Comparison of Primary Stability of Tapered and Parallel Walled Implants in Poor Quality Bone: An in vitro study

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ABSTRACT

Objectives: Obtaining primary stability upon placement is crucial for predictable healing and long-term success of dental implants. Primary stability is very difficult and challenging to achieve in poorer quality bone. Currently, two of the more common dental implant designs are tapered and parallel walled dental implants. The objective of this study was to determine if there was a difference in the primary stability of tapered and parallel dental implants in poor quality bone. The null hypothesis of this study was that there is no difference in the primary stability of tapered and parallel walled dental implants in poor quality bone.

Material and Methods: Two implant designs (tapered and parallel walled dental implants) were evaluated for the primary stability in a medium that represented poor bone quality (Balsa wood). Twenty-four 4.3 x 11.5 mm Hahn™ tapered implants (Glidewell Dental Laboratories, Newport Beach, CA) along with a twenty-four 4.3 mm x 11.5 mm parallel walled prototype Hahn™ implants (Glidewell Dental Laboratories, Newport Beach, CA) were used. All implants had identical surface texture, diameter, length, thread design, and pitch thereby eliminating extraneous variables. The only difference between the two dental implants was the taper. After implant placement in the poor quality bone medium, resonance frequency analysis was recorded for each implant using the Penguin RFA (Aseptico®, Woodinville, WA). The ISQ scores were

uploaded into Stata 16 (StataCorp, College Station, TX) and evaluated. A two-sample t-test was calculated to determine if there was a statistically significant difference in the primary stability between the two implant designs.

Results: In the evaluation of 24 tapered and 24 parallel walled implants, the average ISQ value for the tapered was 67.125 +/- 1.974 and the parallel walled was 64.813 +/- 0.93. The 2-sample t-test yielded a p-value = 0.0000. Since the p-value <0.05, there was a statistically significant difference between the ISQ scores of the two implant designs. The null hypothesis was rejected.

Conclusion: The results of this in vitro study concluded that the tapered implant design provides greater primary stability than parallel walled implants in poor quality bone.

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1.0 Introduction

Dental implants have become a successful treatment modality for partial and fully edentulous patients. The dental implant market has been predicted to reach $6.81 billion by 2024.[1] The goal of dental implant therapy is to support restorations that provide the patient with restored function, esthetics and comfort. Most research investigations have reported long term implant success rates greater than 90%. In spite of this high success rates, dental implants do fail.[2] There are many biological, mechanical, and iatrogenic reasons that account for these failures. [3] [4] Lack of primary stability has proved to be one of these major causes. [5] A greater understanding of why implants fail has led to advancements in implant design, surgical and prosthetic protocols, and diagnostic tests to evaluate the stability of implants at the time of placement and throughout the healing process. Research has shown that implant therapy has been least successful in patients with poorer bone quality. Consequently, improving implant success in such patients has been a priority for implant clinicians.

2.0 CHAPTER 1

2.1 REVIEW OF LITERATURE

2.1.1 Osseointegration

"Osseointegration," as originally described by Brånemark in 1977, is "a direct structural and functional connection between ordered, living bone and the surface of a load carrying implant.[6] This definition has directly influenced the evolution of implant design, surgical approaches, grafting procedures, bone substitutes, healing time, and the overall treatment of implant patients'. The traditional method described by Brånemark called for a two-stage approach with a minimum of 6 months of post placement healing to allow for osseointegration of the implant.[7] During this time, implants were to remain unloaded to assure undisturbed bone apposition onto the implant surface. Since these pioneering concepts were introduced, many authors have discussed variations of these protocols, including immediate placement and immediate loading protocols.[8] In spite of this transitioning paradigm shift in treatment protocols, it has remained clear that osseointegration is required for long-term implant success.

2.1.2 Implant Stability: Primary and Secondary

Successful integration of dental implants is predominantly dependent on the stability of the dental implant following placement. [9] Dental implant stability is a measure of the anchorage or lack of movement of the implant in the alveolar bone. [10] Implant stability can be divided into two different stages: primary and secondary. [11]

2.1.2.1 Primary Stability

The prosthodontic glossary defines primary stability as “contributing factors of mechanical stabilization of a dental implant during the healing phase.” [12] Basically, it is the initial stability or fixation of a dental implant immediately after placement within the bone. It has been well established that primary stability of the dental implant is crucial in obtaining osseointegration. [13] This stability directly affects the rigidity and resistance to movement of the dental implant before the initiation of bone remodeling and the healing process. Studies have shown that micro-movements greater than 50 – 150 um is detrimental to osseointegration. [14] Prevention of micromovement is essential in averting early implant failures.

Micromotion is defined by the International Congress of Oral Implantologists (ICOI) as “the minimal displacement of an implant body from the surrounding bone that is not visible to the naked eye.” [15] A critical threshold of micromotion exceeding 150 um may induce stress and strain sufficient to ultimately interfere with bone remodeling, negatively influencing osseointegration and allowing formation of a fibrous tissue interface. [16] Such formation of a fibrous tissue interface frequently results in insufficient bone at the implant interface and leads to eventual implant failure. [17]

Because the dental implant stability directly affects the bone remodeling process, the ability of the interface to accept stress impacts the overall success of the dental implant. [18] There are many factors involved in achieving adequate primary stability.

