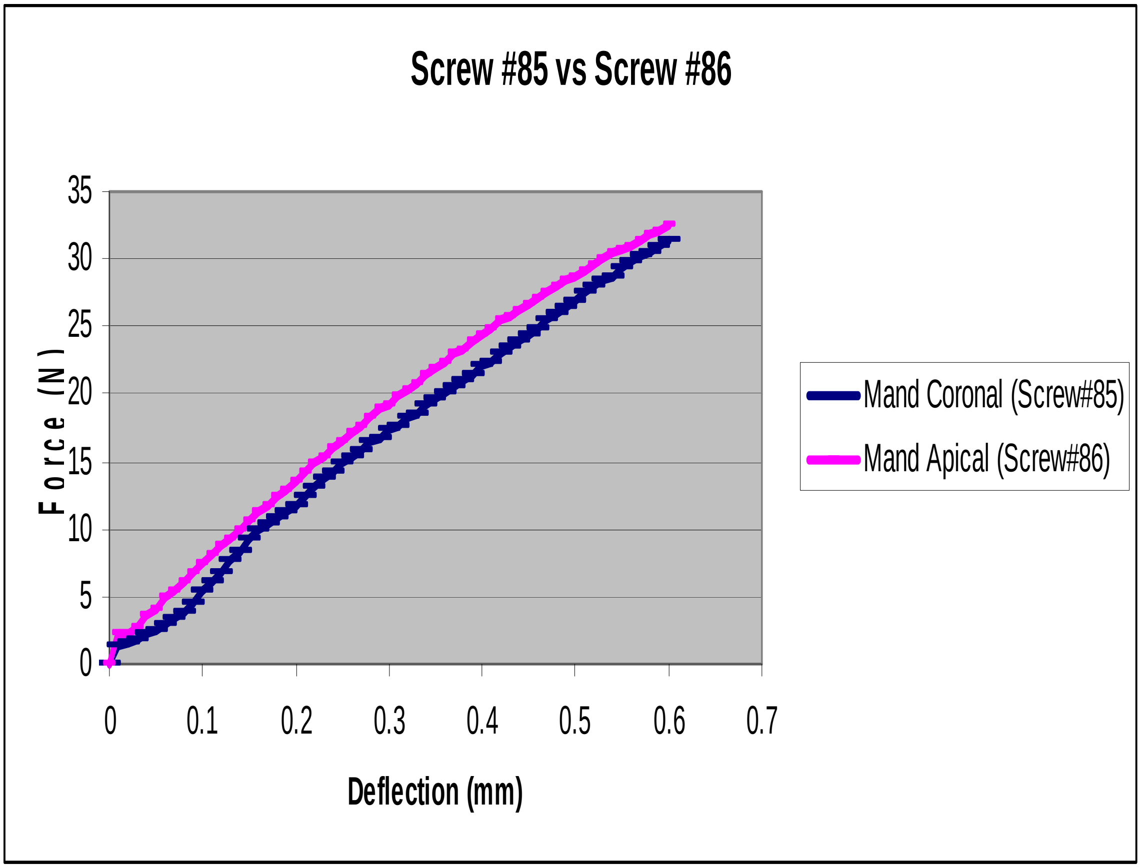
Graph C40: Force vs Deflection for screw #79 and screw #80 - maxilla



