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Effects of synthetic cortical bone thickness and force vector application on temporary anchorage device pull-out strength as related to clinical perspectives of practicing orthodontists

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I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.Sc.D degree and for this assignment.

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A Thesis Presented

Ira Rothstein, D.M.D

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Dedication

I would like to dedicate this thesis to my family, who has been so supportive throughout my entire life, and for their encouragement of all of my pursuits.

Acknowledgements

I would like to acknowledge everyone who assisted me in the completion of this thesis. First, I would like to thank my research mentor, Dr. James Burch, whom I have worked with since my pre-doctoral days. He has provided me with invaluable insight into the research process, and more importantly, he has taught me to always be thinking, and how to express my ideas succinctly. I would also like to thank Dr. Shiva Khatami. She has provided constant support throughout my entire project, and has helped me significantly in producing this final paper. Additionally, I would like to thank Dr. Jeffrey Thompson. His expertise in biomaterials research proved to be instrumental in devising both the study topic and study design. A special thanks goes to Dr. Hardigan for teaching me the fundamentals of statistics, which has provided me with the ability to look deeper than the face value of the evidence based literature upon which our profession is founded, and for assisting me with the data analysis and interpretation in this study. Another special thanks goes to Jim Rothrock for being incredibly patient while assisting me with my bench top testing.

To all of those mentioned, I truly cannot begin to tell you how thankful I am for your help. I understand that assisting me in the completion of this thesis could not have been accomplished without your commitment, time, and advice that you provided me.

Abstract

Background: Temporary anchorage devices (TADs) provide a versatile means by which orthodontic anchorage can be established without the need for patient compliance and complex force systems. Their use is predicated on their ability to remain stable throughout the course of treatment in which they are needed. This has been shown to be the result of "primary stability" which is achieved through mechanical interlocking of the screw threads with the surrounding bone immediately upon placement. Therefore, evaluating the factors that can either enhance or detract from the primary stability of TADs can serve to improve the predictability of their success.

Objectives: The objectives of this study were to describe how variations in synthetic cortical bone thickness and the angle of force applied in relation to the long axis of TADs affects their stability in terms of pull-out strength, and to ascertain the perspectives of practicing orthodontists in the state of Florida on their experiences with temporary anchorage devices with regards to success and failure.

Methods: For the bench top study, 90 1.5x8mm long neck Orthotechnology Spider Screws were randomly allocated to 9 groups of 10 TADs each. The 9 groups were established based on both the thickness of synthetic cortical bone (1.0, 1.5, and 2.0mm) and the angle of force vector applied relative to the long axis of the TADs (45, 90, and 180^0). Pull-out testing was carried out by applying a force to the TADs via a universal testing machine (Instron, Canton, MA) at a rate of 2.0mm/minute. Real-time graphical and digital readings were recorded, with the forces being recorded in Newtons (N). Each miniscrew was subjected to the pull force until peak force values were obtained. For the 45^0 and 180^0 tests, the force registered at the time-point of pull-out, or screw head movement of 1.5mm within the synthetic bone blocks. The determination of 1.5mm of movement was made due the dramatically erratic deflection observed by the digital and graphical readouts at precisely this point.

For the survey portion of this study, A customized survey was developed for this study. The survey was composed of 12 questions, some of which were obtained from a questionnaire that was created by Buschang *et al.*[54] The additional questions were devised by the members of this research project, with the aim of answering questions regarding the clinical experiences that practicing orthodontists experienced with TADs.

Results: For the bench top study: Implants placed in 2.0mm of synthetic cortical bone and pulled at an angle of 180^0 had the highest pull-out strength among all groups (258.38N), while those placed in 1.0mm of synthetic cortical bone and pulled at an angle of 90^0 exhibited the lowest (67.11N). When evaluated separately, a cortical bone thickness of 2.0 mm displayed the highest pull-out forces for the three angles of force application, and 180^0 angle of force displayed the highest-pull-out forces for the three cortical bone thicknesses. Conversely, 1.0mm of cortical bone thickness displayed the lowest pull-out forces for the three angles of force application, and 90^0 angle of force displayed the highest-pull-out forces for the three cortical bone thicknesses.

For the survey**:** The most important factor associated with TAD failure was cited as placement location by 45.7% (n=16) of respondents, while root proximity was cited as the least important factor by 35.3% (n=12) of respondents. For the site from which practitioners indicated that they experience the greatest success, 81.8% cited the palate, while 51.9% responded that they experience the highest failure rates for the posterior maxilla (distal to the cuspids).

Conclusions: A synthetic cortical bone thickness of 2mm and pull forces applied parallel to the long axis of TADs resulted in the greatest resistance to pull-out.

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List of Abbreviations

TADs	Temporary anchorage devices
BIC	Bone to implant contact
N	Newtons
mm	Millimeters
^{0}	Degrees
min	minutes
pcf	pounds per cubic foot

Chapter 1: Introduction

1.1. Anchorage in orthodontics

Orthodontic tooth movement requires the application of forces to the dentition and its supporting structures. As Isaac Newton described in his third law of motion, every action, or force in this case, has an equal and opposite reaction. An exemption from this law of nature in orthodontic practice would surely simplify treatment, as one would not have to consider the reciprocal effects of the forces applied to the teeth. Because orthodontic therapy has its foundations rooted in the biological and physical sciences, it behooves practitioners to consider both the intended and unintended forces that their chosen mechanics will place on the teeth and periodontium.

Orthodontic anchorage was first defined in 1923 by Louis Ottofy as "the base against which orthodontic force or reaction of orthodontic force is applied."[1] In a simplified definition, Proffit[2] defined anchorage as the "resistance to unwanted tooth movement." Essentially, it is a term that acknowledges the role of Newton's third law in every aspect of orthodontic treatment. Treatment success hinges on the ability of the practitioner to control tooth movements in relation to equal and opposite forces.[3] When discussed in terms of force distribution, anchorage can be defined as the dissipation of unwanted forces while maximizing those that are desired.[4]

1.2. The importance of anchorage in orthodontic therapy

While the aforementioned definitions describe anchorage, they do not lend credit to the importance of anchorage control during orthodontic therapy. Ritto stated, "Success or failure of traditional edgewise treatment depends on careful consideration to anchorage for tooth movement."[5] Weichman and Büchter[6] stated that stable anchorage is a pre-requisite for orthodontic treatment with fixed appliances, and Antoszewska, Papadapoulos, Park, and Ludwig[7] stated that anchorage control is a fundamental prerequisite for efficient orthodontic treatment without complications." Additionally, Brettin *et al.* [8] stated that appropriate anchorage in orthodontic treatment is of paramount importance. Marcotte[9] defined anchorage as being comprised of three types: Type A, in which the posterior teeth do not move during anterior retraction, Type B, in which the anterior and posterior teeth move equal amounts during space closure, and Type C, in which the anterior teeth remain stable during posterior protraction.

The pitfalls of ignoring anchorage control in orthodontic therapy have been discussed by multiple authors. As stated by Meister and Masella, [10] "Abandoning control of extraction space allows alignment of the dentition but robs us of the opportunity to significantly retract the dentition, effectively remodel the dentoalveolar/lip relationship, and treat within the relatively stable parameters of the original malocclusion." Concurrently, Geron, Shpack, and Kandos [11] noted that anchorage loss (posterior dental mesialization) in cases with severe crowding, excessive overjet, and bimaxillary protrusion can diminish the amount of anteroposterior correction of the malocclusion and possibly detract from facial esthetics. Furthermore, Gianelly, Smith, Bendar, and Dietz[12] described how inadequate control of molar position in extraction cases with asymmetric crowding results in compromised canine and midline positioning.

1.3. Means of establishing anchorage

Control of anchorage in traditional orthodontic therapy has commonly been achieved by incorporating intra and/or extraoral appliances and counteracting moments via archwire bends to create stability in the reactive dental units. [1] While proper utilization of these techniques may yield adequate anchorage control, there are many drawbacks. One of the primary drawbacks to the use of removable appliances is that patient compliance is essential for a successful outcome.[13] Additionally, an increase in percentage of adults seeking orthodontic treatment has resulted in the need for alternative means of establishing anchorage control when either dental or periodontal conditions may be either inadequate or incomplete.[6]

1.4. Initial use of implants for anchorage

In 1969, Brånemark, Briene, and Adelle [14] noted in their study that endosseous titanium screws may be used to provide stable anchorage for dental prostheses with little to no adverse tissue response, and that under light microscope, there was true bone to implant contact.[15] The phenomenon he described was coined “osseointegration.” The ability of titanium implants to “integrate” with the surrounding bone has since led to advances in all fields of dentistry, from periodontics to prosthetics and orthodontics. In 1984, Roberts, Smith, Moszary, Zilberman, and Smith [16] found that endosseous implants were stable in rabbits after 4 to 8 weeks of continuous orthodontic loads, indicating that titanium implants can provide rigid osseous anchorage for orthodontic treatment purposes. While conventional endosseous implants have been shown to be stable under orthodontic loading conditions and successful in over 90% of cases, there are inherent drawbacks. Generally, endosseous implants vary between 6-15mm in length and 3-5mm in diameter.[4] Due to their size, these implants are highly site specific, often limited to the retromolar region and edentulous areas. They are also costly, require surgical placement, and are difficult to remove once treatment has completed.[6,17]Another drawback is the necessary delay before loading. After placement of traditional endosseous implants, a period of 2-6 months is required for osseointegration of the implant and tissue healing. During this period, the implants should remain unloaded.[15]Although they are not suited for use in a majority of orthodontic patients, endosseous implants may still be the optimal choice for those involving prosthetic reconstruction after orthodontic treatment.

1.5. The development of the orthodontic miniscrew

Weichmann *et al.*[6] note that due to the limitations of traditional endosseous implants for orthodontic use, development of more versatile systems were undertaken with the purpose of improving orthodontic anchorage for all segments of the dental arches. This led to the development of the titanium miniscrew. In 1945, Gainsforth and Higley placed vitallium screws in the mandibles of dogs in an attempt to create “absolute” orthodontic anchorage.[18] While each of the screws ultimately failed, this was the first attempt at utilizing skeletal anchorage in orthodontics. The first clinical use of miniscrews was reported by Creekmore and Eklund in 1983, in which successfully intruded anterior teeth with vitallium miniscrews placed in the anterior nasal spine.[19] Since this report, miniscrews have become a standard part of the armamentarium in both private practice settings and teaching institutions.

1.6. Miniscrews in orthodontics: advantages and disadvantages

Veltri *et al.*[20] stated that the main clinical advantages of skeletal anchorage, which includes miniscrews, bone plates, and ankylosed teeth, over dental and extraoral anchorage are absolute stability and independence from patient compliance. Their use also eliminates the undesirable effects that are found with dentally borne anchorage mechanics.[21] Another advantage of miniscrews is versatility in placement. Practitioners are no longer limited by the large size of endosseous implant. With careful planning, miniscrews can be placed almost anywhere they are desired. This results in an increased number of indications, because placement can now be determined by the mechanics desired as opposed to anatomy. Kuroda, Sugawara, Deguchi, Kyung, and Yamamoto [22] stated that the advantages of titanium miniscrews are their ability to provide rigid anchorage, minimal anatomic limitations, lower cost as compared with traditional endosseous implants, and easier, less traumatic placement. Other advantages include ease of removal after treatment, minimal to no waiting period between placement and loading, and the potential for placement by the orthodontist.[15,23,24]

Along with the advantages of miniscrews come disadvantages. The primary disadvantage is a greater failure rate than with traditional endosseous implants.[17] Costa *et al* found miniscrew failure rates as high as 39% in a study,[6] whereas Kuroda *et al* found success rates as high as 88.6% with 1.3mm diameter screws.[16] Miniscrew success is highly dependent on site differences. The rate of success has been found to be lower in the mandible than in the maxilla,[25] while the lingual of the mandible exhibited the highest failure rates.[6] Cheng *et al* found that placement in mobile mucosa results in high failure rates.[26] Costa, Pasta, and Begamaschi suggested that a force that generates a moment on the implant in the direction of unscrewing may condemn it to failure.[27] Additional disadvantages include potential damage to surrounding hard and soft tissues during placement, irritation and inflammation of peri-implant tissues, and additional cost to the patient for a specialist other than the orthodontist to perform the placement.[21]

1.7 Miniscrew design

The orthodontic miniscrew is comprised of three parts: The head, neck, and body. While the geometry of each of these components may vary among manufacturers, the ultimate objective of practitioners is to choose a design that will produce the greatest retention throughout the course of treatment. For this reason, many studies have evaluated miniscrew related factors associated with stability.

Lin, Yu, Liu, Lin, and Lin stated that the optimal design should avoid failure and minimize strain on the surrounding bone. In their study, the authors evaluated seven miniscrew variables and their correlation to stresses placed on surrounding cortical bone. They utilized finite element analysis, a means of digitally analyzing how objects will react under various loading conditions.[28] They found that screw material, head exposure length, and screw diameter were the primary determinants of stress production.[29]

Most commercially available miniscrews utilized in orthodontics are composed of a titanium alloy (Ti-6Al-4V) as opposed to commercially pure titanium. It has been reported that titanium alloy has the advantages of being biocompatible, exhibits increased retention, and is less prone to breakage. Commercially pure titanium is less dense than the alloy, resulting in increased potential for breakage.[30] Additionally, the “softer” nature of commercially pure titanium places increased stress per surface area on the surrounding cortical bone due to screw bending during loading.

The diameter of miniscrews ranges from 1.0-2.3mm[31,32]The use of smaller diameter miniscrews is suggested in interdental regions, whereas larger diameter miniscrews are more applicable in edentulous and retromolar areas. While this is the case, it has been shown that diameters less than 1.2mm increase the potential for screw fracture and loosening because they result in increased stresses being applied to the surrounding cortical bone when compared to larger diameter miniscrews.[21,29,30]

Another component of miniscrew design is the taper of the screw body. Miniscrews can be either tapered or cylindrical. Tapered miniscrews exhibit an increase in diameter from the tip towards the head, while cylindrical miniscrews exhibit a constant diameter along the length of the screw body. Florvaag *et al.*[33] found that mean insertion torque was greatest for tapered miniscrews, and removal torque was greater for cylindrical screws. This was similar to the results of the Cha, Takano-Yamomoto, and Hwang.[34] They found that tapered screws had a lower mean maximum removal torque than cylindrical miniscrews after 12 weeks of loading, although their initial stability, based on removal torque, was greater over the first 3 weeks of loading. They also found that bone-implant contact (BIC), which indicates the degree of osseointegration,[35] did not vary significantly between the two types of miniscrews.

The relationship of screw length to its stability has been examined in several studies, but with varying results. Lim, Cha, and Hwang[36] found that longer miniscrews exhibited greater mean insertion torques than shorter screws, and that this difference was greater for cylindrical screws. Another study found that success rates were significantly higher for 8mm miniscrews (90.2%) than with 6mm miniscrews (72.2%).[37] These results suggested that increased stability can be achieved with longer miniscrews. Concurrent with these results, Lin *et al.*[30] suggested utilizing the longest screw possible without jeopardizing the health of adjacent tissues.

1.7. Primary stability

The stability of miniscrews arises mainly from "primary stability."[14] Lee, Kim, Park, and Vanarsdall describe primary stability as the mechanical stabilization achieved immediately after placement.[38] This differs from traditional endosseous implants in that their retention depends on osseointegration of the implant with the surrounding bone. Primary stability is affected by multiple factors, such as bone quantity and quality, surgical technique, and screw geometry. Cortical bone thickness (CBT) and cancellous bone density in the region of implant placement have to be critical factors in obtaining primary stability of orthodontic miniscrews. Antoszewska *et al.*[7]stated that failure of orthodontic miniscrews is most often due to lack of primary stability caused by inadequate cortical bone and soft tissue irritation. As stated by Jung, Yildizhan, and Wherbein, "a prerequisite for sustained success of temporary skeletal anchorage elements is bony anchorage of the implant body by immediate contact between the implant surface and the peri-implant bone at the cellular level.[39]" Deguchi *et al* suggested that because of this, the quantity of cortical bone in the area of miniscrew placement is the major factor in their stability.[40] Concurrently, Baumgartel *et al*. stated that it is the absolute amount of cortical bone, rather than the ratio of cortical to cancellous bone, which is responsible for implant stability.[41] Others showed that maximum stresses occur at the cortical bone level when miniscrews are loaded, and that this stress is decreased significantly with increased cortical bone thickness.[42] Melsen and Verna described the cortical layer to be responsible for transferring the load on the miniscrew to the bone.[43] Additionally, Melsen noted that pathological overload of the bone's adaptive capacity may occur with bone of low density and with a cortical plate thickness less than 0.5mm.[44] This may be due to the direct correlation of cortical bone thickness with removal torque of miniscrews,[45] which has been shown to be a determinant of their stability. Motoyoshi, Inaba, Ono, Ueno, and Shimizu found that placement of miniscrews in areas with ≥ 1mm of cortical bone thickness has significantly greater success rates than those placed in areas with ≤ 1mm of cortical bone.[46] Therefore, they suggested that 1mm of CBT can be used as the threshold for the successful use of miniscrews.

In an examination of the effects of implant angulations in relation to the cortical bone, Deguchi *et al* found that angling miniscrews 30^0 to the surface of the bone surface produced 1.5x greater BIC than placing the miniscrews perpendicular.[40] Pickard, Dichow, Rossouw, and Buschang utilized dried cadaver skulls to test the pull out strength of miniscrews relative to their orientation to the line of action applied. Their findings contradicted the "tent-peg" theory of resistance. They found that miniscrews angled toward the line of force had greater stability than those that are "tent-pegged", or angled away from the direction of force application.[47] This was further confirmed in a study which showed that pull out force of the miniscrews declined as the angle of pull from the long axis of the miniscrews increased.

Although primary stability has been shown to be an essential component to miniscrew success, one study revealed a correlation coefficient of 0.39 when relating cortical bone thickness to pull-out strength of miniscrews.[48] This indicates that the initial mechanical interdigitation is not the sole determinant of an implant's stability. Secondary stability of miniscrews, or that derived from the deposition of new bone around the implant, also contributes to their stability.[22] While studies have found that there are no significant differences in BIC with respect to loading time,[3] Wu, Bai, and Wang found that allowing a healing time of 4 weeks prior to loading orthodontic miniscrews resulted in greater pull-out strengths. This 4 week period has been shown to correlate histologically with abundant bone deposition around the implant[49] and a concurrent increase in secondary stability.