2.1.2.2 Factors involved in primary stability of implants

Primary stability of a dental implant is influenced by multiple factors including bone quality and quantity, surgical technique, and implant surface and design.

2.1.2.2.1 Bone Quality/Quantity

The long-term success of dental implants has been shown to be directly dependent on the quality and quantity of the bone surrounding the implant. [19] Initial bone density is one of the most important factors in achieving primary stability. The bone density allows for the transfer of stress from the prosthesis to the implant-bone interface. Therefore, quality of the bone determines bone-implant contact, which in turn ultimately determines dissipation of the occlusal load. [20]

In 1985, Lekholm and Zarb described four bone qualities that were found in the anterior maxilla and mandible. [21] Quality 1 Bone: homogenous in nature and composed of compact bone; Quality 2 Bone: comprised of thick cortical bone and dense trabecular bone; Quality 3 Bone: composed of very thin cortical bone and dense trabecular bone; and Quality 4 Bone: consisting of almost no cortical bone and low-density trabecular bone. Originally, treatment protocols utilized the same surgical and prosthetic procedures for all 4 Bone categories.

In 1988, Misch proposed four different bone density categories that were independent of the location within the oral cavity (i.e. maxilla vs. mandible) and based on the macroscopic cortical and trabecular bone characteristics.[22] [23] Bone density D1 was classified as completely dense cortical bone and mainly found in the atrophic anterior mandible. D1 Bone was shown to have an approximate BIC of 85%, meaning that approximately 85% of the implant interface upon placement is covered with bone. D2 Bone was defined as dense-to-porous cortical bone and coarse trabecular bone with an approximate 70% BIC. D2 Bone is predominately found in the anterior mandible and sometimes in the posterior mandible. D3 Bone is described as having a thin porous cortical bone and fine trabecular bone with a BIC of approximately 50%. D3 Bone is usually located in the posterior mandible, as well as the anterior and posterior maxilla. D4 Bone consists of only fine trabecular bone with minimal cortical bone. Less than 30% of the interface (BIC) is covered with bone. A later classification was added as D5, which is very soft bone with minimal mineralization and large intertrabecular spaces. [24]

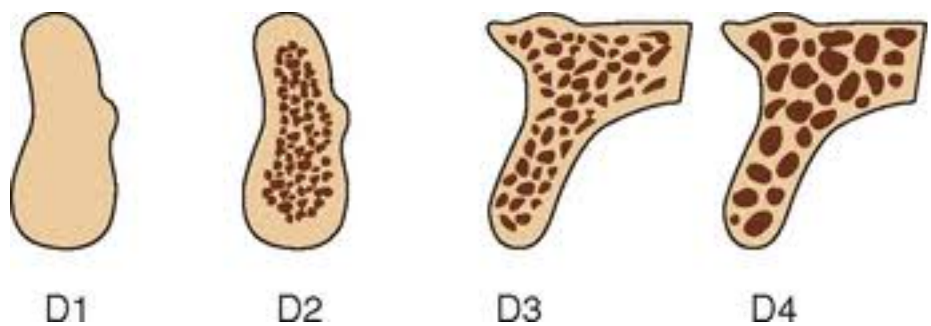

Figure 1: Bone Density Classification according to Misch [25]

The BIC has been shown in the literature to be directly related to implant survival and success rates. Becker et al showed that higher BIC values in the anterior mandible were associated with higher survival rates than in poorer quality bone found in the posterior maxilla. [26] Miyamoto et. al. reported that the initial cortical bone thickness seen in D1 and D2 bone qualities, has a positive impact on dental implant stability. [27] With thicker cortical bone, higher placement torques have been possible; however excessive insertion torque values may result in bone resorption and pressure necrosis, leading to implant failure. [28]

Lower primary stability in D4 bone, along with impaired healing and unpredictable integration has been associated with a decreased implant survival rate. [29] Sennerby et al showed that implants connected to cortical bone by only a few threads had higher primary stability than implants completely surrounded by cancellous bone. Maximizing the primary stability of the implant is important for successful bone apposition and integration. [30]

Recently, cone beam computed tomography (CBCT) has proved helpful in determining bone quality prior to surgical placement of dental implants. With the use of CT numbers (Hounsfield units - HU) and treatment planning software, the bone quality may be correlated from the patient's CBCT. Sir Godfrey Newbold Hounsfield was an English electrical engineer who won the 1979 Nobel Prize for Medicine for his pioneering work with X-ray computed tomography.[31] He developed a bone quality scale based on Hounsfield units. The calibration value of air was set at -1000 HU, water at 0 HU, and dense cortical bone at +1000 HU. Hounsfield units were further classified to include bone qualities: D1 bone >1250 HU, D2 = 850 – 1250 HU, D3 = 350 – 850 HU, and D4 = 0 = 350 HU. This scale has allowed a direct correlation between bone quality seen on a CBCT examination and the patient's bone quality seen during the placement of dental implants. [32] [33]