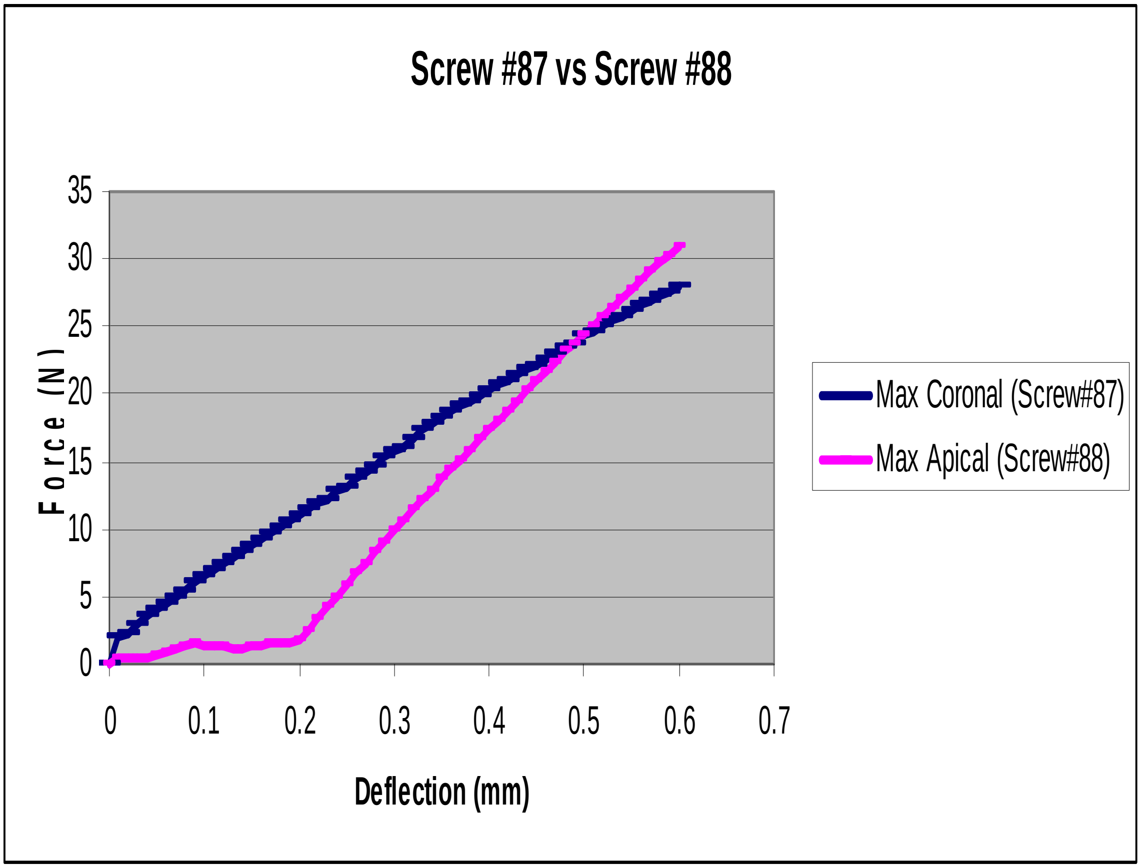
Graph C41: Force vs Deflection for screw #81 and screw #82 - mandible



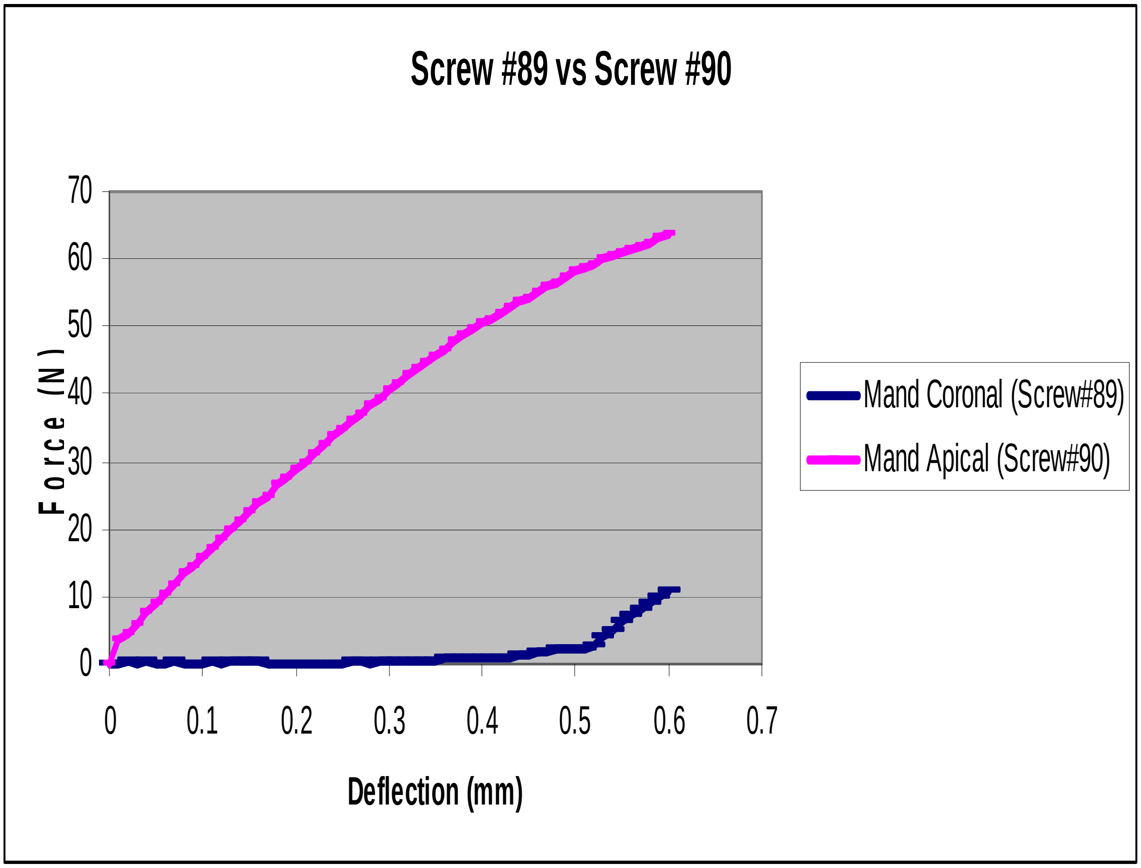
Graph C42: Force vs Deflection for screw #83 and screw #84 - mandible