1.8. Cortical bone factors

Based on the importance of cortical bone thickness on the stability of orthodontic miniscrews, knowledge of how various sites differ in thickness may help practitioners to better determine where their miniscrews may be most stable. The thickness of cortical bone has been shown to differ both between and within the mandible and maxilla. The maxilla and mandible both exhibit the thinnest and weakest cortical bone in the anterior region. Cortical bone thickness in both arches increases posteriorly, although there is a decrease in both thickness and density distal to the maxillary second molar.[40,50,51]A qualitative analysis of alveolar bone density revealed that in the maxilla, the cortex was most dense in the premolar area. Additionally, Peterson, Wang, and Dechow found that the modulus of elasticity was greatest in the molar and incisor regions in dentate maxillae.[52] (Appendix K)Similarly, Lettry, Seedhom, Berry, and Cupone determined that the cortex in the mandibular premolar area has the highest modulus of elasticity.[53] While these findings did not necessarily correlate to thickness, they indicated that the premolar areas have the strongest cortices in the alveolus. The mandible, on average, has been shown to have a greater thickness of cortical bone when related to equivalent maxillary sites. Although these findings would indicate that miniscrew stability and success would be greater in the mandible, this is not the case. The posterior mandible has the thickest cortical bone, yet it is associated with lower success rates than the maxilla. This may be due to pathological overheating of the bone during miniscrew placement, issues with hygiene maintenance, and a smaller zone of attached ginigiva[40]. Additionally, it has been suggested that the higher success rates found in the posterior maxilla may be due to an increase in cancellous bone density in the area.[51]

An evaluation of cortical bone thickness of every interdental site on dry human skulls showed that there are also significant variations within sites. Cone beam tomography revealed that there was a general trend towards increasing cortical bone thickness further apically toward the basal bone in the maxilla and mandible, although the maxilla did exhibit an area of decreasing thickness at 4mm apical to the alveolar crest.[50] These findings indicate that miniscrews should be placed as far apically as possible, as stated by Baumgartel *et al*. Conversely, Deguchi *et al*. found that in the molar areas of the maxilla and mandible, there was no significant difference in cortical bone thickness when CBCT readings were made at 3-4mm apical to the alveolar crest and 6-7mm apical to the crest[40]

Along with increased interdigitiation, greater thicknesses of cortical bone provides improved support and stress distribution. This allows the forces placed on the miniscrews to be distributed to a greater area. Motoyoshi *et al*. described a “cascade” of miniscrew failure.[46] In their finite element analysis, they found that thinner cortices resulted in greater stress distribution to the surrounding cancellous bone. When ≤ 1mm of cortical bone was present, the stresses distributed to the cancellous bone were more prone to result in “overload resorption.” This, as they stated, occurs from a superior to inferior direction along the implant-bone interface. If forces are great enough to produce the resorption, increasing mobility and potential failure are likely.

1.9 Root Contact

Another factor associated with orthodontic miniscrew failure is placement in contact with dental roots.[13] A survey conducted by Buschang, Carillo, Ozenbaug, and Rossouw revealed that the number one reason why orthodontists do not place their own miniscrews is fear of root damage.[54] In a study on beagle dogs which evaluated miniscrew placement relative to root proximity and distance from the alveolar crestal ridge, the authors found that 100% of the implants placed <1mm from the crestal ridge and in contact with dental roots were deemed failures. Conversely, they achieved 100% success when the miniscrews were placed >1mm from the crestal ridge and were not in root contact. Based on their results, they suggest that utilization of a surgical stent and/or cone beam computed tomography imaging (CBCT) may reduce the risk of errant miniscrew placement.[55] Another study found that failure rates of miniscrews to be 79.2% when invasion of the roots occurred, as opposed to 8.3% when no root contact was evident. They suggest that the increase in failure with root invasion may be caused by decreased BIC, physiologic movement of the teeth being transferred to the miniscrew, and slippage of the miniscrew upon contact with the roots. It is hypothesized the physiologic tooth movement during function puts forces on the implant, thereby reducing its stability.[17] In a radiographic evaluation of miniscrew placement, Kuroda *et al*. achieved 90% success rates in non-invading miniscrews. Additionally, they found that traditional radiographic means may be inadequate for determining if root invasion has occurred. In their study, they utilized CBCT imaging to evaluate the 3-dimensional position of miniscrews that appeared to be contacting roots on conventional radiographs. There results showed that although there was close proximity, the appearance of root invasion on a 2-dimensional film does not indicate actual root contact.[16] Additional reports have shown that contact with the root or periodontal ligament space results in a significant increase in miniscrew failure rate. Failure rates of these magnitudes indicate that careful placement is essential, and it has been suggested that there be 2mm of clearance between implant and the PDL space in order to prevent invasion from occurring.[6] Additionally, placing the implants at an angle of 20^0-40^0 to the long axis of the teeth has been shown to reduce the risk of root impingement.[19] Close root proximity between adjacent sites may limit the potential for miniscrew placement interdentally. Due to this, biomechanical considerations and angulations of forces applied to the TADs may be influenced.

1.9. Purposes of this study

Many studies have been undertaken to determine optimal characteristics of orthodontic miniscrews, bone type, and location of placement. Many were based on cadavers, humans, and animals such as dogs and rabbits. Those studies provided an abundance of information on the success and stability of TADs in their respective materials. However, the control of these studies regarding bone type and density was difficult to establish. The study proposed herein was to establish parameters for ideal cortical bone thickness and angulation of force application in a controlled laboratory environment. These findings were to be related to the clinical experiences reported by practicing orthodontists in the state of Florida.

1.10. Significance of this study

This study will provide information regarding the effects that cortical bone thickness and angle of force application has on miniscrew stability. This information can be used by orthodontists to improve their success with miniscrews.

1.11. Specific aims and hypotheses

Specific Aim1: To determine the effect of cortical bone thickness on the pull-out strength of temporary anchorage devices

Specific Aim 2: To determine the effect of the angle of force applied relative to the long axis of temporary anchorage devices on their pull-out strength

Specific Aim 3: To determine the effect of pull force angle combined with Cortical bone thickness on the pull-out strength of temporary anchorage devices

Specific Aim 4: To present information obtained from a survey of practicing orthodontists in the state of Florida on their reported experiences with miniscrews, and the factors which they perceive to be most important for successful TAD use

1.12. Location of study

The design, preparation, and data collection activities of the study took place at:

Nova Southeastern University College of Dental Medicine
3200 South University Drive
Fort Lauderdale, Florida 33328

Chapter 2: Materials and Methods

2.1. Bench top Study:

2.1.1. Temporary anchorage devices

Ninety self-drilling, self-tapping K1 long neck Spider Screws (OrthoTechnology, Tampa, Florida) were received in sealed and sterilized original packaging. (Figure 1) The screws have a screw length of 8.0mm and a screw body diameter of 1.5mm. The height of the soft tissue collar measures 2.0mm, while its diameter measures 3.9mm. The screw head contains both a bracket-like head design with cross hatches, and a perpendicular round slot beneath the tie wings. The screws are fabricated from Grade 5 titanium alloy (Ti 6AL-4V ELI).[56] (Appendix H)

Figure 2.1 OrthoTechnology Long Neck 1.5x8mm K1 Spider Screw

2.1.2. Sawbones synthetic cortical bone analogs

The synthetic bone utilized was procured from Sawbones (Pacific Research Laboratories, Vashon, Washington). The blocks were fabricated from solid, rigid polyurethane foam based on the ASTM F-1839-08 materials testing standards.[57](Appendix I) The blocks consisted of both a cortical bone layer and a cancellous bone layer. The densities used were 40pcf and 15pcf respectively. This was chosen based on the Misch Bone Density Classification Scheme.[58,59] (Appendices J and L) Each block was fabricated with a 4cm thick cancellous bone layer, overlayed with one of 3 cortical bone thicknesses. Two blocks of each of the 1.0, 1.5, and 2.0mm cortical bone thickness were used. The blocks were stored together in a cool, dark environment prior to testing to decrease the chance of environmentally induced variations between the blocks.

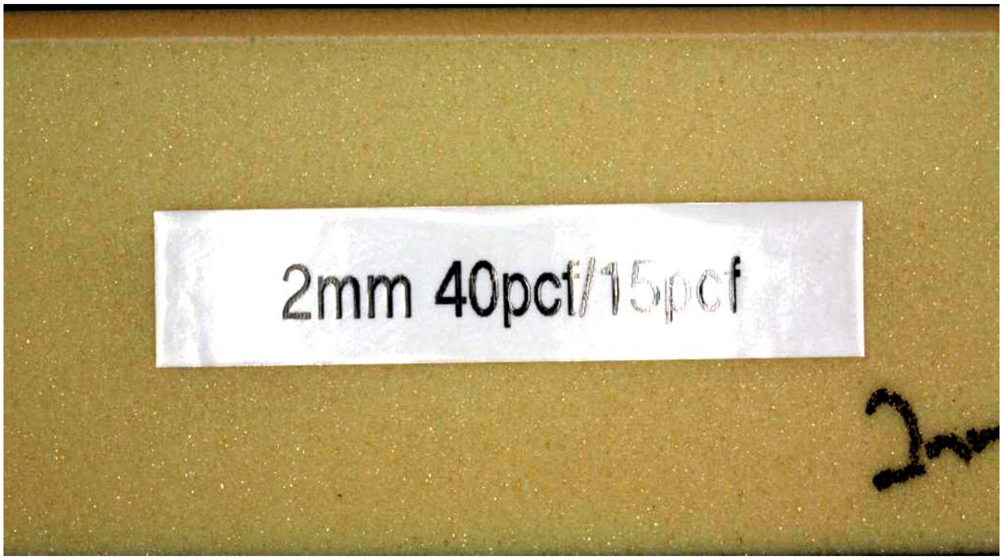


Figure 2.2 Sawbones Synthetic cortical bone block showing cortical and cancellous layers

2.1.3. Groups

The 90 Spider Screws were randomly divided into 9 separate groups of 10 screws each. The screws were removed from their packaging with the OrthoTechnology hand driven Screw Driver Body with attached pick-up driver shaft immediately before placement into their respective bone blocks. Following visual examination for any defects, the screws were manually placed perpendicularly into the bone blocks to a depth of 8.0mm utilizing the hand-driven drive shaft at a rate of two turns per second.

Consistency in placement angle of each miniscrew was assured by the use of a customized jig. The jig was fabricated by creating a small acrylic cube in a clear plastic. A guide hole with the same diameter as the driver shaft (2.45mm) was drilled through the block. Orientation of the guide hole was perpendicularly created by drilling the pilot hole with a mounted drill press at an angle of 90^0 to the flat surface which was placed on the Sawbones surface for placement of the miniscrews. Uniformity in depth of placement was assured by measuring the distance from the bone surface to the top of the screw head with a digital caliper. Prior to mechanical testing, the blocks with the screws in place were stored together.

The 9 groups were established based on both the thickness of synthetic cortical bone and the angle of force vector applied relative to the long axis of the TADs.

Groups A-C: The first three groups consisted of 10 randomly assigned Spider Screws per group placed in bone blocks having 1.0mm of cortical bone thickness. The angle of force application relative to the screw was 45 degrees for group A, 90 degrees for group B, and 180 degrees for group C.

Groups D-F: The next groupings consisted of 10 randomly assigned Spider Screws per group placed in bone blocks having 1.5mm of cortical bone thickness. The angle of force application relative to the screws was 45 degrees for group D, 90 degrees for group E, and 180 degrees for group F.

Groups G-I: The final grouping consisted of 10 randomly assigned Spider Screws per group placed in bone blocks having 2.0mm of cortical bone thickness. The angle of force application relative to the screws was 45 degrees for group G, 90 degrees for group H, and 180 degrees for group I.

2.1.4. Pull-out testing

Pull-out testing was carried out by applying a force to the TADs via a universal testing machine (Instron, Canton, MA). Each of the bone blocks was placed in an adjustable vice with a built-in protractor. Each TAD was placed perpendicular to the bone block surface, the vice allowed the long axes of the TADs to be oriented from 0-90 degrees relative to the arm of the testing machine. Performing the pull-out tests on the 45^0 and 90^0 groups was carried out with a loop fabricated from .016" stainless steel Australian orthodontic wire. This wire was attached to a vice on the Instron arm and looped around the tie wings of the screw heads. Prior to initiating a pull force, the center of the screw head was positioned precisely below the center of the test machine arm. The positioning and proper angle of pull was confirmed by protractor calibration from three reference points. For the 180^0 pull out test, the vice was attached directly to both the screw head and mounted at its base to the Instron arm. (Figure 1)

Following proper orientation of the bone blocks and zeroing of forces exerted by the Instron machine, a pull-force was applied at a rate of 2.0mm/minute. Real-time graphical and digital readings were recorded, with the forces being recorded in Newtons (N). Each screw was subjected to the pull force until peak force values were obtained. For the 45^0 and 180^0 tests, this force corresponded to the point of maximum loading, or screw movement of 1.5mm within the synthetic bone blocks. The determination of 1.5mm of movement was made due the dramatically erratic deflection observed by the digital and graphical readouts at precisely this point.

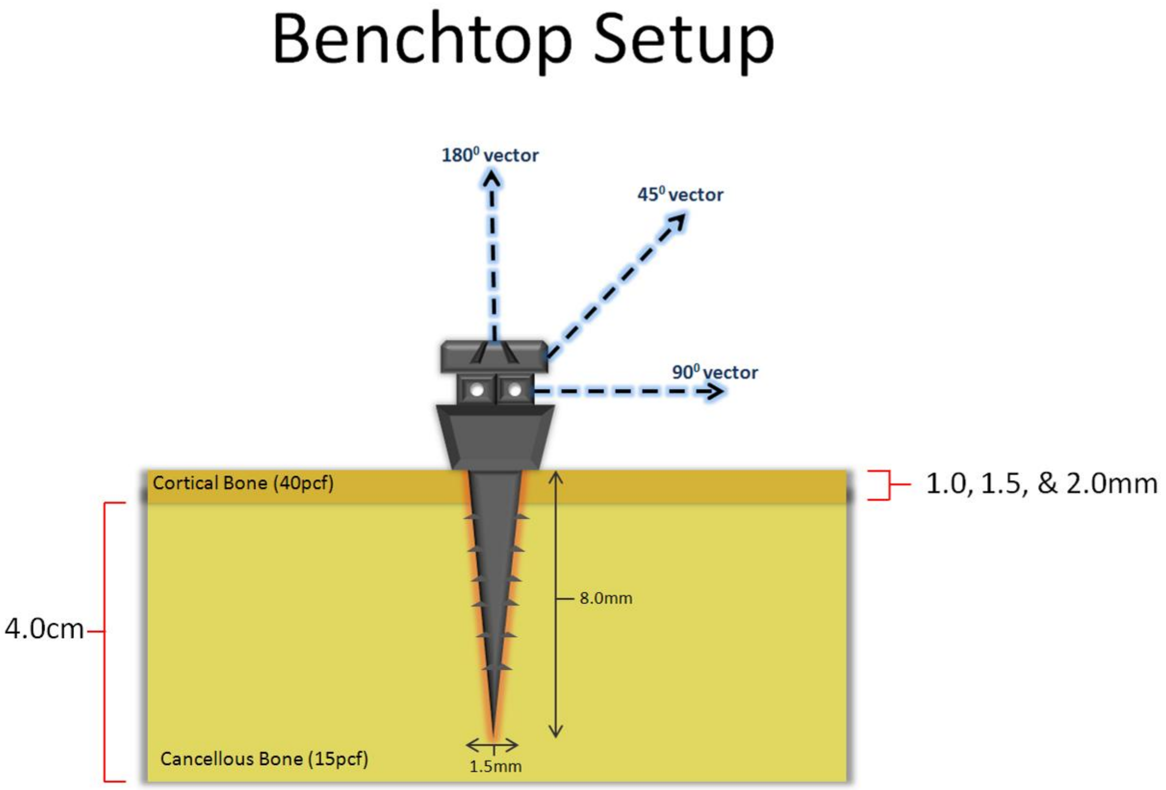


Figure 2.3 Diagrammatic representation of the bench top setup with pull force vectors

2.1.5. Statistical analysis

The data was imported into JMP-8 software (SAS Institute, Cary, NC) and analyzed. Descriptive statistics included the mean, standard deviation, maximum, minimum, and upper and lower 95% confidence intervals. The analysis was performed to determine if there were significant differences between cortical bone thicknesses, angles of force application, and angle by thickness. A Shapiro-Wilk’s W test was performed to determine normality, and was found to be violated. Additionally, Levene’s test for equal variances was also violated. Therefore, generalized models testing was performed to evaluate the data.

2.2. Materials and Methods for the Survey:

2.2.1. Survey design

A customized survey was developed for this study. The survey was composed of 12 questions, some of which were derived from a questionnaire that was created by Buschang *et al.*[54] The additional questions were devised by the members of this research project, with the aim of answering questions regarding the clinical experiences that practicing orthodontists had with TADs. The survey was reviewed by Nova Southeastern University's institutional review board for research with human subjects, and was granted exemption from further review.

2.2.2. Obtaining a list of Florida orthodontists

The list of orthodontists was obtained from the American Association of Orthodontists membership listing. The inclusion criteria included active membership in the American Association of Orthodontists and practice address located in Florida. From the group of orthodontists that satisfied these criteria, a list of 389 orthodontists was obtained.

2.2.3. Study design

Each orthodontist received an email through Surveymonkey.com, which invited them to partake in the survey. Duplicate emails were filtered so that each email address was used only once. The survey email contained a cover letter (Appendix A) which provided a description of the current study and the contact information of the principle investigator. Additionally, a web-link was embedded in the cover letter which would direct the user to the unique survey website, and an opt-out link should they wish to not participate or refuse future emails. If the web-link was selected, the respondent was directed to the survey (Appendix B). Three weeks following the initial email, a reminder email, which was the same as the first email, was sent to all of the orthodontists who had not responded and not opted out. Following this reminder, 1 week was given to allow for response collection.