Table 1: Hounsfield unit assignment to Misch's Bone Density classification

Hounsfield Units (HU)	
D1	**>1250**
D2	**850 - 1250**
D3	**350 - 850**
D4	**0 - 350**

2.1.2.2.2 Surgical Technique

Many techniques and protocols have been discussed in the literature that can osseodensify poor quality bone. This osseodensification increases the bone-implant contact at the implant interface upon initial implant placement. By improving the density of the implant site and increasing the BIC, increased primary stability and greater implant success can be achieved. [34]

One of the more common surgical techniques to enhance primary implant stability in bone of poor density is to under-size the osteotomy.[35] By under-sizing the osteotomy (i.e. using decreased bur diameter resulting in a smaller osteotomy diameter of than that of the implant), the intention is that the implant will compress the bone laterally leading to increased fixation and primary stability. The bone that would normally be lost due to the larger drill sizes is actually laterally compacted, thereby increasing the BIC. [36] Jimbo et al concluded that the undersizing technique is only efficient when the implant bed is decreased by 10% of its diameter and that any further decrease did not improve the primary stability. [37] Turkyilmaz et al placed 60 implants in the posterior maxilla and evaluated various surgical techniques to enhance primary stability in poor density bone. They concluded that using smaller diameter drills for implant placement in low bone density is a viable option to increase primary implant stability, which usually results in better implant survival rates. [38] Tabassum et. al. also found that in poor bone density using an undersized drilling technique locally optimizes bone density and improves the primary stability.[39] Bilhan et. al. placed 90 implants in cow ribs and found that under-dimensional drilling enhanced primary stability, especially in cancellous bone. [40]

With underprepartion of the osteotomy, more force is required to deliver the implant. The maximum force necessary to place the implant in the osteotomy is referred to as insertion torque. Some studies have found that increasing insertion torque, improves the primary stability. [41] Most of the literature has concluded that undersizing the osteotomy in poor quality bone does help to increase implant stability. This has led most implant systems to have both a soft and dense bone protocol where an undersized osteotomy can be used to increase primary stability in cases on poor bone quality

2.1.2.2.3 Osteotomes

In 1994, Summers described the Osteotome technique to improve primary stability. [42] This method involves initially preparing the osteotomy with a pilot drill, followed by use of hand held osteotomes. This allows the bone to be compressed both laterally and apically. The goal of this technique is to retain bone that would normally be removed by compressing it to create a precisely formed implant site instead. [43] Consequently, bone-implant contact is increased.

Shayesteh et.al placed 46 implants in the anterior maxilla of 30 patients using conventional drilling and the osteotome technique. They concluded through resonance frequency analysis (RFA) that the osteotome technique resulted in higher primary stability compared to conventional drilling. [44] Markovic et al placed 102 implants in the posterior maxilla and also found that laterally condensing bone with osteotomes significantly improved implant stability. [45] The increased primary stability was attributed to changes in the micromorphology of the trabecular bone caused by the osteotome compression. [46]

Contrary, a study by Padmanabhan and Gupta found statistically significant higher primary stability using conventional drilling rather than osteotomes. They also found an average crestal bone loss of 1.19mm when using osteotomes compared to a loss of 0.99mm following implant placement using conventional drilling. They concluded that the use of osteotomes should be limited to situations where knife-edge ridges and/or poor bone quality are present. [47]

There is a wide range of osteotome designs and techniques. There likewise exists a learning curve for implant clinicians to assure maximum primary stability when using this method.

2.1.2.2.4 Osseodensification Burs

Osseodensification drilling (OD) is another technique that was recently developed to improve primary stability. During conventional osteotomy drilling, the drills are designed to excavate bone to create room for the implant placement. [48] Huwais introduced "osseodensification burs", which preserve and condense bone during the osteotomy in a non-subtractive fashion.[49] When run in a counterclockwise direction, these burs laterally condense the soft bone resulting in greater bone volume and density, increased bone implant contact, and increased primary stability.[50] Lahens et. al. examined the effect of osseodensification on the primary stability of implants in sheep. They found that osseodensification drilling enhanced primary stability and bone-implant contact regardless of the implant design.[51] Trisi et. al. found a 30% increase in bone volume and an increased ridge width when using osseodensification drills. Increased bone density was attributed to the compression of trabecular bone.[52] Wang et. al. found that though OD increased the percentage of bone at the implant interface, however it did not significantly improve implant primary stability.[53] Almutairi et. al. placed 48 implants where osseodensification burs and conventional drilling were compared. Utilizing periotest values, they did not find a statistically significant difference in primary stability.[54] Though osseodensification is a recent concept, it has been well researched and has shown promising results.