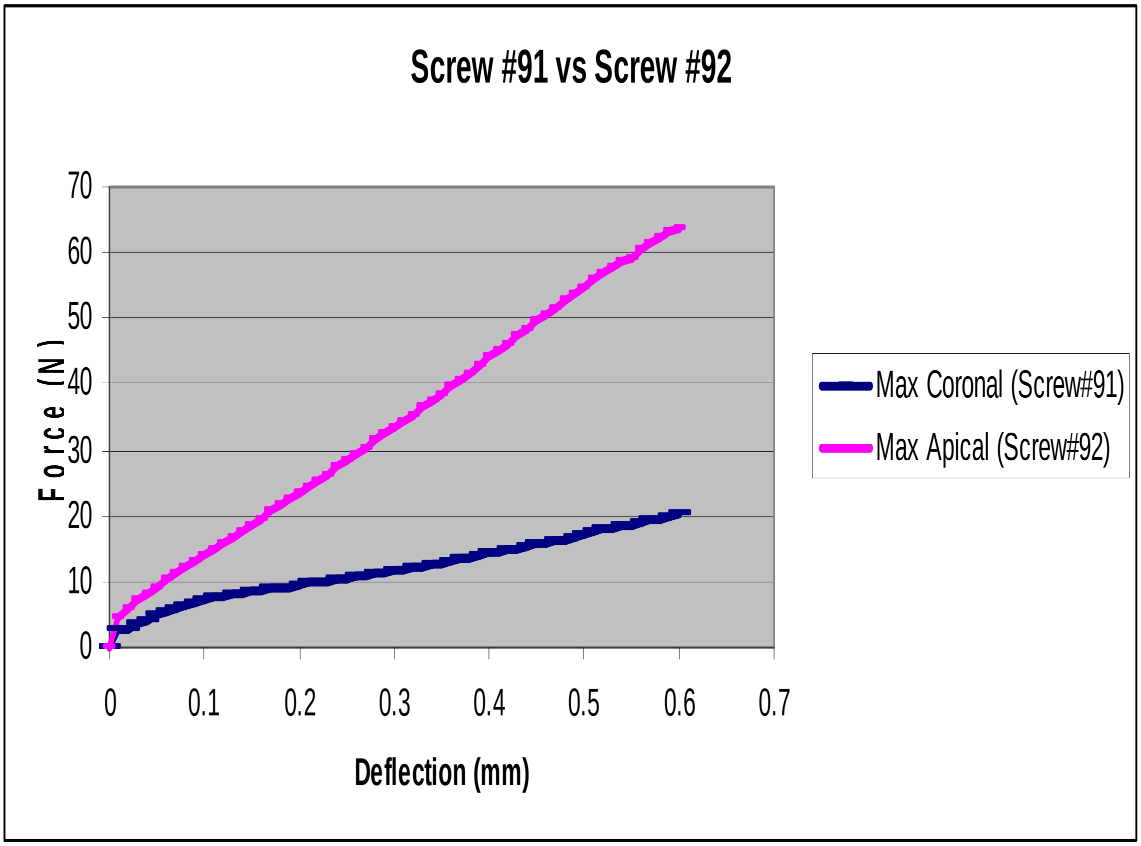
Graph C43: Force vs Deflection for screw #85 and screw #86 - mandible