Chapter 3: Results

3.1. Results of laboratory portion

The independent variables studied were synthetic cortical bone thickness in increments of 1.0, 1.5, and 2.0mm, and angle of force application relative to the vertical axis of the implants in degrees (^{0}). The dependent variable was force in Newtons (N). The assumptions for a 2-way factorial ANOVA are normality, equal variances, and independent observations. The observations are not correlated but the normality test (Shapiro-Wilk W test) demonstrated that the variables were not normally distributed. Levene's test for equal variance was also violated. Given this, a generalized linear model was run to look for difference between the variables. Generalized linear models can be used when response variables follow distributions other than the normal distribution, and when variances are not constant. Significant differences were found between thicknesses, angles, and depth by angle ($p < 0.05$). To find where the specific differences occurred, linear-contrasts (multiple comparison tests) were conducted. (Appendix D)

3.1.1. Difference in pull-out strength between synthetic cortical bone thickness

The 2.0mm cortical bone thickness groups yielded the greatest pull-out forces, while the 1.0mm thickness groups exhibited the lowest. The mean pull-out force difference between 1.0mm and 1.5mm was found to be 34.30N. The confidence interval for the upper and lower 95 percentile between these groups is 41.91N and 26.70N respectively. Between 1.0 and 2.0mm of synthetic cortical bone thickness, the difference between the means was 64.99N. The confidence interval for the upper and lower 95th percentiles was 72.60N and 57.39N respectively. Between the 1.5mm and 2.0mm synthetic cortical bone thickness groups, the mean difference in pull-out force was found to be 30.69N. The confidence interval for the upper and lower 95th percentiles was 38.30N and 30.69N respectively. Among each of these observations, all differences in mean pull-out force were found to be significant at the $p<0.05$ level. (Appendix E)

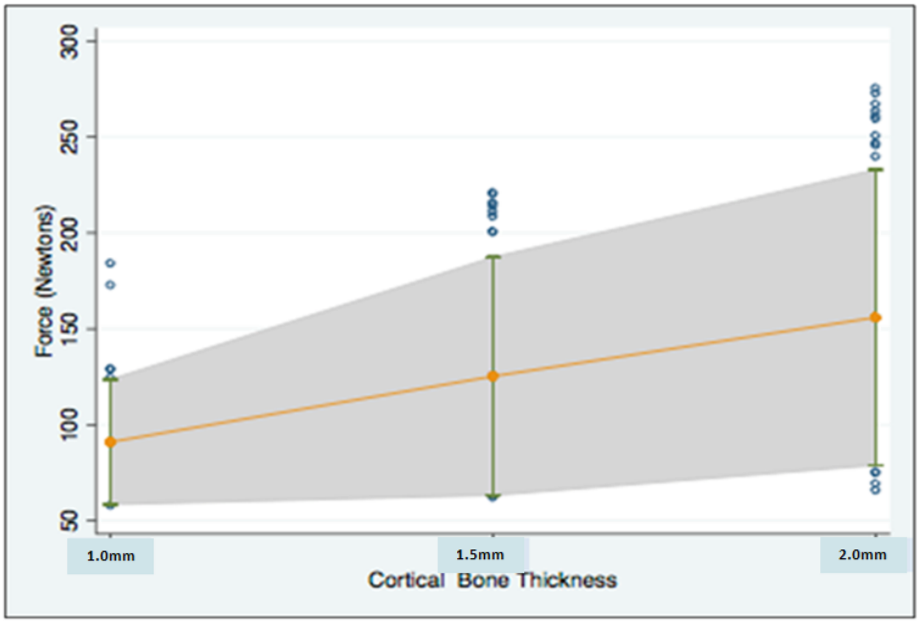


Figure 3.1 Difference in mean pull-out strength between the three thicknesses of cortical bone for all groups

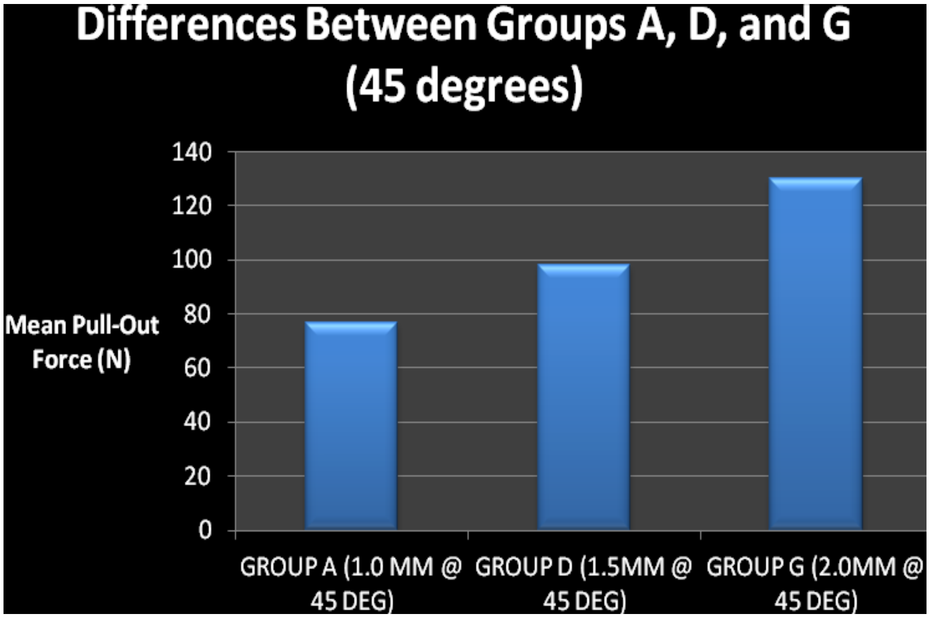


Figure 3.2 Difference in mean pull-out strength between the three thicknesses of cortical bone for 45^0 angle of pull

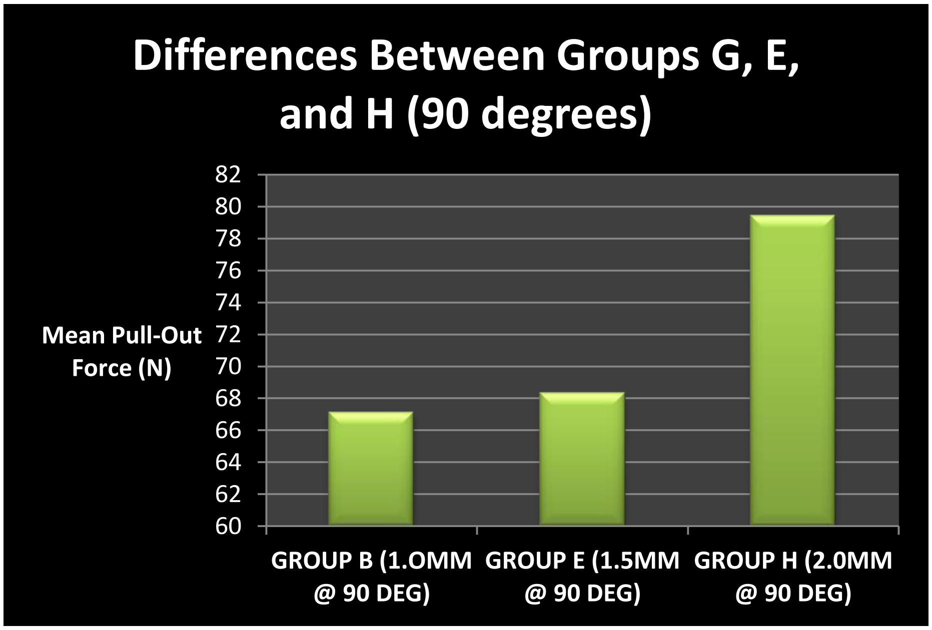


Figure 3.3 Difference in mean pull-out strength between the three thikncesses of cortical bone for 90^0 angle of pull

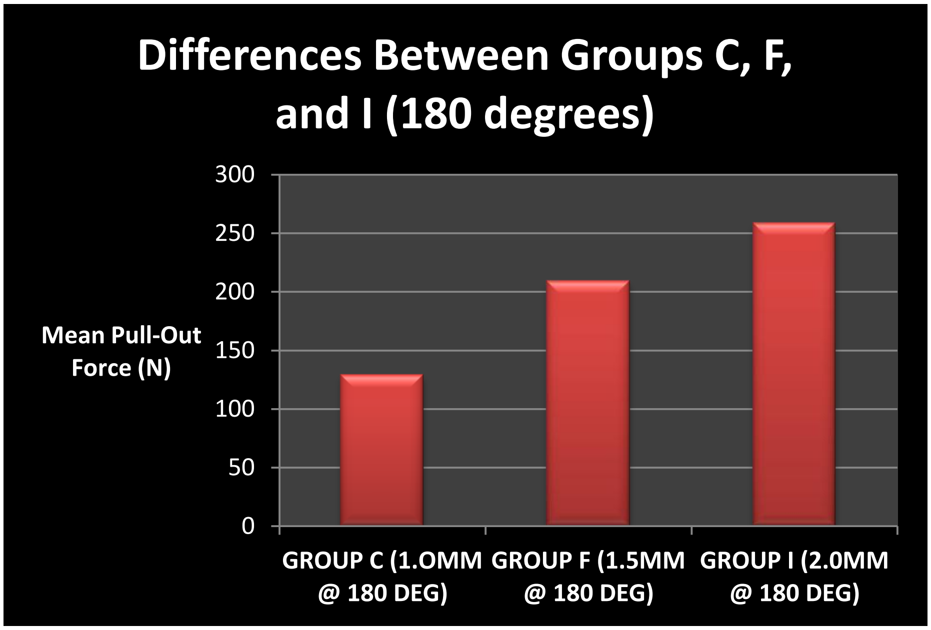


Figure 3.4 Difference in mean pull-out strength between the three thicknesses of cortical bone at 180^0 angle of pull

3.1.2 Difference in pull-out strength by angle (Figures 5-8)

A pull-force vector of 180^0 (or parallel to the long axis of the miniscrew) resulted in the greatest pull-out strengths, while a pull force of 90^0 (perpendicular to the long axis of the miniscrews) yielded the lowest pull-out strengths. The mean pull-out force difference between the 45^0 and 90^0 force vectors was 30.02N. The confidence intervals for the upper and lower 95th percentiles were 37.63N and 22.41N respectively. The mean pull-out force difference between 45^0 and 180^0 force vectors was 97.22N. The confidence intervals for the upper and lower 95th percentiles were 104.83N and 89.61N respectively. The mean pull-out force difference between the 90^0 and 180^0 force vectors was 127.24N. The confidence intervals for the upper and lower 95th percentiles were 134.85N and 119.63N respectively. All differences were found to be significant at the $p<0.05$ level. (Appendix F)

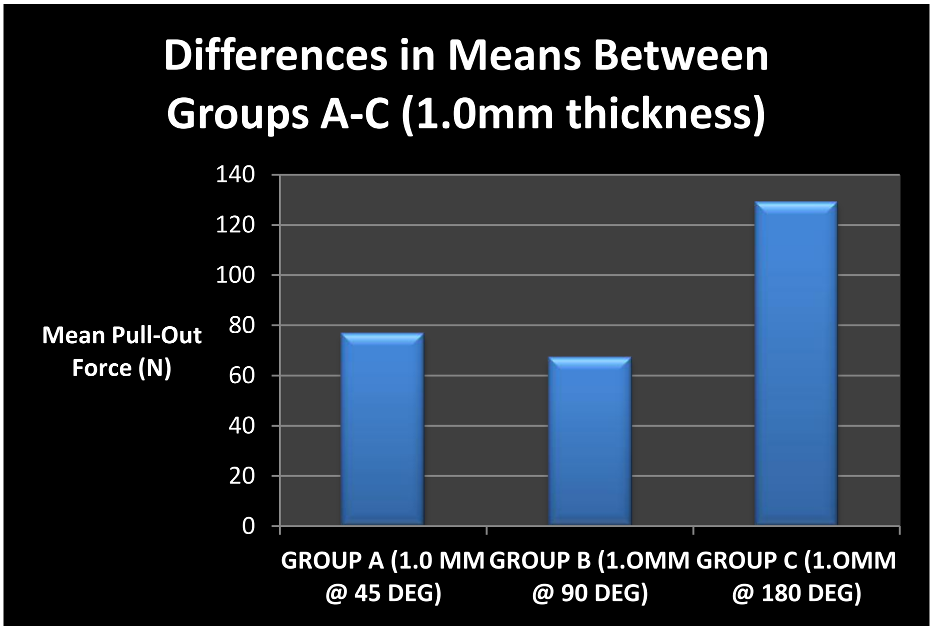


Figure 3.5 Difference in mean pull-out strength between the three angles of force vector application for 1.omm cortical bone thickness groups.

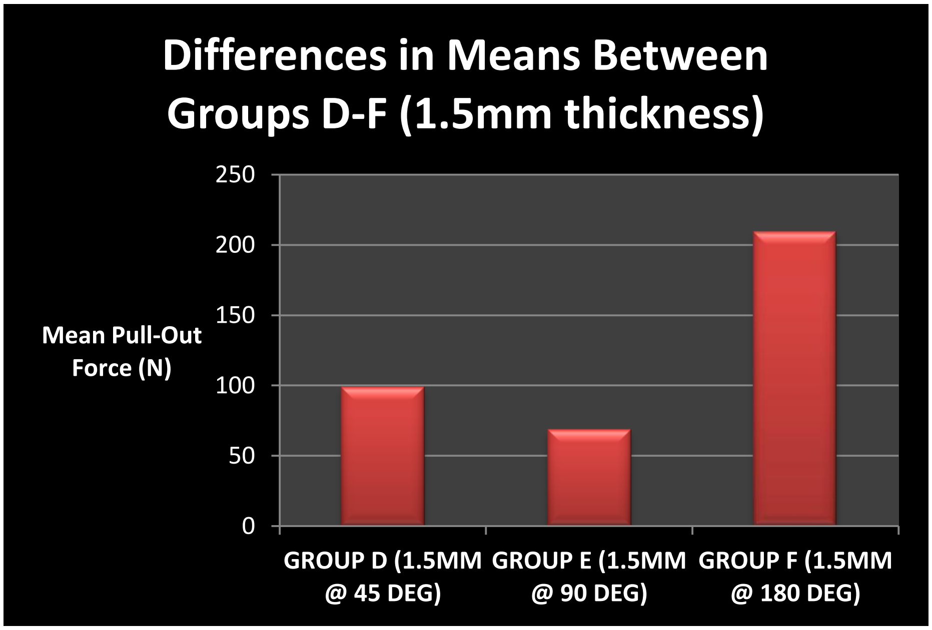


Figure 3.6 Difference in mean pull-out strength between the three angles of force vector application for 1.5mm cortical bone thickness groups

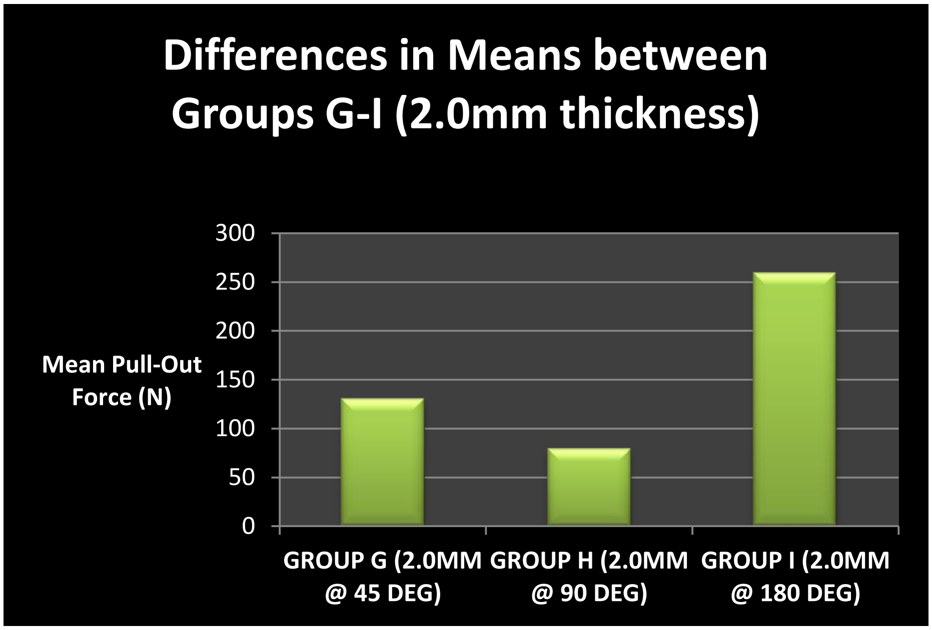


Figure 3.7 Difference in mean pull-out strength between the three angles of force vector application for 2.0mm cortical bone thickness groups

3.1.3. Difference in pull-out strength between angles by cortical bone thickness

The greatest pull-out forces observed were in the 2.0mm x 180^0 group, and the lowest pull out forces observed were in the 1.0mm x 90^0 group The observations within the groups having the same cortical bone thickness with differing angles of force vector application are presented. Between the 1.0mm synthetic cortical bone thickness groups, significant differences in mean pull-out strength were observed between groups A and C and B and C at the $p<0.05$ level (Groups A-C). Among the 1.5mm cortical bone thickness groups (Groups D-F), the differences between pull-out strength were significant for all angles of force application ($p<0.05$) (groups D-F). Between the 2.0mm synthetic cortical bone thickness groups (Groups G-I), significant differences in mean pull-out strength were noted for each of the 3 angles of force application at the $p<0.05$ level.

Between the groups, there were no significant differences observed in mean pull-out force between Group A (1.0mm x 45^0) and Groups E (1.5mm x 90^0) and H (2.0mm x

90^0). Additionally there were no significant differences in mean pull-out force observed between any of the 90^0 force vector groups (Groups B, E, and H). Lastly, there was no significant difference observed between Groups C (1.0mm x 180^0) and G (2.0mm x 45^0) at $p<0.05$.

All other differences in mean pull-out strength between groups of depth by angle were found to be significant at $p<0.05$. The maximum mean pull-out force observed was 258.38N. This corresponded to group I (2.0mm thickness, 180^0), and the minimum mean force needed for TAD pull out was 67.11N. This was found in group B (1.0mm thickness, 90^0). (Appendix G)

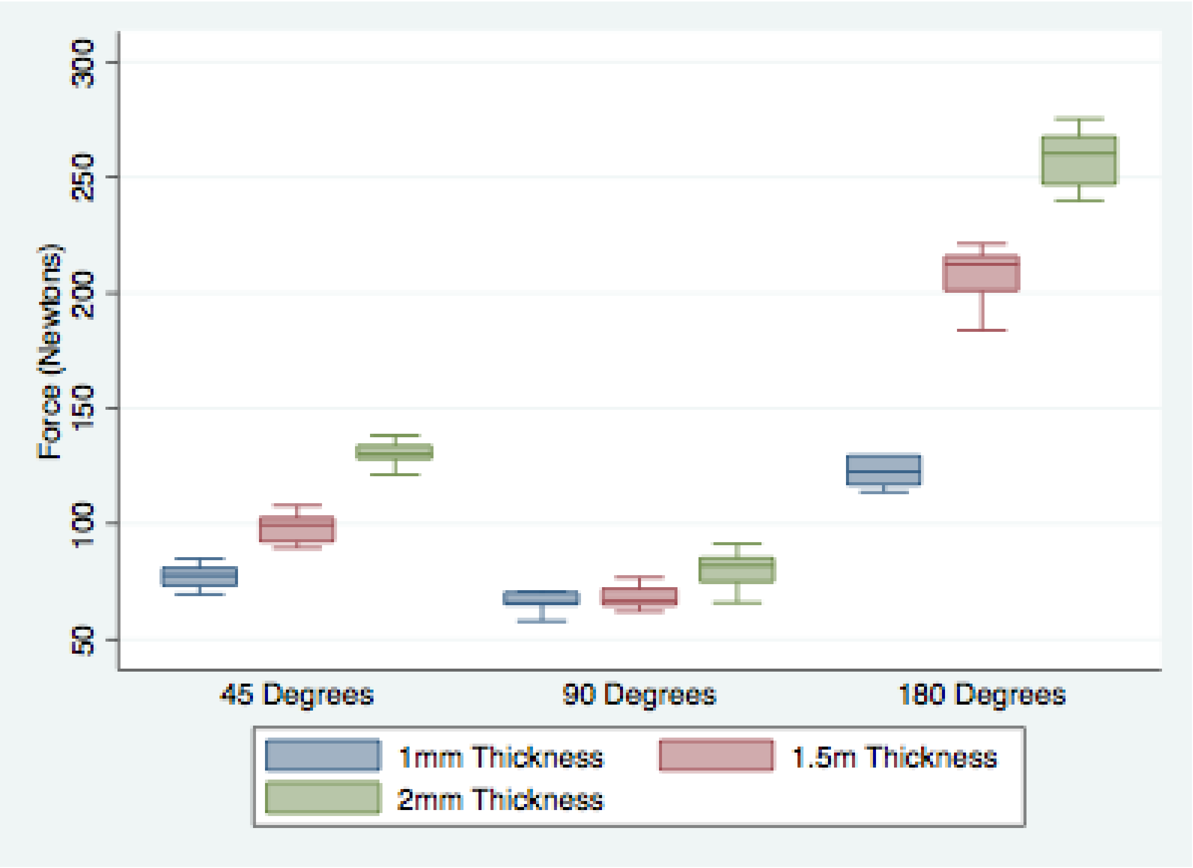


Figure 3.8. Differences in mean pull-out strength of angle by cortical bone thickness

3.2. Results of the Survey

The survey used in this study was intended to describe how practitioners in the state of Florida are using TADs, and to determine the factors which they felt are most applicable to their success and/or failure. The responses were qualitatively evaluated, and the results are presented below. (Appendix C)

3.2.1. Question 1: How many years have you been practicing orthodontics?

Of the 50 respondents, 49 answered this question and 1 skipped the question. 51% of those who answered this question stated that they have been practicing for greater than 20 years,14.3% said that have been practicing from 1-5 years and 16-20 years respectively, 12.2% have been practicing from 11-15 years, and 8.2% have been practicing 6-10 years.