Figure 2: Illustrated is the densifying mode of an osseodensification bur [55]

2.1.2.3 Secondary Stability

Approximately two weeks following implant placement, there is a decrease in the mechanical stability of dental implants most likely due to bone remodeling. Following implant placement, highly cellular but poorly mineralized and non-load-bearing woven bone accumulates at the implant interface. [56] If excessive force is applied to woven bone at the interface, load-bearing bone will not be formed and a soft tissue interface will result.[57] The woven bone interface is then slowly resorbed by osteoclastic activity. [58] Remodeling of the woven bone at the interface consists of a slow resorption phase initiated by osteoclastic activity followed by bone apposition initiated by osteoblastic activity. [59] As new bone is slowly formed at the implant interface, secondary stability is established. This secondary stability is crucial for successful osseointegration. [60] Secondary stability is achieved as additional bone is remodeled at the implant interface [61] The control of micromotion at the bone-implant interface is crucial to obtain secondary stability and prevent soft tissue invasion which leads to implant failure. [62] If sufficient primary stability is not initially achieved, secondary stability will be compromised. [63] Primary stability, bone remodeling, and implant surface conditions are key factors that influence secondary stability.[64]

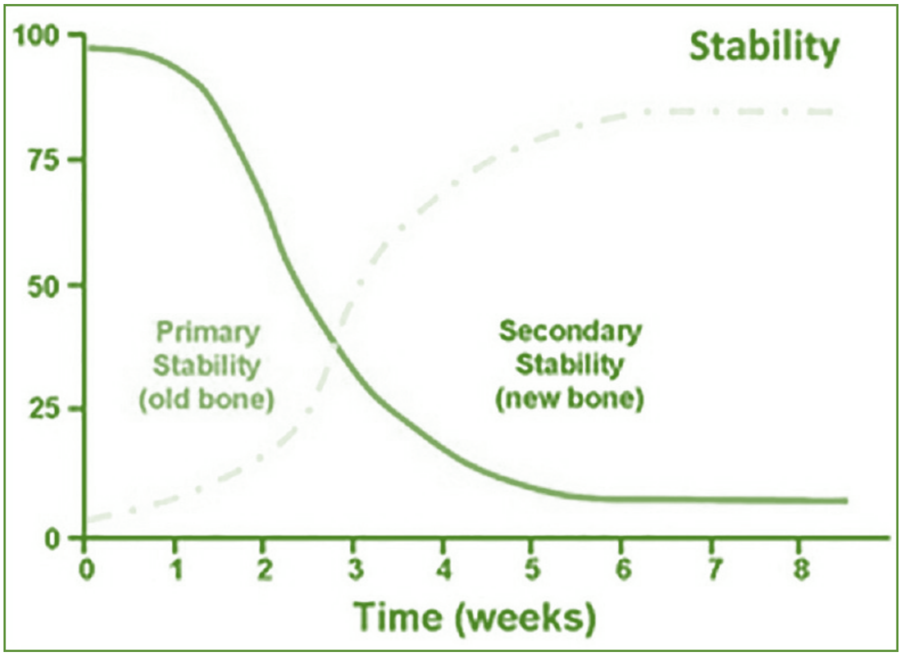

Figure 3: Illustrating how secondary stability replaces the primary stability throughout the healing time [65]

2.1.3 Implant Design

The dental implant market has grown exponentially over the last 15 years. In 2003, Jokstad et. al reported that approximately 80 manufactures around the world were producing 220 different implants.[66] By 2018, there were roughly 500 different manufactures producing over 4,000 different implants.[67] Numerous modifications in implant body design and implant surface texture have been suggested in the literature to increase the success of implants in poor quality bone. Their goal has been to gain better stability and to provide greater surface area to decrease the stress transmitted to the bone.[68] Successful integration of dental implants depends on the chemical, physical, mechanical, and topographic characteristics of their design.[69] Dental implant design has been shown to be a crucial parameter for attaining primary stability. [70 71 72 73]

Implant design directly influences implant handling of biomechanical forces.[74] It has been found that implants placed into good quality bone achieve acceptable primary stability, regardless of their design.[75] The effects of different designs between various implants are more pronounced in poor quality bone. Thus, selection of an implant that can provide adequate primary stability in poor quality of bone is essential.

2.1.3.1 Screw vs Cylindrical

Since the 1990's, the two most common implant designs have included cylindrical and screw type. The screw or threaded design is currently the most popular because of its increased surface area, which allows for increased bone-implant contact (BIC). This contributes to superior primary stability and minimal micromotion. [76 77 78] Vandamme et. al. showed that screw implants have a much greater surface area and consequently enhanced secondary stability. [79] Watzik et. al. concluded that screw implants are beneficial for immediate load procedures and further that cylindrical implants are contraindicated because of their inferior primary stability. [80]

Figure 4: Basic implant design [81]