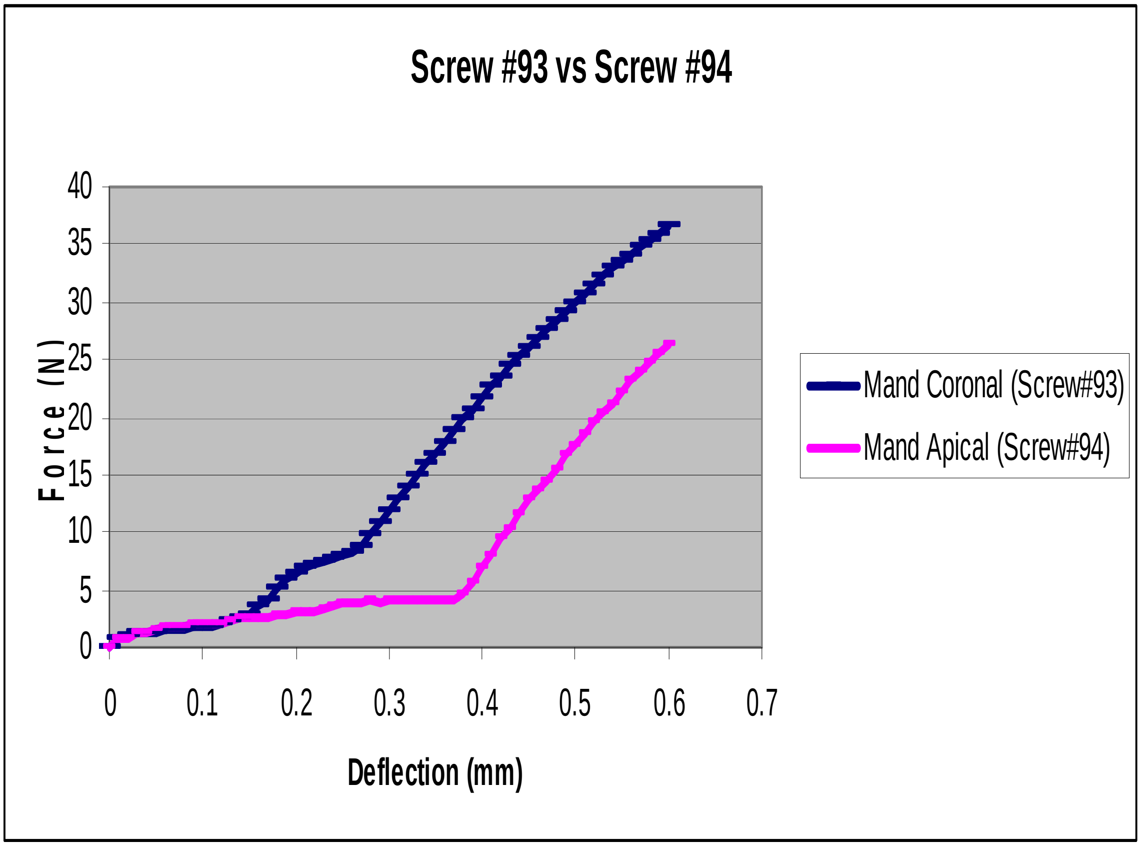
Graph C44: Force vs Deflection for screw #87 and screw #88 - maxilla



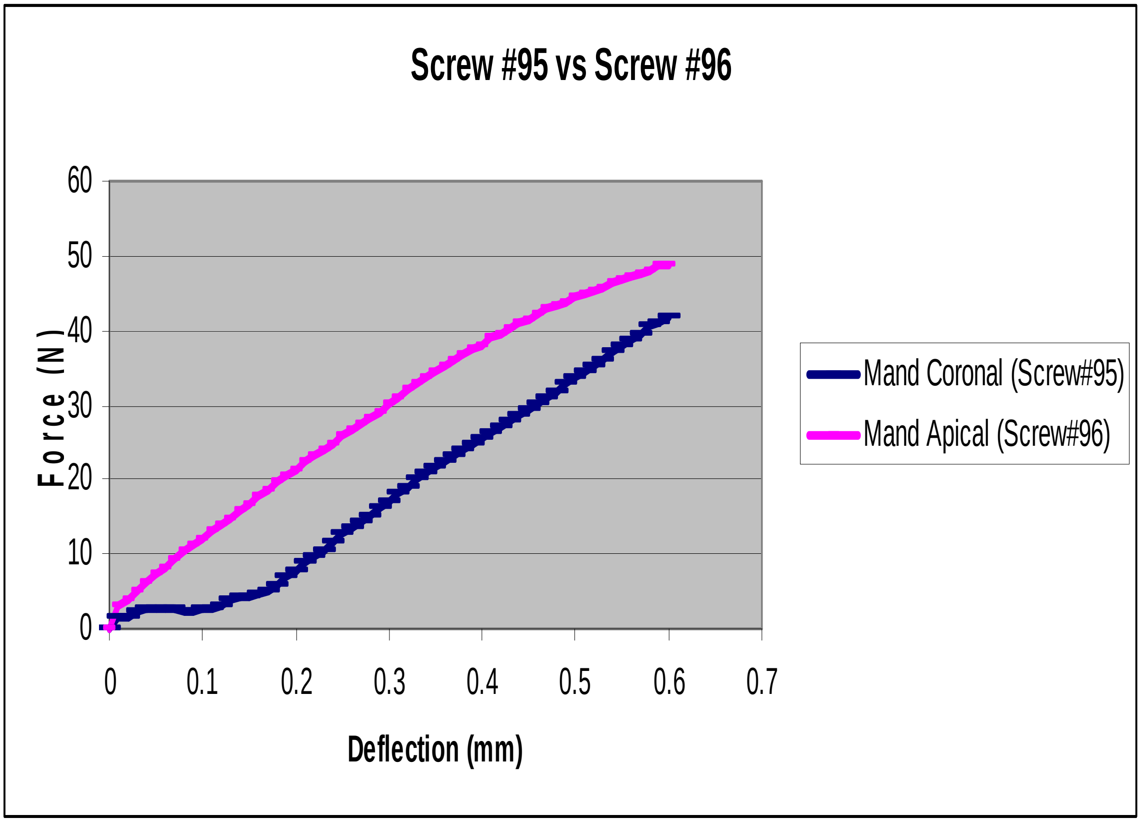
Graph C45: Force vs Deflection for screw #89 and screw #90 - mandible