3.2.2. Question 2: Do you use temporary anchorage devices in your practice?

Of the 50 survey respondents, 49 answered this question and 1 skipped the question. 53.1% of those who answered the question stated that they used TADs, but infrequently, 24.5% stated that they have never used them, 20.4% stated that they use them often, and 2.0% stated that they have used them, but are no longer doing so.

3.2.3. Question 3: Have you learned to use temporary anchorage devices?

Of the 50 survey respondents, 50 answered this question. 60.0% stated that they learned to used them via instruction, 16.0% stated that they learned on their own, 18.0% stated that they have not learned to use them and are no interested in doing so, and 6.0% stated that they have not learned to use them but plan on doing so.

3.2.4. Question 4: How did you learn to use temporary anchorage devices?

Of the 50 respondents, 50 answered this question. 60.0% of the respondents stated that they learned to use TADs through continuing education courses, 10.0% stated that they learned during their residency, 2.0% stated that they learned in study clubs, 2.0% stated that they learned through trial and error, and 26.0% stated that the answer choices provided were not applicable to their learning experiences.

3.2.5. Question 5: Approximately how many of your treatment plans involve the use of temporary anchorage devices?

Of the 50 survey respondents, 38 answered this question and 12 skipped it. Out of the 38 responses, 100% stated that they use TADs in 0-10% of their treatment plans.

3.2.6. Question 6: Do you prefer pre-drilling or self-drilling temporary anchorage devices?

Of the 50 survey respondents, 36 answered this question and 14 skipped it. Out of the 36 responses, 97.2% stated that they prefer self-drilling TADs, while 2.8% stated that they prefer pre-drilling TADs.

3.2.7. Question 7: Based on the answer above, what is your primary reason for choosing one over the other?

Of the 50 respondents, 36 answered this question and 14 skipped it. All of those who answered the previous question answered this question as well. Out of the 36 responses, 63.9% stated that they prefer their technique due to greater ease of placement, 27.8% felt that their chosen technique provides greater TAD stability, 25.0% felt that their preferred technique resulted in less patient discomfort, and 8.3% (n=3) cited other reasons.

The 3 respondents who chose “other” wrote in responses. One did not place TADs, but if they did they would not use a pilot hole, one found no reason to pre-drill unless bone is too dense, and one stated that it was a matter of safety, citing that it is easier to evaluate patient response when placing self-drilling miniscrews, and that the operator can better tell when root contact has occurred.

3.2.8. Question 8: Do you tend to utilize temporary anchorage devices more often for direct or indirect anchorage?

Of the 50 survey respondents, 36 answered this question and 14 skipped it. Out of the 36 responses, 47.2% stated that they used TADs mostly for applying direct anchorage to the dentition, 27.8% stated that they use them as a means of establishing both direct and indirect anchorage equally, and 25.0% stated that they use them mostly for indirect anchorage.

3.2.9. Question 9: Approximately what level of force do you place on temporary anchorage devices?

Of the 50 survey respondents, 36 answered this question and 14 skipped it. Forty-seven point two percent of those who answered the question reported that they apply 151-250 grams to the TADs, 36.1% reported that they apply between 51-150 grams, 11.1% reported that they apply between 25-50 grams, 5.6% reported that they apply between 251-350 grams, and none reported using greater than 350 grams of force.

3.2.10. Question 10: For what treatment plans do you find temporary anchorage devices most useful?

Of the 50 survey respondents, 37 answered this question and 13 skipped it. The respondents were permitted multiple answers for this question. Of the responses, 64.9% indicated that TADs were most useful for cases involving molar intrusion, 59.5% for molar protraction, 24.3% for anterior retraction, 16.2% for anterior intrusion, and 8.1% for other reasons.

The 4 respondents who answered “other” wrote in their answers. Two found miniscrews to be most effective for molar distalization, one found them to be most effective for maximum anchorage control when needed, and one found them to be most applicable when used in conjunction with Class III reverse-pull headgear.

3.2.11. Of the following 6 criteria, please rank in order of importance the factors you perceive to be most applicable to temporary anchorage device failure.

Of the 50 survey respondents, 35 answered this question and 15 skipped it. Of the 35 who answered this question. For the most important factor associated with TAD failure, the responses were as follows: 45.7% (n=16) for placement location, 42.9% (n=15) for operator error, 16.7% (n=5) for vector of force applied to the TAD, 8/8% (n=3) for the level of forces applied to the TADs, and 2.9% (n=1) indicated that root proximity and placement angulation were the most important factors respectively

For the least important factors associated with TAD failure, the responses were as follows: 35.3% (n=12) cited root proximity, 14.7% (n-5) cited forces applied to the TADs, 13.3% (n=4) cited the vector of force applied to the TADs, 8.6% (n=3) cited operator error, and 5.9% (n=2) stated that placement angulation was the least important factor.

Please see (Figure X) for a detailed display of the results.

3.2.12. At what sites of placement have you experience the highest failure rates of temporary anchorage devices?

Of the 50 survey respondents, 31 answered this question and 19 skipped it. Regarding the site which practitioners feel they experience the highest failure rates, the answers were as follows: 51.9% for the posterior maxilla (distal to the cuspids), 30.8% cited the posterior mandible (distal to cuspids), 13.0% cited the anterior mandible mesial to the cuspids), 10.2% cited the anterior maxilla (mesial to the cuspids), and 0.0% cited the palate.

For the site from which practitioners indicated that they experience the greatest success, the responses were as follows: 81.8% for the palate, 15.0% (for the anterior maxilla, 7.7% for the posterior mandible, 4.3% for the anterior mandible, and 3.7% for the posterior maxilla.

Chapter 4: Discussion

The ability to establish and obtain orthodontic anchorage is a prerequisite for efficient orthodontic treatment without complications.[6,7,60] Its importance has lent itself to countless scholarly articles, research studies, and textbook chapters. A practitioner's ability to utilize different anchorage schemes effectively imparts them with the ability to control their desired dentoskeletal movements and carry out treatment both efficiently and predictably. Incorporation of bone-borne temporary anchorage devices (TADs) into the orthodontists' armamentarium has allowed a high level of control that eliminates the need for patient compliance while simplifying treatment mechanics.

In addition to anchorage control, the use of temporary anchorage devices has made many dentoskeletal movements that were once extremely difficult to obtain quite predictable. An example of this can be seen with buccal segment intrusion in anterior open bite malocclusions. As with anchorage, an enhanced ability to control the placement, location, and types of forces to particular segments can be achieved with TADs.

When utilizing TADs in practice, their ability to perform as desired lies in their ability stability under the various forces applied to them, and to remain stable throughout the duration of treatment in which they are incorporated. Multiple studies have shown that the main determinant of TAD stability is created by mechanical interlocking of the screw threads with the surrounding cortical and cancellous bone. This is described as "primary stability[14]," and is similar to that found when one screws a nail into wood. High levels of osseointegration, such as those needed for successful endosseous implant success, are not necessary with TADs, considering they are placed with the intent of atraumatic removal at a future date.[39] and have been shown to remain stable under a continuous 200g force for 6.5 months with as little as 15.33% osseointegration.[3]

The gold-standards for testing the primary stability of TADs are pull-out testing[47] and insertion torque testing.[26,61] Increased forces needed to pull out TADs indicates a higher level of primary stability. Concurrently, TADs designed to resist the highest forces are the most desirable. Part 1 of this study aimed to determine how variations in both synthetic cortical bone thickness and the vector of forces applied to TADs relative to their long axes affect their pull-out strength. Synthetic bone analogs were used in order to allow control over variables such as bone density, local variations in cortical bone thickness, and variations in bone contour. While the findings are not intended to indicate the levels of force to be used in orthodontic therapy, they are intended to provide data that can increase the predictability of TAD success based on how and where these forces are applied.

Synthetic bone analogs were used instead of cadaver bones in order to minimize the variability of thickness, density, and quality. While the synthetic bone blocks are manufactured with consistent thickness and physical properties, cadaver bone has been shown to vary significantly in these properties between sites on the same bone.[34,36 ,62] Additionally, synthetic bone is not subject to dessication and quality change over time, which has been experienced when working with cadaver bone.[62] While the synthetic bone blocks do not present all of the same properties as human bone, their uniformity provides a reliable and consistent medium for controlled biomechanical testing. The ASTM F-1839-08 materials testing standards states that the uniformity and consistent properties of rigid polyurethane foam make it an ideal material for comparative testing of bones screws and other medical devices and instruments. Based on these statements, multiple studies on the mechanical properties of TADs have utilized Sawbones synthetic bone analogs as their test medium.[9, 39, 41] Therefore, this synthetic bone was chosen for this study.

The forces which elicited pull-out in each of the groups were in excess of those utilized in orthodontic tooth movement. However, this study evaluated TAD stability solely from a mechanical perspective. The study was not designed take into account factors such as human error, individual patient variation, or biological factors that can influence clinical TAD stability. Further discussion of the study design, results, and other implications for orthodontists using TADs follows.

4.1. Specific Aim 1: To determine how variations in synthetic cortical bone thickness affect the pull-out strength of temporary anchorage devices

To determine how variations in synthetic cortical bone thickness affected the pull-out strength of TADs, placement angle, angle of force application, and rate of force application were controlled. Findings indicate that for the 3 angles applied herein, a thickness of 2.0mm of synthetic cortical bone thickness yielded the highest average pull out strength, while 1.0mm of synthetic cortical bone yielded the lowest. This is in accordance with the results of multiple studies, indicating that placing TADs in areas with greater cortical bone thickness results in greater primary stability.[40, 41, 42, 43] The most plausible reason for this is that in areas of increase cortical bone thickness, there is inherently greater bone-implant contact. This in turn, results in a greater resistance to pull out due to increased mechanical interlocking of the screw threads. Based on this information, practitioners should place miniscrews in the areas of greatest cortical bone thickness.

4.2. Specific Aim 2: To determine how variations in the vector of force application relative to the long axis of the TADs affects the pull-out strength of temporary anchorage devices

To determine how variations in the angle of force vector relative to the long axis of the TADs affects their pull-out strength, the placement angle, thickness of synthetic cortical bone, and rate of force application were controlled. The findings indicated that the angle of force application yielded significant differences in pull-out strengths within the 1.0 and 2.0mm groups, with the 180^0 angles resulting in the greatest resistance to pull-out. The lowest pull-out strength was noted when the TADs were pulled at an angle of 90^0 relative to their long axes. No significant differences were found between the varying angles of force application in each of the 1.5mm cortical thickness groups.

These results concurred with the results of studies by Pickard and Petrey,[47,62], in which TADs exhibited the greatest pull-out strength oriented more parallel with the line of force applied. Similarly, the results of this study indicated that applying forces more parallel to the long axes of the TADs resulted in increased stability, independent of miniscrew orientation. This may occur for two reasons. Stresses on the bone surrounding the TAD were more evenly distributed with parallel forces, whereas increased stresses build around the apex and neck when forces are applied at an angle, and when forces are applied parallel to the long axes, the full expression of thread engagement occurs.

4.3. Specific Aim 3: To determine how both synthetic cortical bone thickness and the vector of force application combined affect the pull-out strength of temporary anchorage devices

An evaluation of the pull-out strength variations caused by the thickness of cortical bone and angulations of force application combined revealed that by altering each of the variables together, differing observations are noted. Referring to the results of the variables individually, it can be seen that increasing the cortical bone thickness and applying forces parallel to the long axes of the TADs results in the greatest primary stability.

This is very idealistic, because when treatment planning, the location of TAD placement is dictated by the mechanics needed to illicit the desired dentoskeletal movements. Due to this, it is often impossible to place the TAD in the area of greatest cortical bone thickness, or in a location that offers a parallel vector of force. Utilizing cone-beam tomography, measurements of buccal cortical plate thickness has been found to be greatest in the premolar-molar areas of both the maxilla and mandible, with increasing thickness as one moves apically from the alveolar crest.[34]

When analyzing how altering thickness by angle affects the pull-out strength of TADs, the data reveals that alterations in either placement location or angle of force application may be made to increase stability based on estimations of cortical bone thickness from these studies. For instance, no significant differences in pullout strength were observed between 1.0mm of cortical bone thickness with a force angled at 45^0 and both 1.5 and 2.0mm of cortical bone thickness with forces applied at 90^0. Additionally, there were no significant differences between any of the groups tested at a pull force vector at 90^0, or between 1.0mm at 180^0 and 2.0mm at 45^0.

Based on this information, if a practitioner is placing a TAD in the anterior region, which has cortical bone thicknesses ranging from 0.82-1.27mm in the mandible and 0.75-1.17mm in the maxilla[50], angling the TADs more parallel to the vector of force may offset some of the decreased stability due to thinner cortical bone. Additionally, when placing the TADs palatally, their location along either the alveolar ridge or parasagittal areas can be best determined by the direction of force that will be applied to the TAD.

4.4. Discussion of survey results

The survey was intended to provide insight to the clinical experiences practicing orthodontists in Florida have had with TADs. Fifty of the 389 (12.8%) orthodontists who were solicited for participation in the survey responded to at least one question. This response rate is in accordance with the results of previous web-based survey studies by Hardigan and Buschang *et al*, which reported that response rates for surveys sent via electronic mail were 11%,and 6% repectively.[54, 63] The results of this survey reflect the clinical experiences of those who answered the survey, and cannot be generalized to include those of all orthodontists.

Over half of those who responded to this survey have practiced for more than 20 years, and over 75% have practiced for 11 years or more. While this may have been due to the demographic makeup of orthodontic practitioners Florida, this may also be due a greater interest in the topic by those who were not trained in the use of TADs during their residency years. A majority stated that they learned how to use TADs in continuing education course, whereas only 10% stated they learned during their residency. In their 2008 survey, Buschang *et al.* found similar demographic results, with 58.5% of respondents having at least 15 years of practice experience, and 8.4% having been trained in their use during residency.[54] These results show that the use of TADs is becoming more widely used, and that those who have graduated from residency within the past decade are likely to have received formal training in their application.

All of the survey respondents stated that they utilize TADs in 0-10% of their cases. Although the usefulness and versatility of TADs has been extensively cited in the literature, it seems as though their use in practice is more limited. This may indicate that TADs are generally used when there is a true benefit to them, or that those who answered the question do not find them very useful. TADs do not serve to eliminate the need for biomechanical and tooth borne considerations for the development of anchorage. Rather, practitioners seem to use them as an adjunctive treatment option to be used when obvious tooth borne or extra-oral anchorage is not an option. The respondents indicated that TADs were most commonly applied in cases involving either molar protraction or molar intrusion. This differs from the results obtained a survey conducted in 2009, which noted that the majority of practitioners find TADs most useful for anterior en masse retraction.[64] A majority of appliances utilized for obtaining anchorage (headgear, Nance, etc.) produce a distal holding force which assists anterior retraction Means to maintain the position of anterior teeth for molar protraction have fewer appliance options (i.e. reverse pull headgear), thus relying more on time consuming archwire or auxiliary modifications(elastics, uprighting springs, torquing springs, etc). TADs offer another option if placed anteriorly if when applying a pull force, and posteriorly when applying a push force. Regarding the forces applied to the dentition from TADs, 47.2% applied, by their estimation, 151-250g, and 36.1% applied 51-150g in the majority of their cases.

These forces fall within the optimal ranges for bodily tooth movement and root uprighting, which are 70-120g and 50-100g respectively.[65] This concurs with the information provided, in that a majority of orthodontists utilized TADs predominantly for molar protraction and anterior retraction, both of which involved bodily movement and root uprighting.

Over 97% of the respondents preferred self-drilling TADs, citing that this choice was based predominantly on a greater ease of placement, and less patient discomfort. Other studies have shown that a majority of orthodontists place their own TADs,[57] and the self-drilling design allows their placement without any site preparation or other inter-specialty referral. Most orthodontic practices are open and do not isolate individual patients to allow the preferred private and calm patient environment. Therefore, the preference for the one-step placement technique afforded by the self-drilling design is not surprising.

When questioned about the factors that played the greatest role in implant failure, the greatest response was placement location, while operator error was ranked second among the most commonly perceived reasons for failure. These results reflect the thoughts of only those who responded, as operator error likely plays a significant role in miniscrew failure. When miniscrews are placed manually, without the aid of a torque gauge or guide stent, there is increased potential for excessive forces applied and wobble of the TADs during placement. This, in turn, may result in decreased TAD longevity. The following question in the survey added to this response, revealing that practitioners ranked the posterior maxilla as the site in which they experienced the highest rates of failure, and the palate as being the site in which the highest success rates were observed.

These results conflict with those noted in one study[22]which noted that the posterior maxilla had higher success rates than the posterior mandible. In their study, the authors suggest that, while the posterior mandible has a thicker cortical plate, higher failure rates are noted. Regarding the vector of force being applied to the miniscrews, only 16.7% of respondents cited that this was the primary factor associated with miniscrew failure. While this may not be the perception of the majority, this shows that practitioners are considering the way in which they are applying forces to the miniscrews, and determining the significance of this particular factor in miniscrew success was the primary goal of the laboratory portion of this study

4.5. Conclusions

The current study evaluated how cortical bone thickness and the angle of force relative to the long axis of TADs affected primary stability. The perspective of Florida orthodontists on their experiences with TADS was evaluated via a survey. The results show that the greater cortical bone thickness, combined with an angulation of force paralleling the long axis of TADs resulted in the greatest resistance to pull out. While the forces observed in this study were in excess of those routinely used for orthodontic tooth movement[65], the results can be applied to improve the predictability of TAD stability.

4.6. Limitations

The current study was performed under laboratory conditions with synthetic bone substrates. Individual variation among human subjects, potential for bone remodeling, and other factors associated with TAD success and failure where inherently not accounted for. The findings are to be used only when clinically applicable. Incorporation of the data obtained in this study in future clinical treatment planning is not intended to be mutually exclusive from the other factors associated with miniscrew stability or other reliable modes of anchorage development. Rather, this data was intended to provide information to help improve the success in the use of TADs.