2.1.3.2 Tapered vs Parallel Wall

The original 1970's Branemark implant design had parallel walls. That design has given way to tapered dental implants introduced in the late 1990's for cases involving closely approximating natural tooth roots.[82] These implants were initially intended for the replacement of missing lateral incisors [83] [84], narrow or concave ridges [85], and interdental sites compromised by convergent roots of adjacent teeth.[86] With the addition of multiple threads to the tapered design [87], studies have shown an increase in implant stability in low bone density due to compression of bone during insertion. [88] This increase in primary stability has favored tapered implants to be used in sites with poorer bone quality [89], inadequate bone quantity [90], and in sites planned for immediate placement.[91] O'Sullivan et. al. correlated the amount of compression to three factors: the degree of implant taper, the relationship of the final drill diameter to the diameter of the implant, and the mechanical properties of the bone. [92]

O'Sullivan et. al. compared five different implant designs in a human cadaver study and found that parallel walled implants can reach their maximum stability if the coronal part is placed in cortical bone. However, tapered implants apply lateral compressive forces to the surrounding walls when placed in sites with poor bone quality and hence provided a more favorable design than parallel walled implants.[93] Additionally, they found that tapered implants had similar stability in all types of bone quality. O'Sullivan et. al. also evaluated the mechanical stability of dental implants with a 1° and 2° of taper compared with the standard parallel walled Brånemark design. They concluded that implants designed with a 1° taper result in better primary stability compared with the standard Brånemark design. [94]

Menicucci et al compared conical and cylindrical implants and found higher insertion torques for tapered implants (31.5 Ncm) compared with straight-walled implants (25.5 Ncm).[95]

Lozano-Carrascal et al in prospective clinical study compared OSP implants to tapered MIS implants in human mandibles. They found that tapered implants achieved higher primary stability measured through ISQ and insertion torque.[96] Romanos placed 90 parallel walled and 90 tapered implants in cow ribs, which were described as type IV bone, and found greater implant stability for tapered implants.[97] Other similar studies have utilized RFA analysis and artificial bone blocks or animal models and concluded that tapered implants show significantly higher ISQ values than cylindrical shaped implants.[98] [99]

An additional advantage of tapered implants is that they require less quantity of bone at their apex due to a decreased apical diameter. Therefore, they are less likely to perforate the buccal plate, when osseous undercuts are present. [100] Mijiritsky et. al. found a 96% success rates with varying diameters and lengths. Rokn et. al.[101] compared stability changes of tapered and parallel walled implants in different types of bone. They concluded that for denser D1-D3 bone, greater primary stability occurred regardless of the implant design. They also found that the tapered wall implant had a higher initial stability as well as better stability throughout the bone remodeling stages. They attributed their results to the fact that the tapered design created more lateral bone compression during implant placement.

Coutant et. al. placed Nobel Active tapered implants and Nobel Speedy cylindrical implants into poor quality cadaver bone. They found adequate primary stability with the tapered implants and little to no stability with the cylindrical implants. [102] However, only five specimens were examined in this study and both the tapered and cylindrical implants exhibited different thread designs.

George et.al. compared tapered and cylindrical dental implants and concluded that the delivery torque and primary stability of tapered implants was greater and resulted in a higher success rate. [103] However, a limitation of this study was that different implant types and thread designs were used.

Friberg et al [104] as well as Astrand et. al. [105] also reported that tapered implants had greater primary stability and success in poorer quality bone. Following a 1-year clinical evaluation of immediate loading of tapered implants, Glauser et al recommended their use when immediate loading is planned.[106]

Tapered and parallel walled implants distribute biomechanical forces differently. Tapered implants divert forces toward the apex, making this type of implant more desirable for immediate placement.[107] Parallel walled implants distribute forces throughout the entire implant because the parallel walls of the osteotomy are damaged by the preceding implant threads. [108] Glauser et. al. stated that tapered implants distributed occlusal forces to adjacent bone more favorably than parallel walled implants.[109]

Some authors have postulated that the higher delivery torque and the compression with tapered implant does not always lead to high implant stability. [110] Excessive bone compression generated by the tapered design can exceed the physiologic tolerance and cause cell death, necrosis, and ultimately bone resorption. [111] [112] Finite element analysis studies have found a potential for excessive stress concentrations to occur in the crestal or apical regions of various tapered implant designs when used in low-density bone. [113] [114]

However, research as that of Khayat et. al. disproved this concept. [115] They used placement torques up to 125 N/cm did not see any greater bone resorption or lack of osseointegration from such compression when using the tapered implant design.

2.1.3.3 Rough vs Smooth Surface

Implant surface characteristics have been shown to have a significant impact on osseointegration and primary stability. [116] The original dental implants were all well polished, however many advancements have been made regarding the implant surfaces. In poor quality bone, implants with acid-etched surfaces achieve higher BIC than implants with a machined surface.[117] [118] Numerous studies have shown that roughened surfaces are associated with an increased primary stability compared to smooth surfaces. A roughened surface provides increased surface area and a greater mechanical link to the tissues. [119] [120] Veis et. al. in a primate study showed that a roughened surface was advantageous in achieving osseointegration following immediate loading . [121] Garber recommended using a roughened implant surface for immediate placement situations to achieve increased early bone-implant contact resulting in accelerated osseointegration and secondary stabilization.[122] Numerous other studies have shown that roughened surfaces reduce healing time as they promote peri-implant osteogenesis by increasing the proliferation and metabolic activity of osteoblasts. [123] [124] Khang et. al. found that surface-roughened implants have a failure rate five times lower than machined surface implants.[125] Thus, the field of oral implantology agrees on the benefits of roughened implants and the majority of the implants on the market are now roughened.