Graph C46: Force vs Deflection for screw #91 and screw #92 - maxilla



Graph C47: Force vs Deflection for screw #93 and screw #94 - mandible



Graph C48: Force vs Deflection for screw #95 and screw #96 - mandible

REFERENCES

Adell R, Hansson BO, Branemark, P-I, Breine U. Intra-osseous anchorage of dental prostheses, II. Review of clinical approaches. Scand J Plast Reconstr Surg 1970;4:19-34.

Adell R, Lekholm U, Rockler B, Branemark P. A 15-yearstudy of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;6:387-416.

Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting direct bone anchorage in man. Acta Orthop Scand 1981;52:155-170.

Albrektsson T, Zarb G, Worthington D, Erikson R. The long-term efficacy of currently dental implants. A review and proposed criteria of success. Int J Oral Maxillofacial Implants 1986;1:11-25.

Angle EH. Treatment of malocclusion of the teeth, ed 7, Philadelphia, 1907, SS White Mfg Co.

Atkinson SR. Balance – the magic word. Am J Orthod 1964;50:189-202.

Block MS, Hoffman DR. A new device for absolute anchorage for orthodontics. Am J Orthod Dentofacial Orthop 1995;107:251-258.

Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallen O, Öhman A. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg 1977;11:Suppl 16.

Brettin B, Grosland N, Qian F, Southard K, Stuntz T, Morgan T, Marshall S, Southard T. Bi-cortical Versus Mono-Cortical Orthodontic Skeletal Anchorage. Am J Orthod Dentofacial Orthop.2008;134:625-35.

Brinley C, Behrents R, Kim K, Condoor S, Kyung, Buschang, P. Pitch and Longitudinal Fluting Effects on the Primary Stability of Miniscrew Implants. Angle Orthod 2009;79:1156-1161.

Burstone C. Rationale of the segmented arch. AJO 1962;45:805-822.

Burstone C. The biomechanic rationale of orthodontic therapy. In: Melsen, B, ed. *Current controversies in orthodontics*, 1st edition, p. 131-146. Chicago: Quintessence.

Burstone C. Modern Edgewise Mechanics and the Segmented Arch Technique. Glendora: Ormco, 1995.

Buschang P, Carrillo R, Ozenbaug B, Rossouw P. 2008 Survey of AAO Members on Miniscrew Usage. J Clin Orthod 2008;42:513-518.

Butcher A, Wiechmann D, Koerdt S, Wiesmann HP, Piffko J, Meyer U. Load-related implant reaction of mini-implants used for orthodontic anchorage. Clin. Oral Impl. Res. 16, 2005; 473-479.

Carano A. Testa M. The distal jet for upper molar distalization. J Clin Orthod 1996; 30:374-380.

Cha J, Kil J, Yoon T, Hwang C. Miniscrew stability evaluated with computerized tomography scanning. Am J Orthod Dentofacial Orthop 2010;137:73-9.