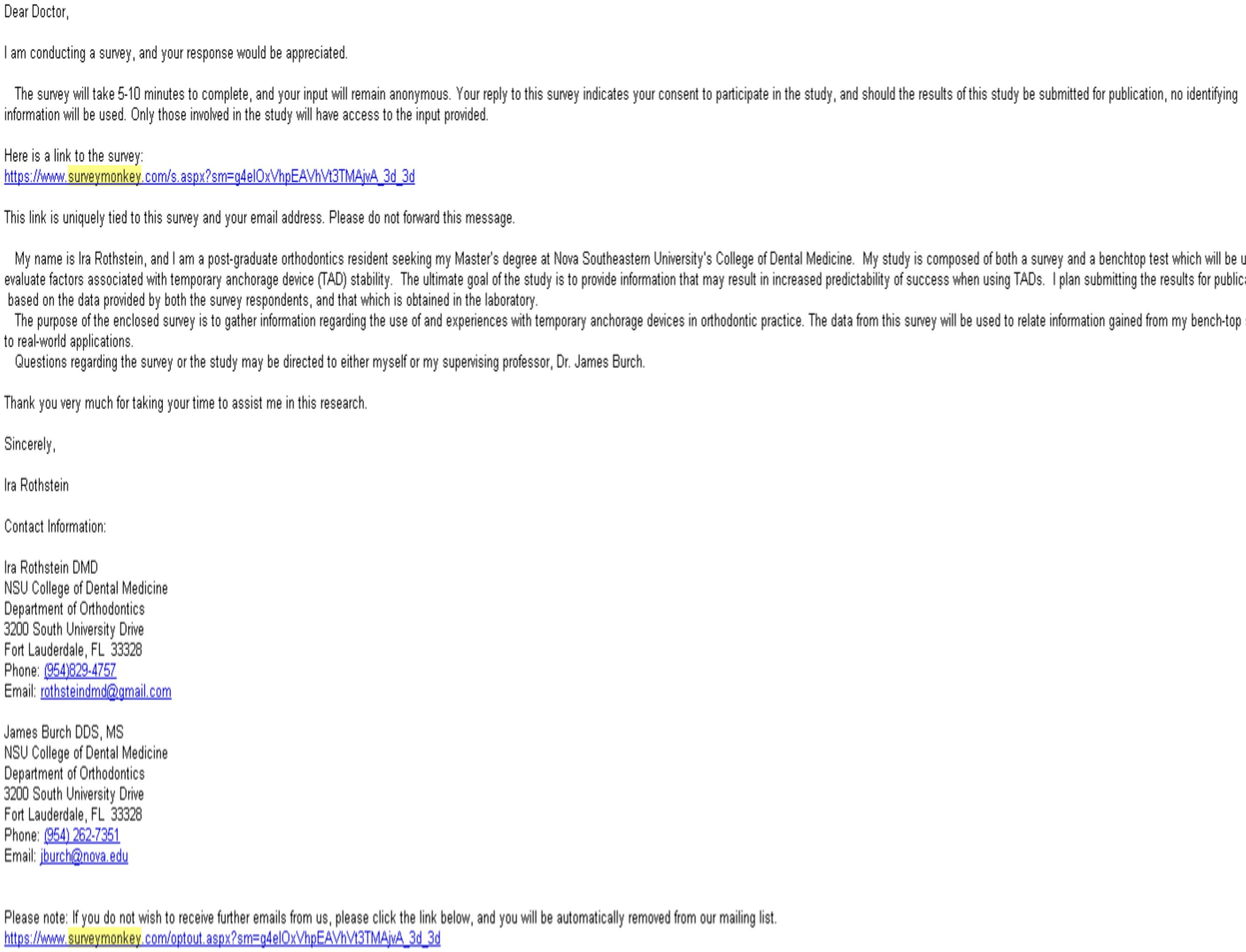
Additionally, the results of the survey are indicative only of orthodontists who responded to the survey. While the sample was intended to be representative of all practicing orthodontists, but due to differing regional, national, and international trends, the information obtained can only be assumed to represent 1/8 of orthodontists only in the state of Florida.

4.7. Future implications

While TADs are a relatively new tool in the orthodontist's armamentarium, there has been a significant amount of research published regarding both the optimal environment for placement, and the design of TADs. A majority of these studies have been performed on non-human mammals, such as beagle dogs, cadaver bones, and synthetic bone blocks. While studies of the past indicate up to a 95% success rate with TAD use. A future split mouth prospective intra-oral in-vivo study of TADs is recommended.

Appendices

Appendix A. Survey Cover Letter



Dear Doctor,

I am conducting a survey, and your response would be appreciated.

The survey will take 5-10 minutes to complete, and your input will remain anonymous. Your reply to this survey indicates your consent to participate in the study, and should the results of this study be submitted for publication, no identifying information will be used. Only those involved in the study will have access to the input provided.

Here is a link to the survey:
https://www.surveymonkey.com/s.aspx?sm=g4elOxVhpEAVhVt3TMAjvA_3d_3d

This link is uniquely tied to this survey and your email address. Please do not forward this message.

My name is Ira Rothstein, and I am a post-graduate orthodontics resident seeking my Master's degree at Nova Southeastern University's College of Dental Medicine. My study is composed of both a survey and a benchtop test which will be u
evaluate factors associated with temporary anchorage device (TAD) stability. The ultimate goal of the study is to provide information that may result in increased predictability of success when using TADs. I plan submitting the results for public
based on the data provided by both the survey respondents, and that which is obtained in the laboratory.

The purpose of the enclosed survey is to gather information regarding the use of and experiences with temporary anchorage devices in orthodontic practice. The data from this survey will be used to relate information gained from my bench-top
to real-world applications.

Questions regarding the survey or the study may be directed to either myself or my supervising professor, Dr. James Burch.

Thank you very much for taking your time to assist me in this research.

Sincerely,

Ira Rothstein

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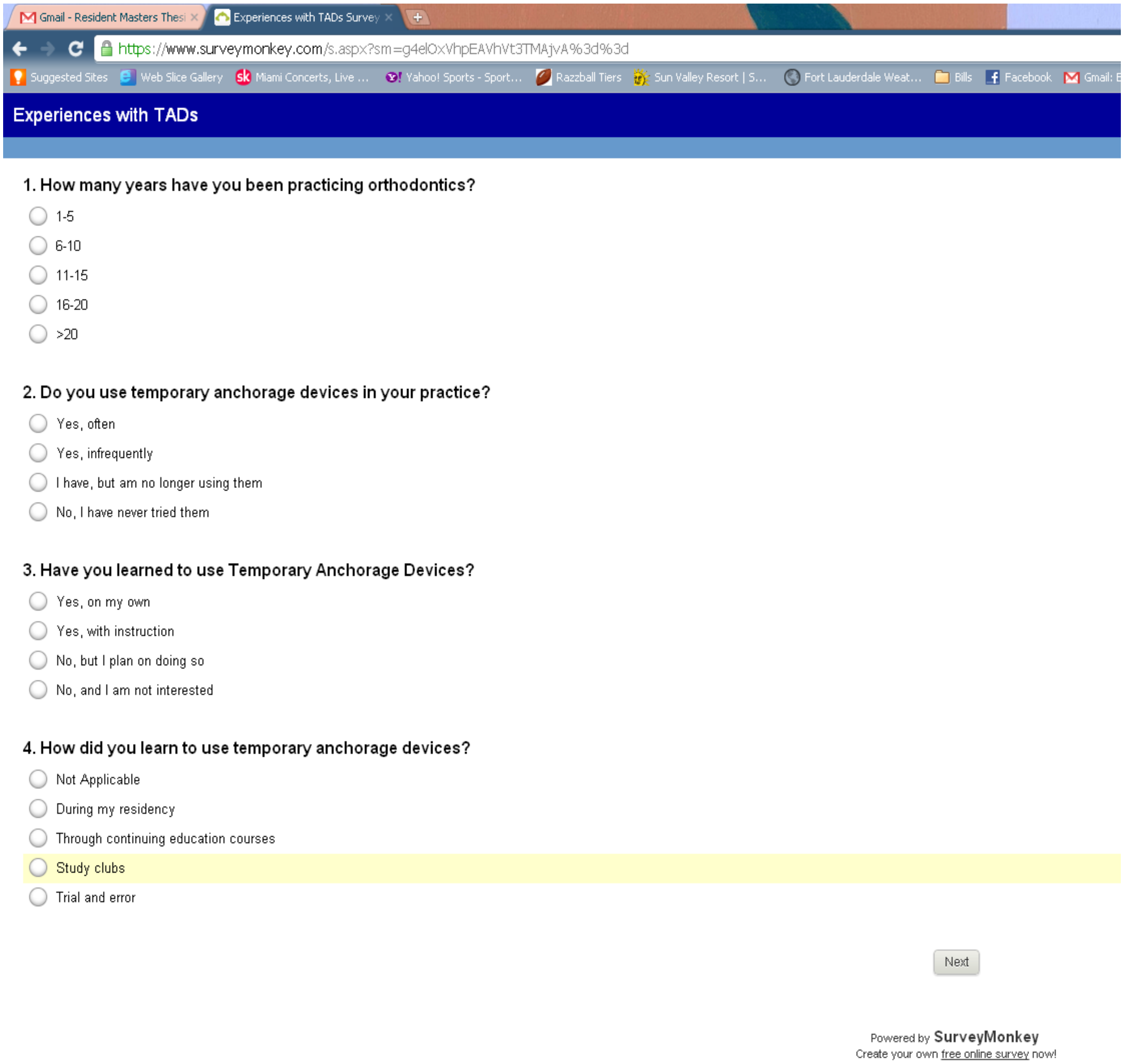
Please note: If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list.
https://www.surveymonkey.com/optout.aspx?sm=g4elOxVhpEAVhVt3TMAjvA_3d_3d

Appendix B. Online Survey



Experiences with TADs

1. How many years have you been practicing orthodontics?

○ 1-5
○ 6-10
○ 11-15
○ 16-20
○ >20

2. Do you use temporary anchorage devices in your practice?

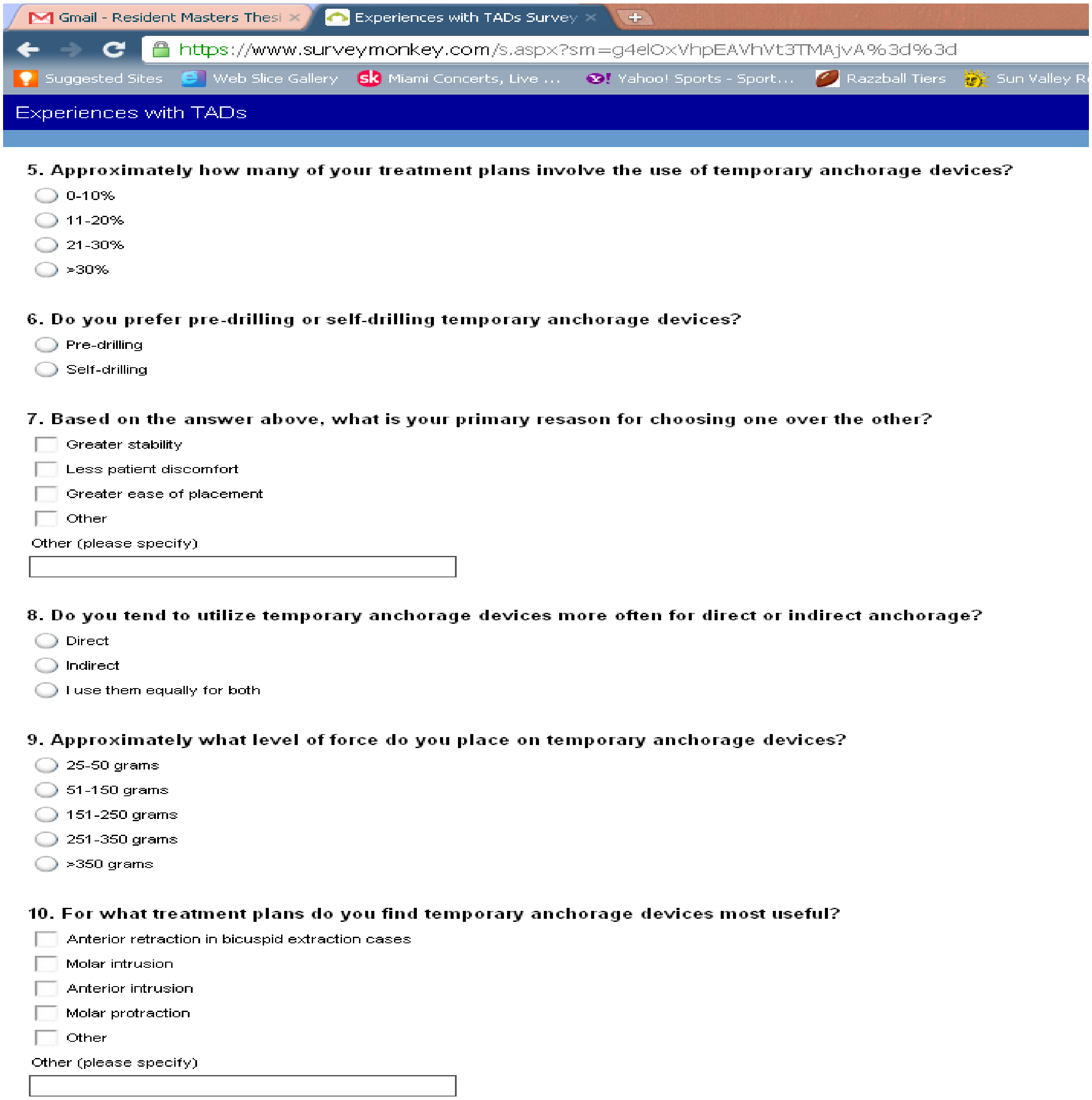
○ Yes, often
○ Yes, infrequently
○ I have, but am no longer using them
○ No, I have never tried them

3. Have you learned to use Temporary Anchorage Devices?

○ Yes, on my own
○ Yes, with instruction
○ No, but I plan on doing so
○ No, and I am not interested

4. How did you learn to use temporary anchorage devices?

○ Not Applicable
○ During my residency
○ Through continuing education courses
○ Study clubs
○ Trial and error



Experiences with TADs

5. Approximately how many of your treatment plans involve the use of temporary anchorage devices?

○ 0-10%
○ 11-20%
○ 21-30%
○ >30%

6. Do you prefer pre-drilling or self-drilling temporary anchorage devices?

○ Pre-drilling
○ Self-drilling

7. Based on the answer above, what is your primary resason for choosing one over the other?

☐ Greater stability
☐ Less patient discomfort
☐ Greater ease of placement
☐ Other

Other (please specify)

8. Do you tend to utilize temporary anchorage devices more often for direct or indirect anchorage?

○ Direct
○ Indirect
○ I use them equally for both

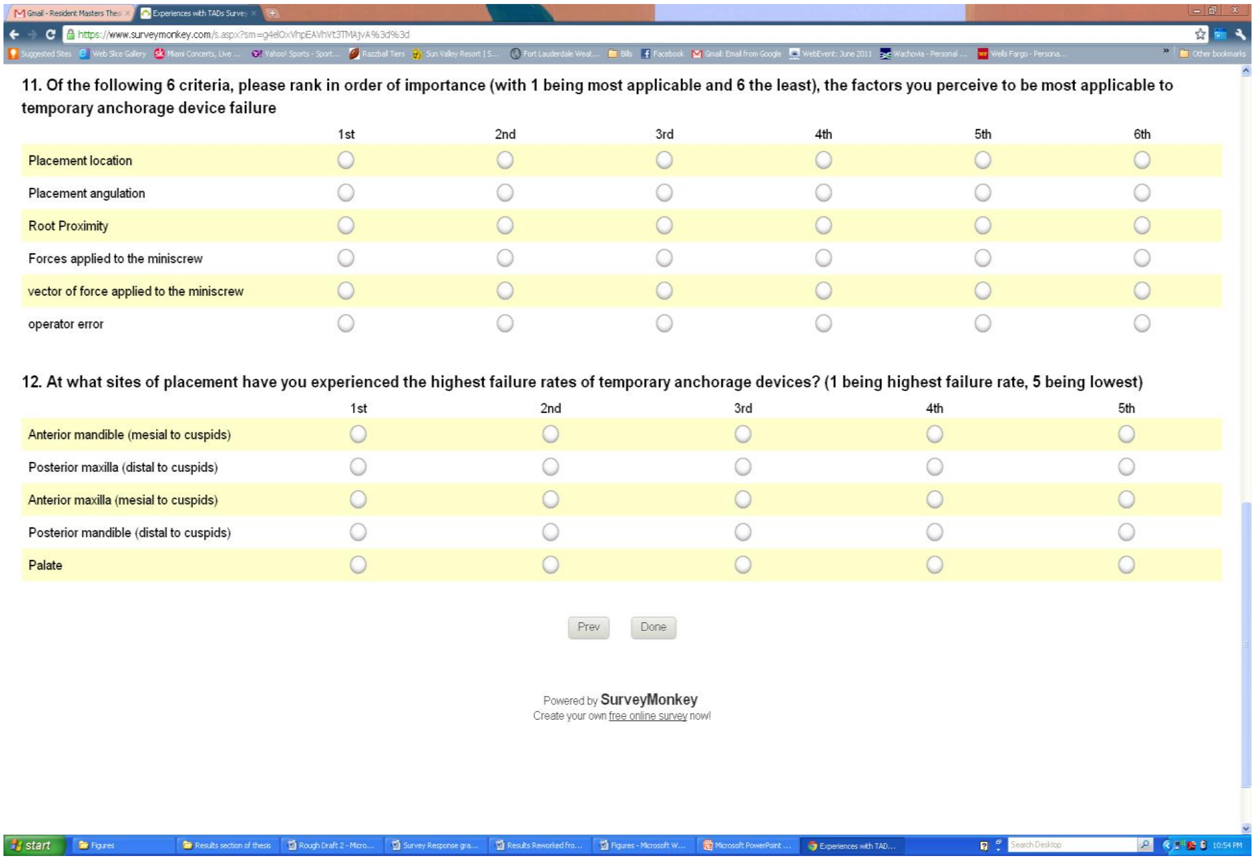
9. Approximately what level of force do you place on temporary anchorage devices?

○ 25-50 grams
○ 51-150 grams
○ 151-250 grams
○ 251-350 grams
○ >350 grams

10. For what treatment plans do you find temporary anchorage devices most useful?

☐ Anterior retraction in bicuspid extraction cases
☐ Molar intrusion
☐ Anterior intrusion
☐ Molar protraction
☐ Other

Other (please specify)



11. Of the following 6 criteria, please rank in order of importance (with 1 being most applicable and 6 the least), the factors you perceive to be most applicable to temporary anchorage device failure

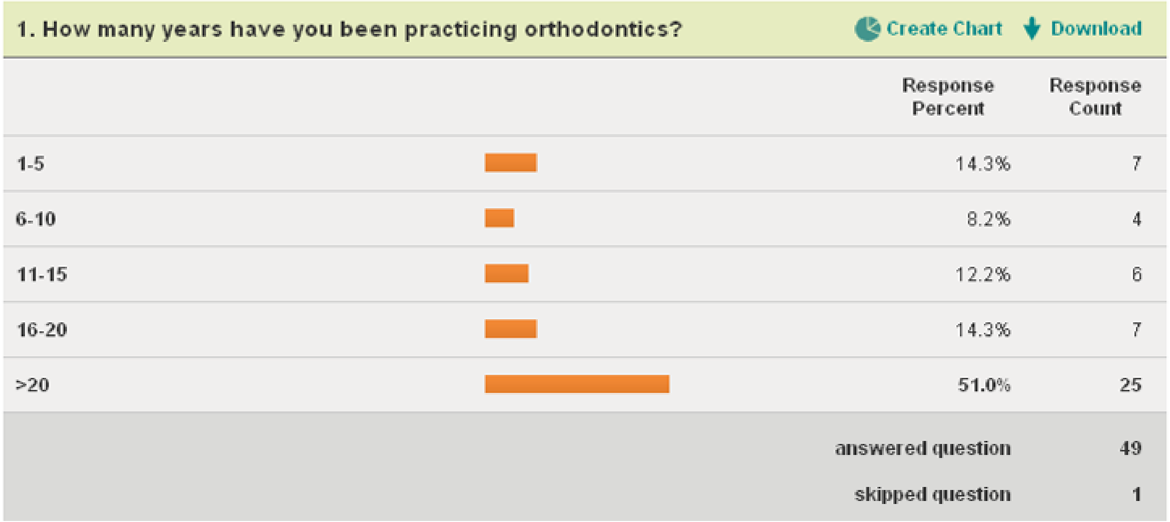
	1st	2nd	3rd	4th	5th	6th
Placement location	○	○	○	○	○	○
Placement angulation	○	○	○	○	○	○
Root Proximity	○	○	○	○	○	○
Forces applied to the miniscrew	○	○	○	○	○	○
vector of force applied to the miniscrew	○	○	○	○	○	○
operator error	○	○	○	○	○	○

12. At what sites of placement have you experienced the highest failure rates of temporary anchorage devices? (1 being highest failure rate, 5 being lowest)

	1st	2nd	3rd	4th	5th
Anterior mandible (mesial to cuspids)	○	○	○	○	○
Posterior maxilla (distal to cuspids)	○	○	○	○	○
Anterior maxilla (mesial to cuspids)	○	○	○	○	○
Posterior mandible (distal to cuspids)	○	○	○	○	○
Palate	○	○	○	○	○

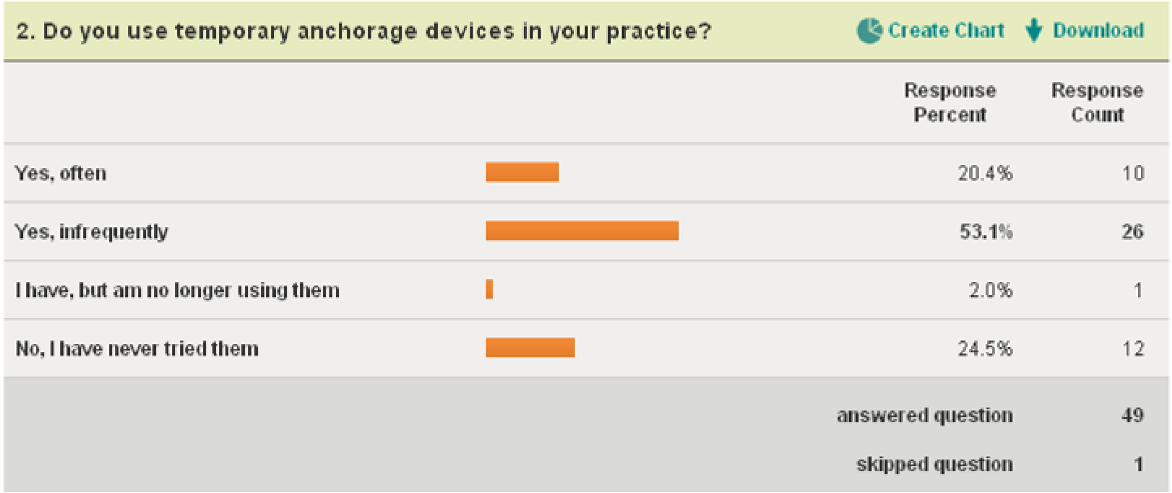
Powered by SurveyMonkey
Create your own free online survey now!