2.1.3.4 Threads

There are many different implant thread configurations and all directly impact bone/implant contact. Threads may help to improve initial stability, increase implant surface area, and distribute stress to the implant over a greater surface area. [126] [127] Falco et. al. found that large aggressive threaded implant designs are more favorable in poor quality bone.[128] Trisi et. al.

found an approximate 10% increase in BIC in cancellous bone with large thread designs over classical designs. [129]

The thread pitch, defined as the distance from the center of one thread to the center of the next thread, has a significant effect on the surface area.[130] As thread pitch decreases, surface area increases which, in turn leads to better stress distribution.[131] Abuhessein et. al. showed that stresses are more sensitive to thread pitch in poorer quality cancellous bone.[132] Finite element analysis research has shown that a square thread design provided the best primary stability and was recommended to be used in immediate loading cases.[133]

3.0 Ways to Evaluate Dental Implant Stability

Ways to evaluate dental implant stabilization and bone density have been well documented in the literature. Techniques such as histologic analysis, tactile perception, radiographs, periotest, resonance frequency analysis (RFA) and cutting torque resistance analysis have enabled clinicians to evaluate dental implant primary stability.

3.1.1 Histologic Analysis

Histologic analysis has been documented in the literature as a reliable method to evaluate both the peri-implant bone quantity and bone-implant contact (BIC). A dyed specimen of the implant and peri-implant bone may be evaluated. Though this technique is very accurate, it is an invasive and destructive procedure. Consequently, it is only utilized in nonclinical studies and experiments. [134]

3.1.2 Tactile Sensation

A subjective technique to determine stability is the use of tactile sensation by the implant clinician placing the implant. Based on cutting resistance and seating torque of the implant, a perception of "adequate" stability may be determined by the sensation of an abrupt stop when the implant is seated.[135] The obvious disadvantage of this technique is relying on the subjective evaluation of a single clinician. Such results are not quantifiable. Additional factors that may further skew results include density and amount of cortical bone present, sharpness of the drills, possible marrow spaces within the bone, and placement technique.

3.1.3 Radiographs

Radiographic imaging is widely used to assess the quantity and quality of the bone both pre- and post- implant delivery. Following surgery, radiographic imaging is a noninvasive method used to assess any changes in the quantity and quality of the supporting bone, and to estimate the incidence and progression of associated crestal bone loss.

There are many limitations that exist with the use of conventional radiographs in obtaining an accurate assessment of implant stability. Conventional two-dimensional periapical and panoramic radiographs do not provide information on facial or lingual bone loss, which tend to precede mesiodistal bone loss. [136] In addition, bone quality or density cannot be accurately quantified via 2-dimensional x-rays.[137] Studies have shown that changes in bone mineralization cannot be radiographically detected until 40% of the demineralization has occurred.[138] Finally, crestal bone changes can only be reliably measured if the bitewing radiograph was perfectly parallel with the implant upon exposure. [139] In order to compare images taken at different time periods, a standardized technique would need to be used to provide reliable and repeatable measurements.[140] In conclusion, two-dimensional radiographic imaging is simple, quick, and noninvasive; however it is limited in its capability of accurately assessing the stability of dental implants.

The use of CBCT examinations to determine primary stability is questionable. Because of CBCT artifacts, measurement of bone at the implant interface is inaccurate. The most common artifact is beam hardening, which usually results in a radiolucency on one side of the implant in

CBCT cross-sectional images. [141] Other artifacts that may decrease accuracy of CBCT evaluation are streaking, noise, and motion issues.

3.1.4 Percussion Test

The percussion test is an older method to assess the level of integration.[142] A blunt instrument (dental mirror handle) is used to tap the implant. Based upon vibrational-acoustic science and impact response theory, the resulting sound will correlate to the degree of osseointegration.[143] It has been postulated that a high-pitched ringing “crystal” sound would imply successful osseointegration. In contrast, a low-pitched “dull” sound would indicate a lack of osseointegration. A dull sound is made because there is inadequate bone at the implant interface causing the vibrations move more slowly across the distance between the implant and the surrounding tissue.[144] The obvious disadvantages of this technique are that it is extremely subjective, unreliable, and not quantifiable.

3.1.5 Insertion Torque

Torque is a measurement of the rotational friction between the implant and bone combined with the force required to cut the bone and the pressure force from the surrounding bone. Johansson et. al. described the insertion torque as the amount of torque required to insert an implant into the prepared osteotomy.[145] Insertion torque can be measured at the time of implant placement and can provide the clinician with an objective assessment of the bone density.[146] Increased insertion torque has been associated with reduced micromotion and higher success rates.[147] However, a spectrum of insertion torques have been described by various authors throughout the literature.