Cheng HC, Yen E, Chen LS, Lee ST. The analysis of failure cases using Orthoanchor K1 mini-implant system as orthodontic anchorage. J Dent Res. 2003;82(Spec Iss B):B-214, 1624.

Cheng SJ, Tseng IY, Lee JJ, Kok SH. A prospective study of the risk factors associated with failure of mini-implants used for orthodontic anchorage. Int J Oral Maxillofac Implants. 2004 Jan-Feb;19(1):100-6.

Cole, WA. Accuracy of patient reporting as an indication of headgear compliance. Am J Orthod Dentofacial Orthop 2002;121:419-423.

Costa A, Raffaini M, Melsen B. Miniscrews as orthodontic anchorage: a preliminary report. Int J Ad Orthod Orthogn Surg. 13(3): 201-9, 1998.

Creekmore TD, Eklund MK. The possibility of skeletal anchorage. J Clin Orthod. 1983 Apr;17(4):266-9.

Dalstra M, Cattaneo PM, Melsen B. Load transfer of miniscrews for orthodontic anchorage. Orthod. 2004 1:53-62.

Deguchi T, Hasu M, Murakami K, Yabuuchi T, Kamioka H, Yamamoto TT. Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic patients. Am J Orth and Detofacial Orthod 2006;129:721e7-12.

Egolf R, BeGole E, Upshaw H. Factors associated with orthodontic patient compliance with intraoral elastic and headgear wear. Am J Orth and Detofacial Orthod 1990;97:336-348.

Erverdi, N, Keles, A and Nanda, R. The use of skeletal anchorage in open bite treatment: A cephalometric evaluation. Angle Orthod 2004 74(3):381-390.

Favero L, Brollo P, Bressan E. Orthodontic anchorage with specific fixtures: related study analysis. Am J Orthod Dentofacial Orthop. 2002 Jul;122(1):84-94.

Fortini A, Lupoli M, Giuntoli F, Fanchi L. Dentoskeletal effects induced by rapid molar distalization with the first class appliance. Am J Orthod Dentofacial Orthop 2004;125(6):697-704.

Freudenthaler JW, Haas R, Bantleon H-P. Bicortical titanium screws for critical orthodontic anchorage in the mandible: a preliminary report on clinical applications. Clin Oral Impl Res 2001;12:358-363.

Gabriel HF. Motivation of the headgear patient. Angle Orthod 1968;38:129-135.

Gainsforth B, Higley L. A study of orthodontic anchorage possibilities in basal bone. Am J Orthod Oral Surg 1945;31:106-17.

Gelgor IE, Buyukyilmaz T, Karaman AI, Dolanmaz D, Kalayci A. Intraosseous screw-supported upper molar distalization. Angle Orthod. 2004 Dec;74(6):838-50.

Ghosh J, Nanda RS. Evaluation of an intraoral maxillary molar distalization technique. Am J Orthod Dentofacial Orthop 1996;110:639-646.

Guyman G, Kokich VG, Oswald R. Ankylosed teeth as abutments for palatal expansion in the rhesus monkey. AJO 1980;77:486-499.

Hilgers JJ. The pendulum appliance for Class II non-compliance therapy. J Clin Orthod 1992;26:700-703.

Huja SS, Litsky AS, Beck FM, Johnson KA, Larsen PE. Pull-out strength of monocortical screws placed in the maxillae and mandibles of dogs. Am J Orthod Dentofacial Orthop. 2005 Mar;127(3):307-13.

Hylander WL. Patterns of stress and strain in the Macaque manbile. In Carlson DS, editor: Craniofacial biology. Ann Arbor, Mich, 1981, Center for Human Growth and development, pp 1-35.

Jacobson A. A key to the understanding of extraoral forces. Am J Orthod 1979;75:361-86.

Jones ML, Richmond S. Initial tooth movement: force application and pain – a relationship? Am J Orth and Dentofacial Orthod 1985;88:111-116.

Kadiologlu O, Buyukyilmaz T, Zachrisson BU, Maino BG. Contact damage to root surfaces of premolars touching miniscrews during orthodontic treatment. Am J Orthod Dentofacial Orthop. 2008 Sep;134(3):353-60.

Kingsley NW. Treatise on oral deformities as a branch of mechanical surgery, New York,1880, Appleton.

Kokich VG. Managing complex orthodontic problems: the use of implants for anchorage. Semin Orthod 1996;2:153-160

Kuroda S, Katayama A, Takano-Yamamoto T. Severe anterior open-bite case treated using titanium screw anchorage. Angle Orthod. 2004 Aug;74(4):558-67.