Appendix C. Survey Responses



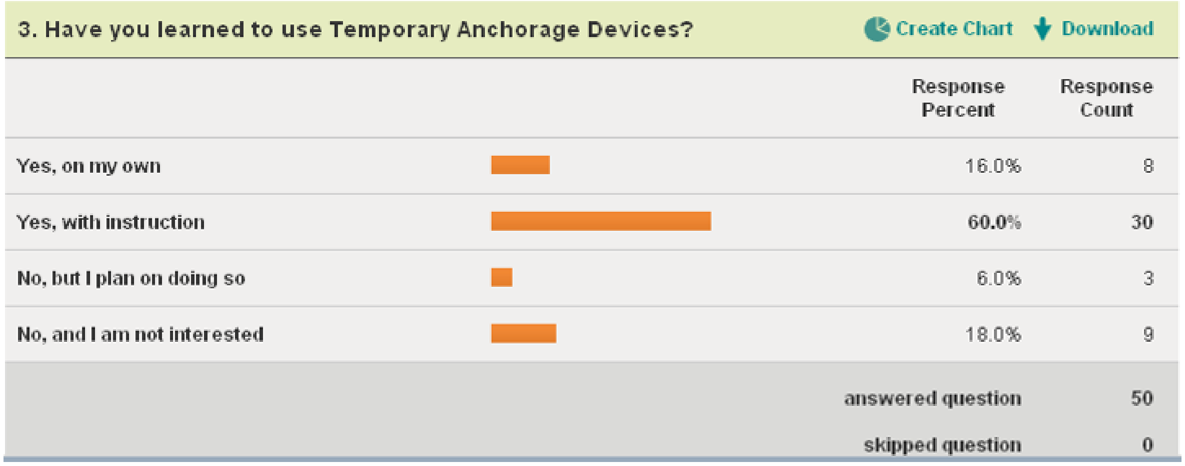
1. How many years have you been practicing orthodontics?

	Response Percent	Response Count
1-5	14.3%	7
6-10	8.2%	4
11-15	12.2%	6
16-20	14.3%	7
>20	**51.0%**	**25**
	answered question	49
	skipped question	1



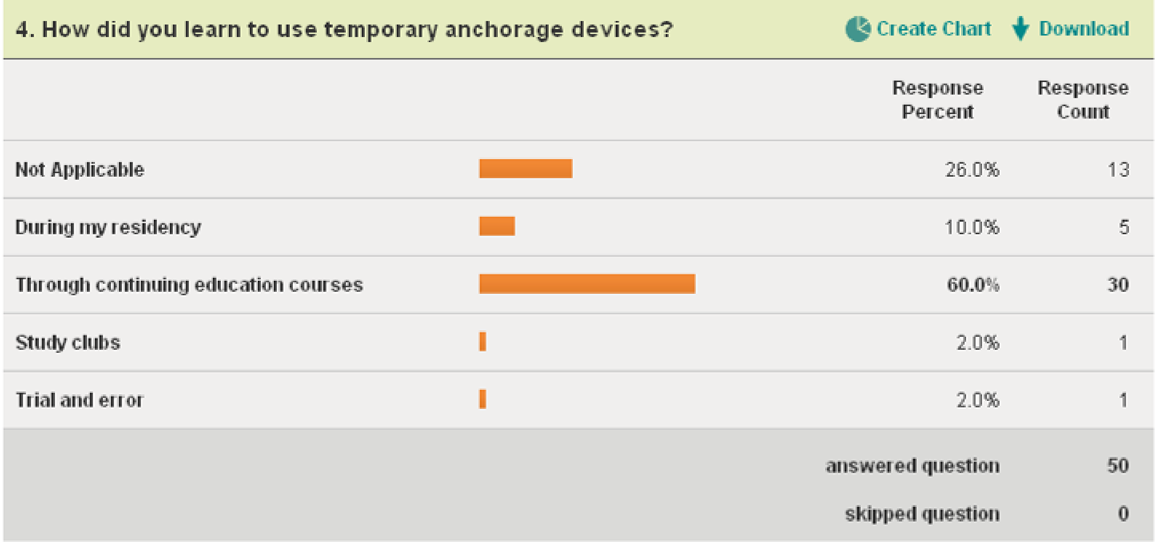
2. Do you use temporary anchorage devices in your practice?

	Response Percent	Response Count
Yes, often	20.4%	10
Yes, infrequently	**53.1%**	**26**
I have, but am no longer using them	2.0%	1
No, I have never tried them	24.5%	12
	answered question	49
	skipped question	1



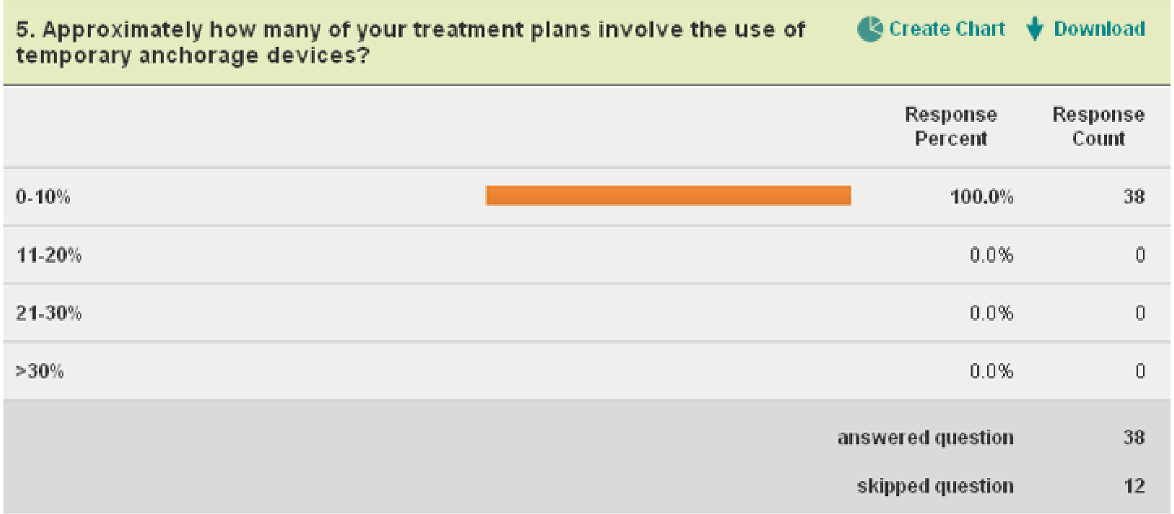
3. Have you learned to use Temporary Anchorage Devices?

	Response Percent	Response Count
Yes, on my own	16.0%	8
Yes, with instruction	**60.0%**	**30**
No, but I plan on doing so	6.0%	3
No, and I am not interested	18.0%	9
	answered question	50
	skipped question	0



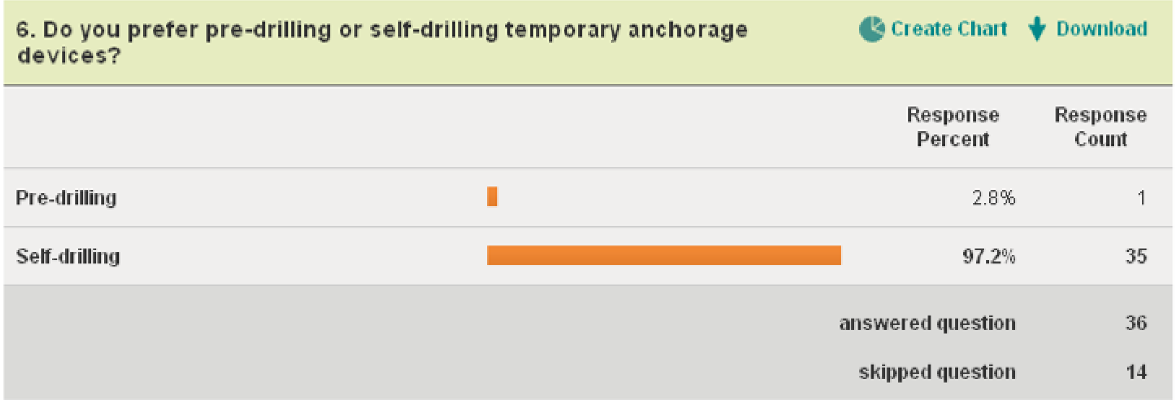
4. How did you learn to use temporary anchorage devices?

	Response Percent	Response Count
Not Applicable	26.0%	13
During my residency	10.0%	5
Through continuing education courses	60.0%	30
Study clubs	2.0%	1
Trial and error	2.0%	1
	answered question	50
	skipped question	0



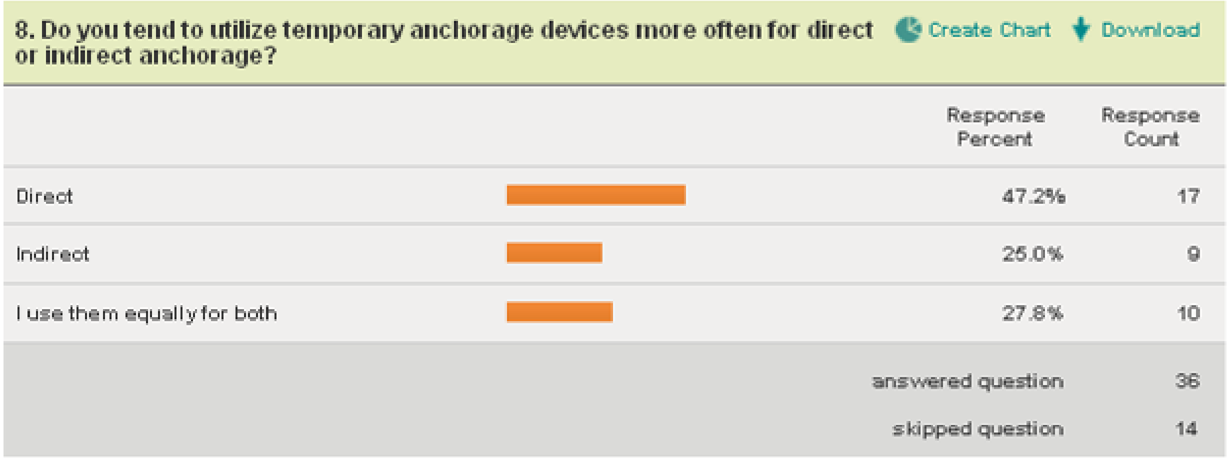
5. Approximately how many of your treatment plans involve the use of temporary anchorage devices?

	Response Percent	Response Count
0-10%	100.0%	38
11-20%	0.0%	0
21-30%	0.0%	0
>30%	0.0%	0
	answered question	38
	skipped question	12



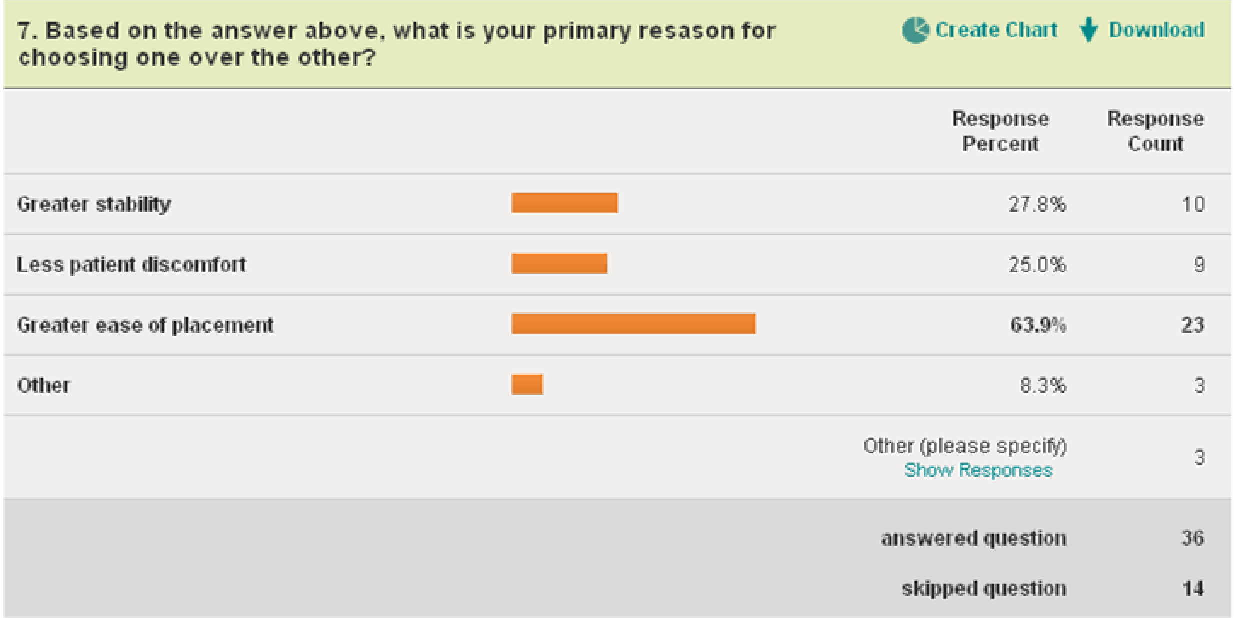
6. Do you prefer pre-drilling or self-drilling temporary anchorage devices?

	Response Percent	Response Count
Pre-drilling	2.8%	1
Self-drilling	97.2%	35
	answered question	36
	skipped question	14



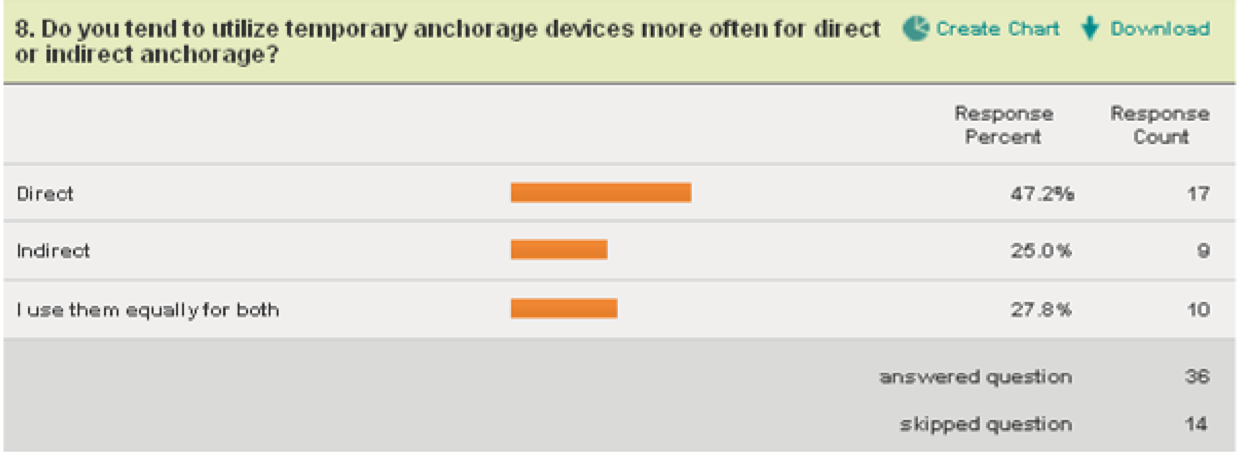
8. Do you tend to utilize temporary anchorage devices more often for direct or indirect anchorage?

	Response Percent	Response Count
Direct	47.2%	17
Indirect	25.0%	9
I use them equally for both	27.8%	10
answered question		36
skipped question		14



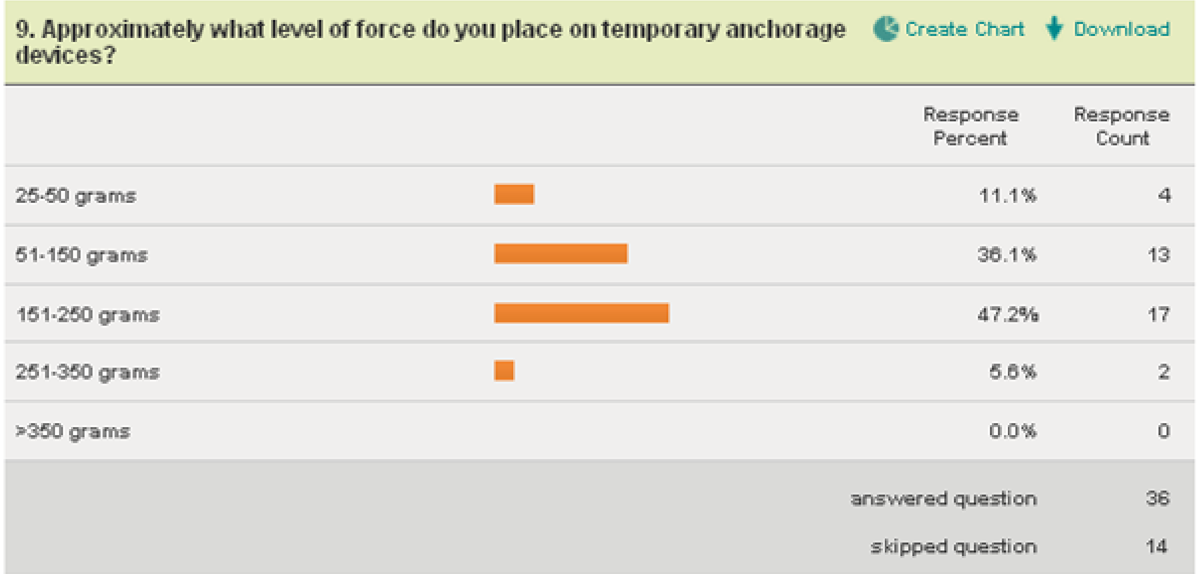
7. Based on the answer above, what is your primary resason for choosing one over the other?