Ottoni et. al. placed 46 single-tooth implants and found that a minimum of 32 N/cm was necessary for integration of the implant. They concluded that achieving high insertion torque is related to higher primary stability.[148] A study by Barewal et. al. found that an insertion torque of 20 N/cm is adequate for immediately loading a single tooth implant.[149]

High insertion torque may reduce adverse micromotion, but some studies have indicated that increased torque does not always correlate with higher degrees of stability.[150] For example, high insertion torque may reach high primary stability, however the stress may cause pressure necrosis, which may jeopardize secondary stability.[151] Lim et. al. stated that excessive insertion torque resulted in undesired heat, bone ischemia, delayed bone healing, and implant failure.[152] Norton et. al. found that decreased insertion torques yielded favorable survival rates with optimal bone levels compared with higher torque values. [153] Norton also reported that a torque of only 25 N/cm was sufficient for an immediately placed and restored single implant. [154] Some implants may fracture at the crest if too much torque is required to insert the implant.

The insertion torque (IT) allows the clinician to have an estimation of the bone, which may be useful in determining the optimal healing time for the implant.[155] The IT value is an important factor in determining an implant's primary stability. However this can only be measured at implant placement and does not allow for an accurate assessment of the secondary stability. [156] The comparability of insertion torques between different implant systems has proved to be difficult. [157] No universal standard for the ideal torque necessary for implant placement or ensuing loading protocol has been established for each implant system.[158]

3.1.6 Reverse Torque Test

Unlike insertion torque that measures bone density and the torque required to place an implant, the reverse torque measures the “critical torque threshold” where the bone-implant contact has been destroyed.[159] Reverse torque evaluates the friction or bond between the implant and surrounding bone by applying a reverse torque to the implant. If the applied torque results in implant rotation, then the implant has failed. [160] This test depends on the amount of bone contact at the implant interface and compression forces between the bone and implant. Sullivan et. al. found that reverse-torqueing at 20 N/cm is a safe, reliable method for verifying osseointegration. [161] However, this threshold for reverse torque testing has not been research supported. Implants placed in poorer quality bone may be significantly lower than implants in dense cortical bone. The reverse torque test provides an “all or none” outcome whether or not the implant has osseointegrated, It can potentially jeopardize or destroy ongoing bone remodeling if used incorrectly. [162]

3.1.7 Periotest

The periotest was developed in 1983 to be used on natural teeth to evaluate periodontal stability.[163] This test was established to quantitatively measure tooth mobility based on the damping characteristics of the periodontal ligament surrounding a tooth. A sensor inside the unit measures the damping ability while an electromechanically controlled tapping head percusses a tooth or implant.[164] Specialized software relates contact times as a function of mobility and expresses the number as a Pertiotest Value (PTV) ranging from -8 (low mobility) to +50 (high mobility). [165] [166] [167] PTV values of -8 to 0 are interpreted as successful osseointegration. A clinical examination prior to loading an implant has been recommended for values of +1 to +9, and further that +10 to +50 values indicate that osseointegration is insufficient. Dilek et. al. recommended that ideal periotest values should range from -8 to +9. [168] Abboud et. al. reported that periotest values no higher than + 4 are required for primary stability. [169]

The periotest has been accepted as a diagnostic tool to evaluate the primary stability of an implant. [170] It can measure all surfaces of the abutment or prosthesis; however, in order to be accurate the rod must make contact at the correct angle and distance.[171] The rod must maintain a distance of 0.6-2.0mm from the implant. [172] Studies have confirmed that for every 1mm change in striking distance, there will be a difference of 1.5 in PTV.[173] Ito et. al. stated that "if the perpendicular contact angle is larger than 20 degrees or if the parallel contact angle is larger than 4 degrees, the measured value is invalid". [174]

Single values of PTV's are of limited clinical value, however by performing repeated measurements over time, implant stability can be validated more accurately. Due to the sensitivity of this test and potential operator error, the periotest may not be as reliable as other testing modalities. In a review of the reliability of the Periotest, Bilhan et. al. recommended that if using the Periotest, the clinician should utilize other modalities as well to monitor implant primary stability. [175] Due to the sensitivity of this test and potential operator error, the periotest may not be as reliable as other testing modalities.