Kyung HM, Park HS, Bae SM, Sung JH, Kim IB. Development of orthodontic micro-implants for intraoral anchorage. J Clin Orthod 2003;37:321-8.

Lawry DM, Heggie AA, Crawford EC, Ruljancich MK. A review of the management of anterior open bite malocclusion. Aust Orthod J. 1990 Mar;11(3):147-60.

Lim S, Cha J, Hwang, C. Insertion Torque of Orthodontic Miniscrews According to Changes in Shape, Diameter and Length. Angle Orthod 2008;78(2)234-240.

Lin JC, Liou EJ. A new bone screw for orthodontic anchorage. J Clin Orthod. 2003 Dec;37(12):676-81.

Liou EJ, Pai BC, Lin JC. Do miniscrews remain stationary under orthodontic forces? Am J Orthod Dentofacial Orthop. 2004 Jul;126(1):42-7.

Lorenzo, F. Orthodontic anchorage with specific fixtures: Related study analysis. Am J Orthod Dentofacial Orthop 2002;122:84-94.

Majzoub Z, Finotti M, Miotti F, Giardino R, Aldini NN, Cordioli G. Bone response to orthodontic loading of endosseous implants in the rabbit calvaria: early continuous distalizing forces. Eur J Orthod. 1999 Jun;21(3):223-30.

Marcotte, M. Biomechanics in orthodontics, 1st edition, p. 12. 1990. Toronto: BC Decker.

Masumoto T, Hayashi I, Kawamura A, Tanaka K, Kasai K. Relationships among facial type, buccolingual molar inclination, and cortical bone thickness of the mandible. Eur J Orthod. 2001 Feb;23(1):15-23.

McQueen, D., Sundgren, J.E., Iversson, B., Lundstrom,L., Ekenstam,B.F., Svensson, A., Albrekston, T., Branemark, P.I., (1982) Auger Electron Spectroscopic Studies of Titanium Implants. In:Lee A.J.C., Albrektson, T. and Branemark, P.I., eds Clinical Applications Of Biomaterials, 179-185. New York: John Wiley and Sons.

Melsen B, Costa A. Immediate loading of implants used for orthodontic anchorage. Clin Orthod Res. 2000 Feb;3(1):23-8.

Melsen B. Mini-implants: Where are we? J Clin Orthod. 2005 Sep;39(9):539-47.

Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, Takano-Yamamoto T. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. . 2003 Oct;124(4):373-8.

Morarend C, Qian F, Marshall SD, Southard KA, Grosland NM, Morgan TA, McManus M, Southard, TE. Effect of screw diameter on orthodontic skeletal anchorage. Am J Orthod Dentofacial Orthop 2009;136(2):224-9.

Motoyoshi M, Hirabayashi M, Uemura, Shimizu N. Recommended placement torque when tightening an orthodontic mini-implant. Clin Oral Impl Res 2006;17:109-114.

Motoyoshi M, Yoshida T, Ono A, Shimizu N. Effect of cortical bone thickness and implant placement torque on stability of orthodontic mini-implants. Int J Oral Maxillfac Implants 2007;22(5):779-84.

Ngantung V, Nanda RS, Bowman SJ. Posttreatment evaluation of the distal jet appliance. Am J Orthod Dentofacial Orthop 2001;120:178-185.

Ohmae M, Saito S, Morohashi T, Seki K, Qu H, Kanomi R, Yamasaki KI, Okano T, Yamada S, Shibasaki Y. A clinical and histological evaluation of titanium mini-implants as anchors for orthodontic intrusion in the beagle dog. Am J Orthod Dentofacial Orthop. 2001 May;119(5):489-97.

Parfitt AM. The physiological and clinical significance of bone histomorphometric data. In Recker RP, editor: Bone histomorphometry: techniques and interpretation, Boca Raton, FL, 1983, CRC Press, pp 143-223

Parfitt AM. Bone remodeling: relationship to the amount and structure of bone, and the pathogenesis and prevention of fractures. In Riggs BL, editor: Osteoporosis: etiology, diagnosis, and management, New York, 1988, Raven Press, pp 45-93.

Park HS.. Micro-implant Anchorage for Forced Eruption of Impacted Cuspids. Journal of Clinical Orthodontics 2004;38(5):297-302.

Park HS, Bae SM, Kyung HM, Sung JH. Micro-implant anchorage for treatment of skeletal Class I bialveolar protrusion. J Clin Orthod. 2001 Jul;35(7):417-22.