	Response Percent	Response Count
Greater stability	27.8%	10
Less patient discomfort	25.0%	9
Greater ease of placement	63.9%	23
Other	8.3%	3
Other (please specify)		3
answered question		36
skipped question		14



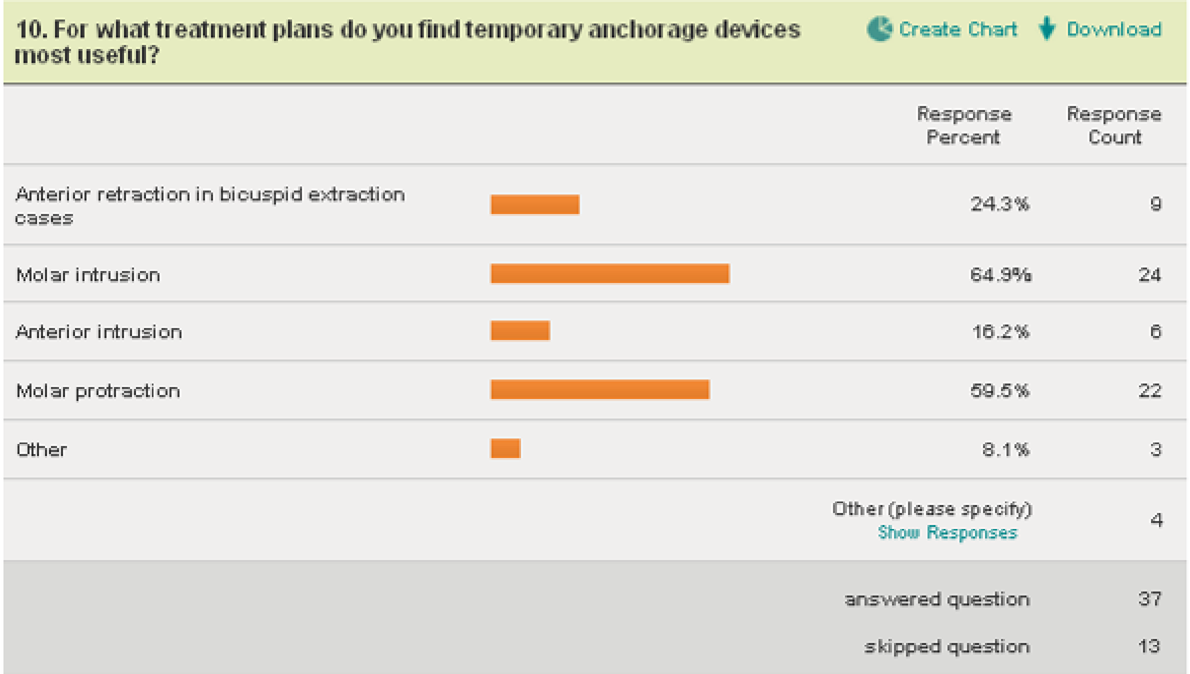
8. Do you tend to utilize temporary anchorage devices more often for direct or indirect anchorage?

	Response Percent	Response Count
Direct	47.2%	17
Indirect	25.0%	9
I use them equally for both	27.8%	10
answered question		36
skipped question		14



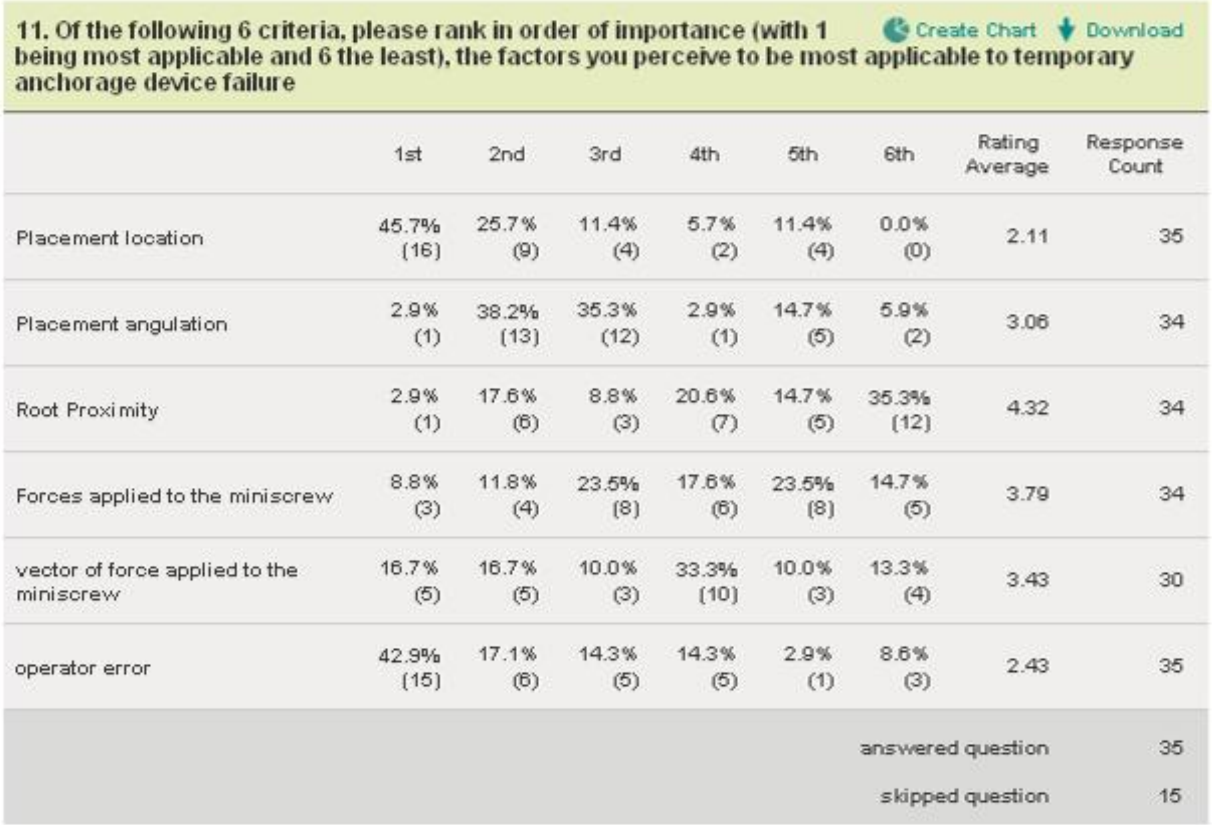
9. Approximately what level of force do you place on temporary anchorage devices?

	Response Percent	Response Count
25-50 grams	11.1%	4
51-150 grams	36.1%	13
151-250 grams	47.2%	17
251-350 grams	5.6%	2
>350 grams	0.0%	0
	answered question	36
	skipped question	14



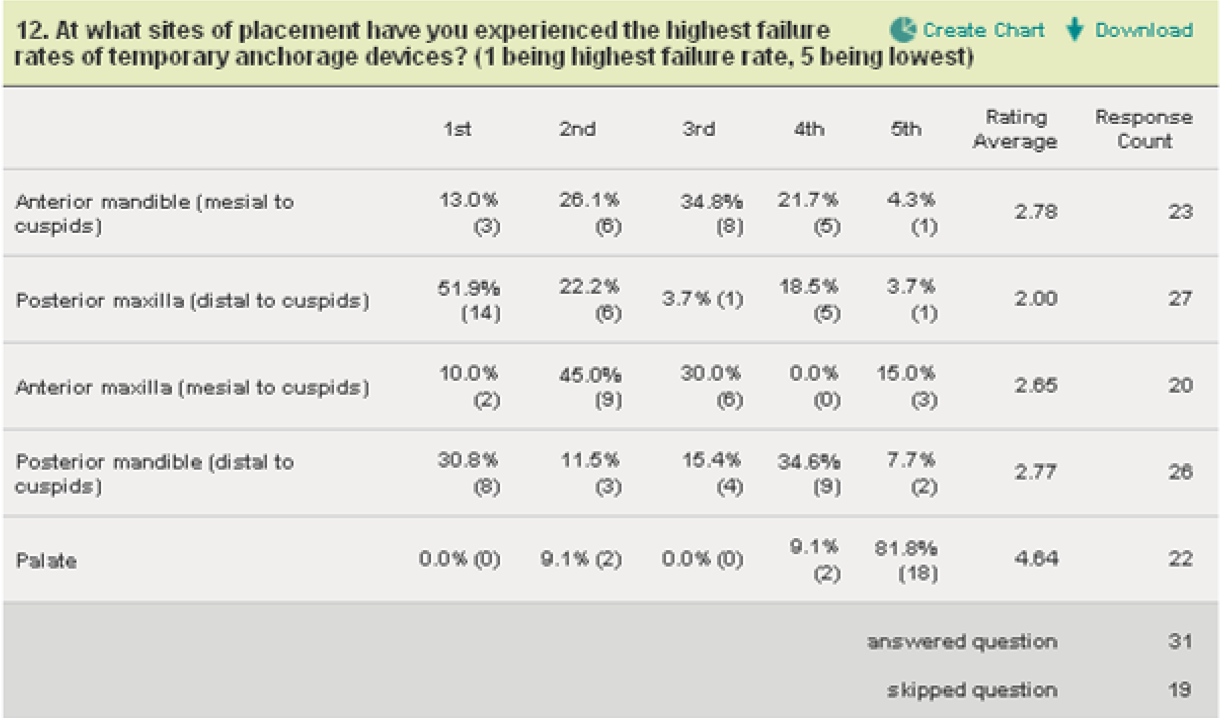
10. For what treatment plans do you find temporary anchorage devices most useful?

	Response Percent	Response Count
Anterior retraction in bicuspid extraction cases	24.3%	9
Molar intrusion	64.9%	24
Anterior intrusion	16.2%	6
Molar protraction	59.5%	22
Other	8.1%	3
	Other (please specify)	4
	answered question	37
	skipped question	13



11. Of the following 6 criteria, please rank in order of importance (with 1 being most applicable and 6 the least), the factors you perceive to be most applicable to temporary anchorage device failure

	1st	2nd	3rd	4th	5th	6th	Rating Average	Response Count
Placement location	45.7% (16)	25.7% (9)	11.4% (4)	5.7% (2)	11.4% (4)	0.0% (0)	2.11	35
Placement angulation	2.9% (1)	38.2% (13)	35.3% (12)	2.9% (1)	14.7% (5)	5.9% (2)	3.06	34
Root Proximity	2.9% (1)	17.6% (6)	8.8% (3)	20.6% (7)	14.7% (5)	35.3% (12)	4.32	34
Forces applied to the miniscrew	8.8% (3)	11.8% (4)	23.5% (8)	17.6% (6)	23.5% (8)	14.7% (5)	3.79	34
vector of force applied to the miniscrew	16.7% (5)	16.7% (5)	10.0% (3)	33.3% (10)	10.0% (3)	13.3% (4)	3.43	30
operator error	42.9% (15)	17.1% (6)	14.3% (5)	14.3% (5)	2.9% (1)	8.6% (3)	2.43	35
							answered question	35
							skipped question	15



12. At what sites of placement have you experienced the highest failure rates of temporary anchorage devices? (1 being highest failure rate, 5 being lowest)

	1st	2nd	3rd	4th	5th	Rating Average	Response Count
Anterior mandible (mesial to cuspids)	13.0% (3)	26.1% (6)	34.8% (8)	21.7% (5)	4.3% (1)	2.78	23
Posterior maxilla (distal to cuspids)	51.9% (14)	22.2% (6)	3.7% (1)	18.5% (5)	3.7% (1)	2.00	27
Anterior maxilla (mesial to cuspids)	10.0% (2)	45.0% (9)	30.0% (6)	0.0% (0)	15.0% (3)	2.65	20
Posterior mandible (distal to cuspids)	30.8% (8)	11.5% (3)	15.4% (4)	34.6% (9)	7.7% (2)	2.77	26
Palate	0.0% (0)	9.1% (2)	0.0% (0)	9.1% (2)	81.8% (18)	4.64	22
						answered question	31
						skipped question	19

Appendix D: Raw Data from Bench top study

Effects Test

Source	DF	L-R ChiSquare	Prob>ChiSq
Group	2	163.354	<0.0001
Degree	2	280.281	<0.0001
Group*Degree	4	124.899	<0.0001

Descriptive Statistics:

Cortical Bone Thickness		**Degree Pull Force Vectors**		
		45 Degrees	**90 Degrees**	**180 Degrees**
1.0 mm	**Mean (N)**	76.62	67.11	129.06
	SD	5.31	6.51	29.46
	Min (N)	69.38	57.93	81.38
	Max (N)	84.71	82.76	184.28
1.5 mm	**Mean (N)**	98.30	68.29	209.10
	SD	6.48	4.95	11.37
	Min (N)	89.51	62.13	183.75
	Max (N)	107.89	76.62	221.13
2.0 mm	**Mean (N)**	129.96	79.43	258.38
	SD	5.20	7.98	12.03
	Min (N)	121.38	65.70	240.00
	Max (N)	138.13	91.20	275.45

Appendix E: Cortical bone thickness differences.

Degrees	Degrees	Difference	Lower 95% CI	Upper 95% CI	Difference
2.0 mm	1.0 mm	64.99	57.39	72.60	*P < 0.05
1.5 mm	1.0 mm	34.30	26.70	41.91	*P < 0.05
2.0 mm	1.5 mm	30.69	23.08	38.30	*P < 0.05

Appendix F: Angle of pull force differences.

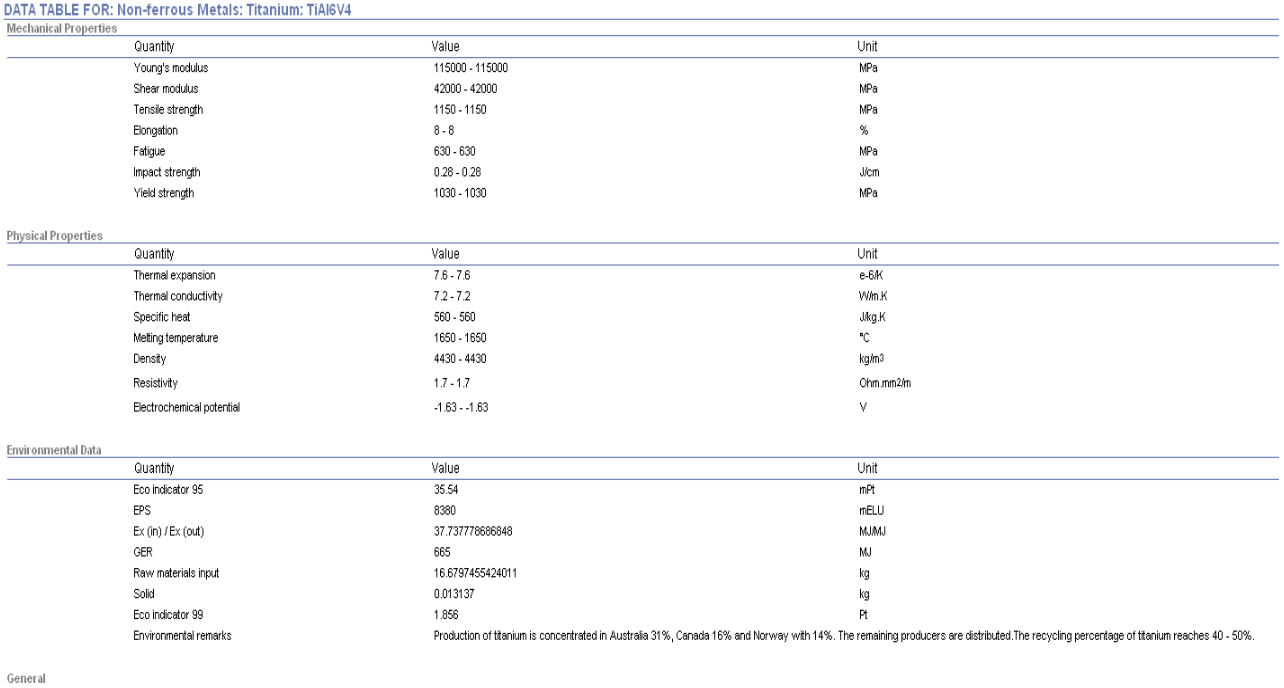
Group	Group	Difference	Lower 95% CI	Upper 95% CI	Difference
180 Degrees	90 Degrees	127.24	119.63	134.85	*P < 0.05
180 Degrees	45 Degrees	97.22	89.61	104.83	*P < 0.05
45 Degrees	90 Degrees	30.02	22.41	37.63	*P < 0.05

Appendix G: Angle by Thickness differences

Group	Group	Difference	Lower 95% CI	Upper 95% CI	Difference
2.0 mm,180 Degrees	1.5 mm,45 Degrees	191.28	173.68	208.87	*P < 0.05
2.0 mm,180 Degrees	1.5 mm,90 Degrees	190.09	172.50	207.68	*P < 0.05
2.0 mm,180 Degrees	1.0 mm,45 Degrees	181.76	164.17	199.35	*P < 0.05
2.0 mm,180 Degrees	1.5 mm,180 Degrees	178.95	161.36	196.54	*P < 0.05
2.0 mm,180 Degrees	1.0 mm,90 Degrees	160.08	142.49	177.67	*P < 0.05
2.0 mm,90 Degrees	1.5 mm,45 Degrees	142.00	124.41	159.59	*P < 0.05
2.0 mm,90 Degrees	1.5 mm,90 Degrees	140.81	123.22	158.40	*P < 0.05
2.0 mm,90 Degrees	1.0 mm,45 Degrees	132.48	114.89	150.07	*P < 0.05
2.0 mm,90 Degrees	1.5 mm,180 Degrees	129.67	112.08	147.26	*P < 0.05
2.0 mm,180 Degrees	2.0 mm,45 Degrees	129.32	111.73	146.91	*P < 0.05
2.0 mm,180 Degrees	1.0 mm,180 Degrees	128.42	110.83	146.01	*P < 0.05
2.0 mm,90 Degrees	1.0 mm,90 Degrees	110.80	93.21	128.39	*P < 0.05
2.0 mm,90 Degrees	2.0 mm,45 Degrees	80.04	62.45	97.63	*P < 0.05
2.0 mm,90 Degrees	1.0 mm,180 Degrees	79.15	61.56	96.74	*P < 0.05
1.0 mm,180 Degrees	1.5 mm,45 Degrees	62.85	45.26	80.44	*P < 0.05
2.0 mm,45 Degrees	1.5 mm,45 Degrees	61.96	44.37	79.55	*P < 0.05
1.0 mm,180 Degrees	1.5 mm,90 Degrees	61.67	44.08	79.26	*P < 0.05
2.0 mm,45 Degrees	1.5 mm,90 Degrees	60.77	43.18	78.36	*P < 0.05
1.0 mm,180 Degrees	1.0 mm,45 Degrees	53.34	35.75	70.93	*P < 0.05
2.0 mm,45 Degrees	1.0 mm,45 Degrees	52.44	34.85	70.03	*P < 0.05
1.0 mm,180 Degrees	1.5 mm,180 Degrees	50.53	32.94	68.12	*P < 0.05

2.0 mm,45 Degrees	1.5 mm,180 Degrees	49.63	32.04	67.22	*$P < 0.05$
2.0 mm,180 Degrees	2.0 mm,90 Degrees	49.28	31.69	66.87	*$P < 0.05$
1.0 mm,180 Degrees	1.0 mm,90 Degrees	31.65	14.06	49.24	*$P < 0.05$
1.0 mm,90 Degrees	1.5 mm,45 Degrees	31.20	13.61	48.79	*$P < 0.05$
2.0 mm,45 Degrees	1.0 mm,90 Degrees	30.76	13.17	48.35	*$P < 0.05$
1.0 mm,90 Degrees	1.5 mm,90 Degrees	30.01	12.42	47.60	*$P < 0.05$
1.0 mm,90 Degrees	1.0 mm,45 Degrees	21.68	4.09	39.27	*$P < 0.05$
1.0 mm,90 Degrees	1.5 mm,180 Degrees	18.88	1.28	36.47	*$P < 0.05$
1.5 mm,180 Degrees	1.5 mm,45 Degrees	12.32	-5.27	29.91	NS
1.5 mm,180 Degrees	1.5 mm,90 Degrees	11.14	-6.45	28.73	NS
1.0 mm,45 Degrees	1.5 mm,45 Degrees	9.51	-8.08	27.10	NS
1.0 mm,45 Degrees	1.5 mm,90 Degrees	8.33	-9.26	25.92	NS
1.5 mm,180 Degrees	1.0 mm,45 Degrees	2.81	-14.78	20.40	NS
1.5 mm,90 Degrees	1.5 mm,45 Degrees	1.18	-16.41	18.77	NS
1.0 mm,180 Degrees	2.0 mm,45 Degrees	0.90	-16.70	18.49	NS

Appendix H: Physical Properties of Ti 6AL-4V.



DATA TABLE FOR: Non-ferrous Metals: Titanium: TiAl6V4

Mechanical Properties

Quantity	Value	Unit
Young's modulus	115000 - 115000	MPa
Shear modulus	42000 - 42000	MPa
Tensile strength	1150 - 1150	MPa
Elongation	8 - 8	%
Fatigue	630 - 630	MPa
Impact strength	0.28 - 0.28	J/cm
Yield strength	1030 - 1030	MPa

Physical Properties

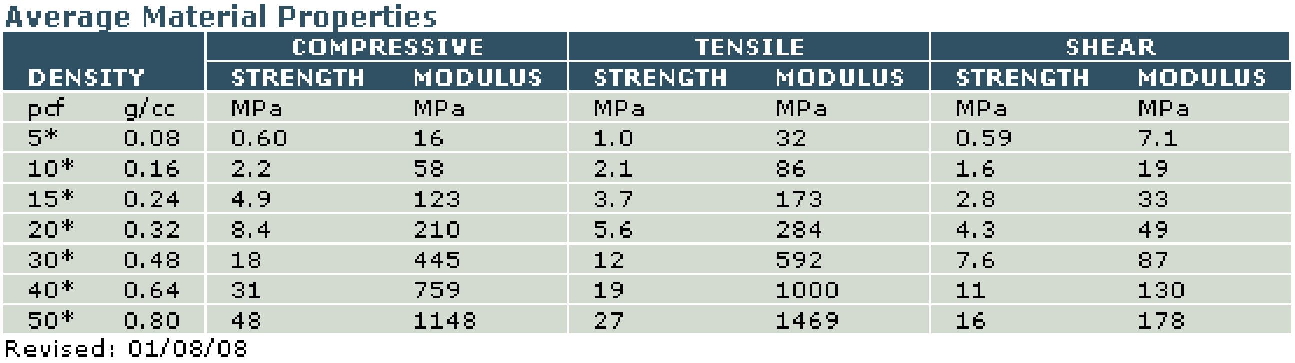
Quantity	Value	Unit
Thermal expansion	7.6 - 7.6	e-6/K
Thermal conductivity	7.2 - 7.2	W/m.K
Specific heat	560 - 560	J/kg.K
Melting temperature	1650 - 1650	°C
Density	4430 - 4430	kg/m^3
Resistivity	1.7 - 1.7	Ohm.mm^2/m
Electrochemical potential	-1.63 - -1.63	V

Environmental Data

Quantity	Value	Unit
Eco indicator 95	35.54	mPt
EPS	8380	mELU
Ex (in) / Ex (out)	37.737778686848	MJ/MJ
GER	665	MJ
Raw materials input	16.6797455424011	kg
Solid	0.013137	kg
Eco indicator 99	1.856	Pt
Environmental remarks	Production of titanium is concentrated in Australia 31%, Canada 16% and Norway with 14%. The remaining producers are distributed.The recycling percentage of titanium reaches 40 - 50%.	

General

Appendix I: Physical properties of Sawbones (40pcf cortical layer, 15pcf cancellous layer)

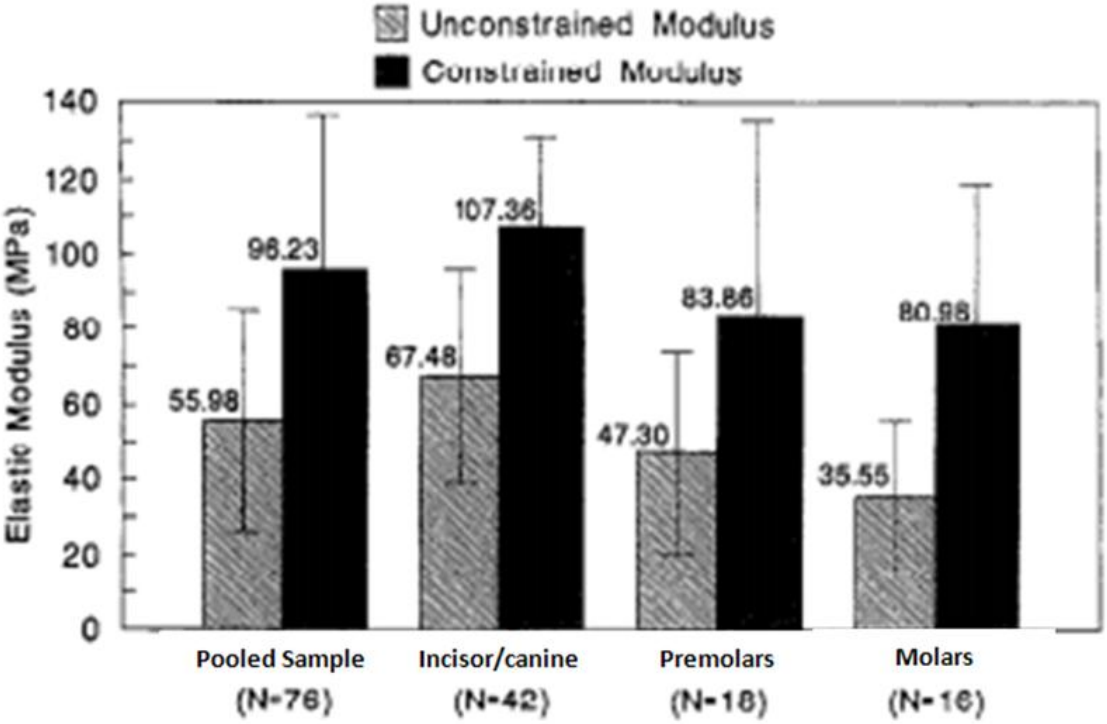


Average Material Properties

DENSITY		COMPRESSIVE		TENSILE		SHEAR	
		STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH	MODULUS
pcf	g/cc	MPa	MPa	MPa	MPa	MPa	MPa
5*	0.08	0.60	16	1.0	32	0.59	7.1
10*	0.16	2.2	58	2.1	86	1.6	19
15*	0.24	4.9	123	3.7	173	2.8	33
20*	0.32	8.4	210	5.6	284	4.3	49
30*	0.48	18	445	12	592	7.6	87
40*	0.64	31	759	19	1000	11	130
50*	0.80	48	1148	27	1469	16	178

Revised: 01/08/08

Appendix J: Material properties mandibular bone



Elastic modulus values for constrained (with cortical plates present) and unconstrained (without cortical plates present) test conditions for the human mandibular trabecular bone. The elastic modulus value in region 1 (anterior) is significantly higher than in regions 2 and 3($p<0.05$)

Appendix K: Material properties of maxillary bone[66]

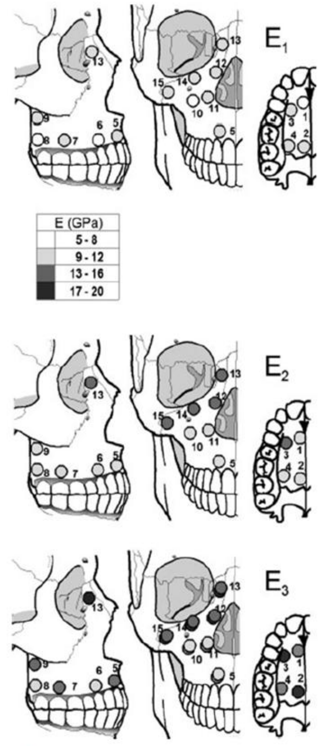


Fig. 5. Elastic moduli at each site in three views are represented by shade.

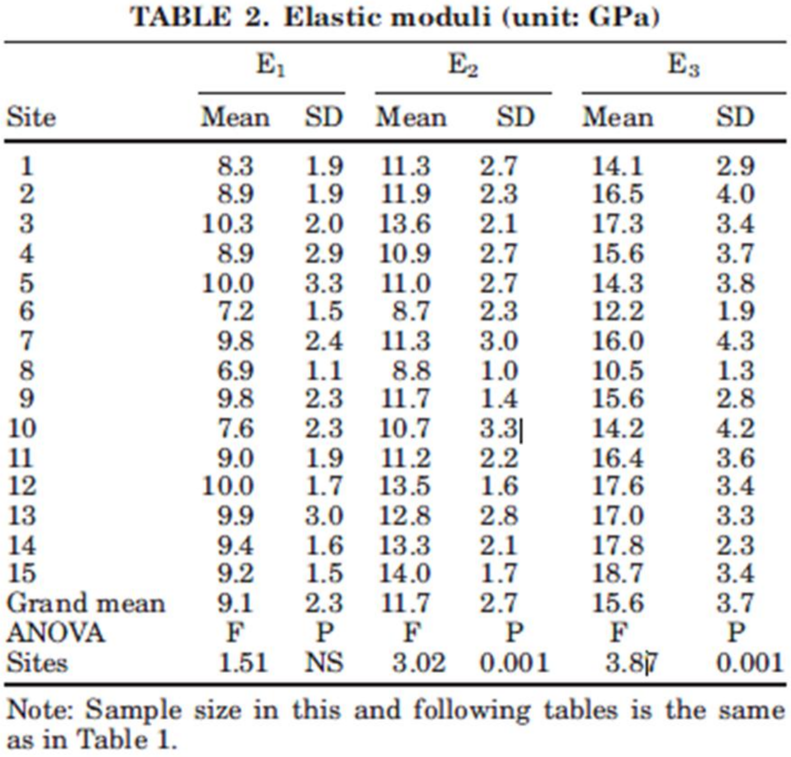
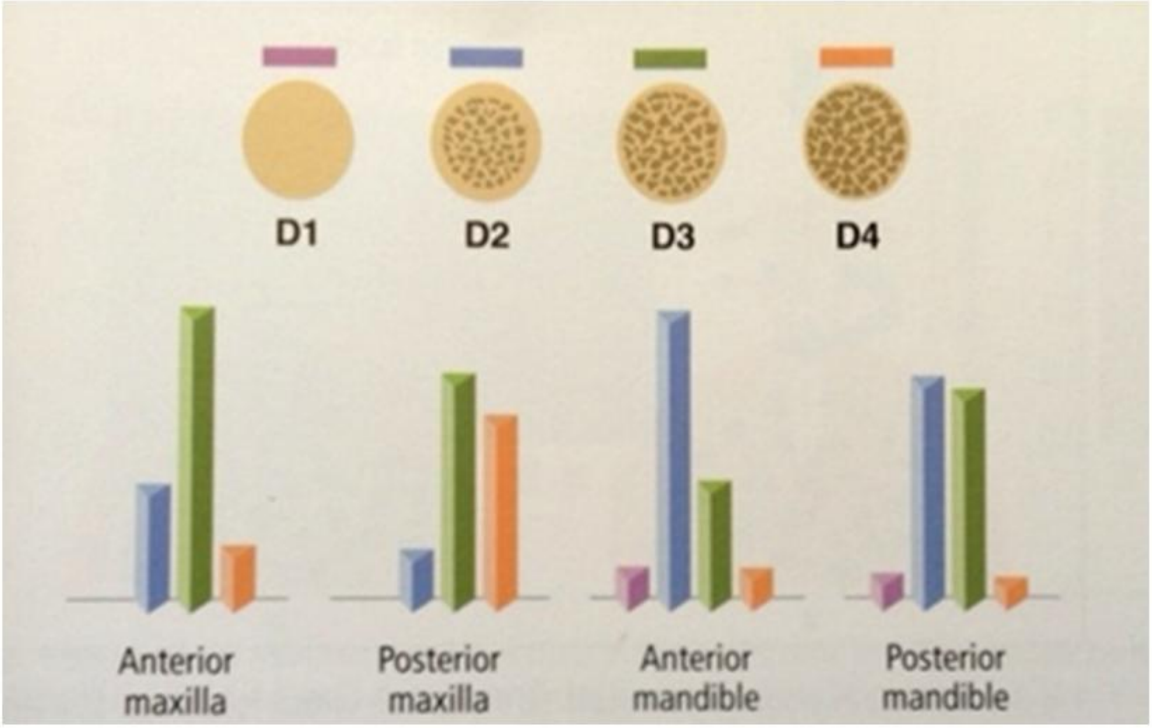


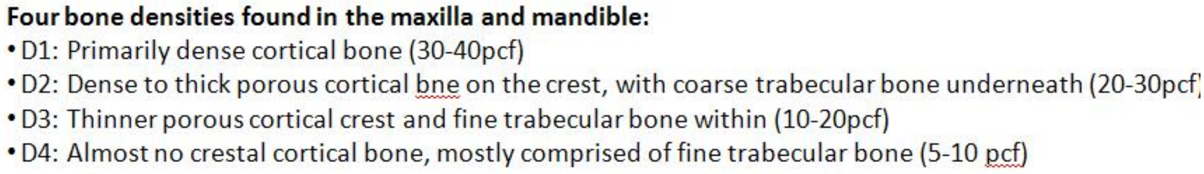
TABLE 2. Elastic moduli (unit: GPa)

	E_1		E_2		E_3	
Site	Mean	SD	Mean	SD	Mean	SD
1	8.3	1.9	11.3	2.7	14.1	2.9
2	8.9	1.9	11.9	2.3	16.5	4.0
3	10.3	2.0	13.6	2.1	17.3	3.4
4	8.9	2.9	10.9	2.7	15.6	3.7
5	10.0	3.3	11.0	2.7	14.3	3.8
6	7.2	1.5	8.7	2.3	12.2	1.9
7	9.8	2.4	11.3	3.0	16.0	4.3
8	6.9	1.1	8.8	1.0	10.5	1.3
9	9.8	2.3	11.7	1.4	15.6	2.8
10	7.6	2.3	10.7	3.3	14.2	4.2
11	9.0	1.9	11.2	2.2	16.4	3.6
12	10.0	1.7	13.5	1.6	17.6	3.4
13	9.9	3.0	12.8	2.8	17.0	3.3
14	9.4	1.6	13.3	2.1	17.8	2.3
15	9.2	1.5	14.0	1.7	18.7	3.4
Grand mean	9.1	2.3	11.7	2.7	15.6	3.7
ANOVA	F	P	F	P	F	P
Sites	1.51	NS	3.02	0.001	3.87	0.001

Note: Sample size in this and following tables is the same as in Table 1.

Appendix L: Misch Bone Density Classification with related synthetic bone densities

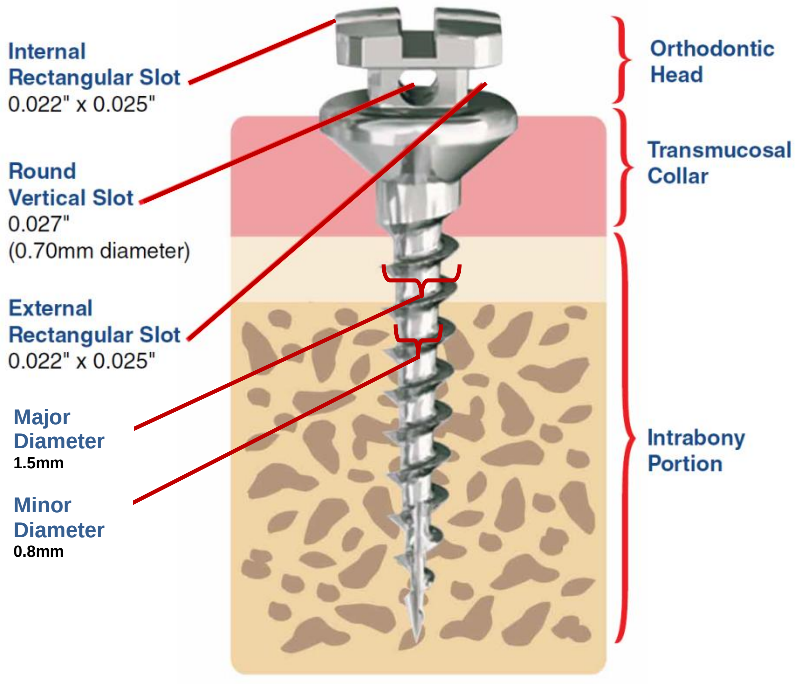


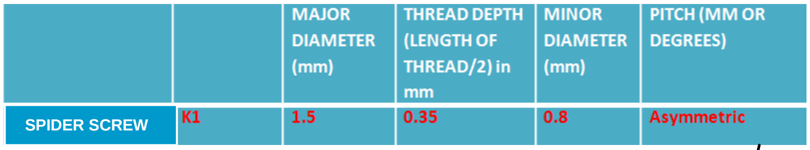


Four bone densities found in the maxilla and mandible:

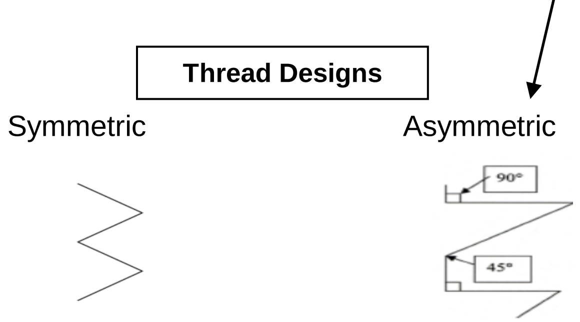
- D1: Primarily dense cortical bone (30-40pcf)
- D2: Dense to thick porous cortical bne on the crest, with coarse trabecular bone underneath (20-30pcf)
- D3: Thinner porous cortical crest and fine trabecular bone within (10-20pcf)
- D4: Almost no crestal cortical bone, mostly comprised of fine trabecular bone (5-10 pcf)

Appendix M: Orthotechnology K1 Spider Screw Geometry





		MAJOR DIAMETER (mm)	THREAD DEPTH (LENGTH OF THREAD/2) in mm	MINOR DIAMETER (mm)	PITCH (MM OR DEGREES)
SPIDER SCREW	K1	1.5	0.35	0.8	Asymmetric



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