Park HS, Kwon TG. Sliding mechanics with microscrew implant anchorage. Angle Orthod 2004;74(5):703–10.

Park HS, Kyung HM, Sung JH. A simple method of molar uprighting with micro-implant anchorage. J Clin Orthod. 2002 Oct;36(10):592-6.

Park HS, Jeong SH, Kwon OW. Facotrs affecting the clinical success of screw implants used as orthodontic anchorage. Am J OrthoD Dentofacial Orthop 2006;130;18-25.

Park YC, Lee SY, Kim DH, Jee SH. Intrusion of posterior teeth using mini-screw implants. Am J Orthod Dentofacial Orthop. 2003;123(6):690-4.

Quinn RS, Yoshikawa DK. A reassessment of force magnitude in orthodontics. Am J Orthod 1985; 83: 252–260.

Ren Y, Maltha JC, Kuijpers-Jagtman AM. Optimum force magnitude for orthodontic tooth movement: a systematic literature review. Angle Orthod. 2003 Feb;73(1):86-92.

Roberts WE, Helm FR, Marshall KJ, Gongloff RK. Rigid endosseous implants for orthodontic and orthopedic anchorage. Angle Orthod. 1989 Winter;59(4):247-56.

Roberts WE, Marshall KJ, Mozsary PG. Rigid endosseous implant utilized anchorage to protract molars and close an atrophic extraction site. Angle Orthod 1990;60:135-152.

Roberts WE, Garetto LP, Simmons KE: Principles of orthodontic biomechanics; metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors: Bone biodynamics in orthodontic and orthopedic treatment. Ann Arbor, 1992, University of Michigan Press, pp 189-225.

Roberts WE, Arbuckle GR, Analoui M. Rate of mesial translation of mandibular molars using implant-anchored mechanics. Angle Orthod. 1996;66(5):331-8.

Runge M, Martin J, Bukai F. Am J Orthod Dentofacial Orthop 1999;115:153-157.

Salzmann JA. Factors in successful orthodontic therapy before and after using appliances. AJO 1963;49:581.

Sassouni V. A classification of skeletal facial types. Am J Orthod 1969 Feb;55(2):109-23.

Shapiro PA, Kokich VG. Treatment alternatives for children with severe maxillary hypoplasia. Eur J Orthod 1984;6:141-147.

Starnbach HK, Kaplan A. Profile of an excellent orthodontic patient. Angle orthod 1975;45:141-145.

Su Y, Wilmes B, Honscheid R, Drescher D. Comparison of self-tapping and self-drilling orthodontic mini-implants: An animal study of insertion torque and displacement under lateral loading. Int J Oral Maxillofac Implants 2009;24(3):404-11.

Tsunori M, Mashita M, Kasai K. Relationship between facial types and tooth and bone characteristics of the mandible obtained by CT scanning. Angle Orthod. 1998 Dec;68(6):557-62.

Tseng YC, Hsieh CH, Chen CH, Shen YS, Huang IY, Chen CM. The application of mini-implants for orthodontic anchorage. Int J Oral Maxillofac Surg. 2006; 35:704–707.

Turley PK, Kean C, Schur J, Stefanac J, Gray J, Hennes J, Poon LC. Orthodontic force application to titanium endosseous implants. Angle Orthod. 1988 Apr;58(2):151-62.

Umemori M, Sugawara J, Mitani H, Kamamura H. Skeletal anchorage for open bite correction. Am J Orthod Dentofacial Orthop. 1999; 115:166–174.

Van Roekel NB. The use of Brånemark system implants for orthodontic anchorage: report of a case. Int Journal Maxillofac Implants 1989;4:341-344.

Weinstein S, Haack DC, Morris LY, Snyder BB, Attaway HE. On an equilibrium theory of tooth position. Angle Orthod 1963;33:1-26.

Wieslander L. The effects of orthodontic treatment on the concurrent development of the crainiofacial complex. Am J Orthod 49:15-27, 1963.

Weiss J, Eiser HM. Psychological timing of orthodontic treatment. AJO 1977;72:198-204.

Wilmes B, Drescher D. Impact of Insertion Depth and Predrilling Diameter on Primary Stability of Orthodontic Mini-Implants. Angle Orthod. 2009;79:609-614.

Yao JC, Lai EH, Chang JZ, Chen I, Chen Y. Comparison of treatment outcomes between skeletal anchorage and extraoral anchorage in adults with maxillary dento alveolar protrusion. Am J Orthod Dentofacial Orthop. 2008; 134:615–638.