3.1.8 Cutting Torque Resistance (CRA)

Cutting torque resistance analysis (CRA), developed in 1994 by Johansson and Strid, is a test that measures the energy required to complete an implant osteotomy. [176] The electric motor is used as the diagnostic source to measure the energy required to cut bone during the implant surgery. Studies have shown this test may be correlated with bone density. A torque gauge is incorporated within the drill to measure the insertion torque. [177] Advantages of this method are detecting bone density and quality during the surgery.[178] However, this technique is difficult to standardize, does not provide the necessary information until the osteotomy is prepared, and is only measureable at implant placement. [179]

3.1.9 Resonance Frequency Analysis (RFA)

In 1996, Meredith developed the Resonance Frequency Analysis technique (RFA) to analyze implant stability. [180] RFA is a noninvasive technique that records and quantifies the lateral stability of an implant. The first generation RFA consisted of a stainless steel or titanium cantilevered transducer with 2 piezoceramic elements. One element received a 5-15 kHz vibrating frequency and vibrated the transducer; the other passed the vibration onto the RFA to analyze the response of the beam.[181] The first flexural frequency of the beam was measured in Hertz (Hz) and described the stability of the implant. The resonance frequency increased in direct proportion to the increases in the stiffness of the bone-implant interface.[182] The main disadvantage of the 1st generation RFA was that each transducer had its own resonance frequency that could vary between different transducers. The resulting varying values between different transducers were of limited value.

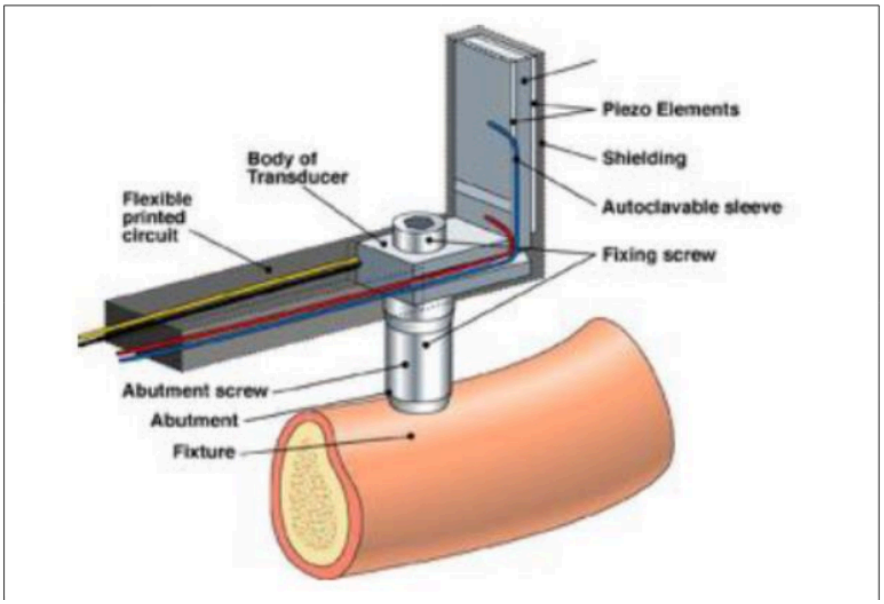

Figure 5: Schematic of first generation RFA transducer [183]

Newer generation RFA's [Ostell ISQ (Osstell, Gothenburg, Swedent) and Penguin RFA (Aseptico, Woodinville, WA)] have calibrated transducers ("smart pegs") with a magnetic top that is attached to the implant. The peg is excited through magnetic pulses with alternating waves of amplitude that cause the peg to vibrate, steadily increasing in pitch until the implant resonates.[184] Increased frequencies correlate with stiffer bone-implant interface and thus higher stability.[185] Newer generation RFA transducers are calibrated and autoclavable. Even though different implants require different transducers (smart pegs), all smart pegs show comparable values of implant stability.

Newer generation RFA transducers convert and report the Hertz waves into Implant Stability Quotient (ISQ) values. The ISQ score ranges from 0 to 100 with higher score correlating to higher stability. ISQ measurements are usually taken in two directions (MD and BL). The ISQ measures axial stability, stiffness of the implant, stiffness of the implant-bone interface, and stiffness of the surrounding bone.[186] The ISQ score is affected by implant diameter, surface character, bone contact ratio, implant site, surgical procedure, bone quality and bone quantity.[187]

The force applied by the RFA is equivalent in terms of direction and intensity of a fixed lateral force applied to the implant. This may simulate the clinical loading conditions on a much-reduced scale.[188] Zix et. al. found that RFA analysis of implant stability was more accurate and precise than the Periotest.[189]

RFA analysis has been shown to be a useful clinical tool from the time of implant placement throughout prosthetic rehabilitation.[190] It has allowed individualized treatment planning regarding one-or two stage procedures, immediate loading, healing time, type of prosthetic reconstruction, and detection of failing implants.[191] Sennerby et. al. have recommended loading protocols based on the ISQ values. Their chart considers ISQ values above 70 as “safe” and suitable for immediate loading protocols,[192] and further that a range of 55-70 as moderately stabile and finally an ISQ value below 55 as questionable In summary, RFA has been established as a non-invasive method to quantify implant stability and can be used repeatedly in the intra-operative and post-operative settings. [193]

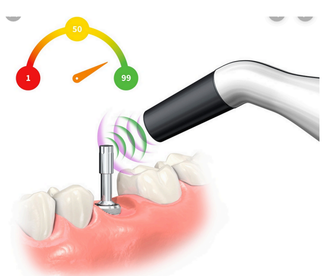

Figure 6: Newer generation RFA recording (Penguin RFA (Aseptico, Woodinville, WA))

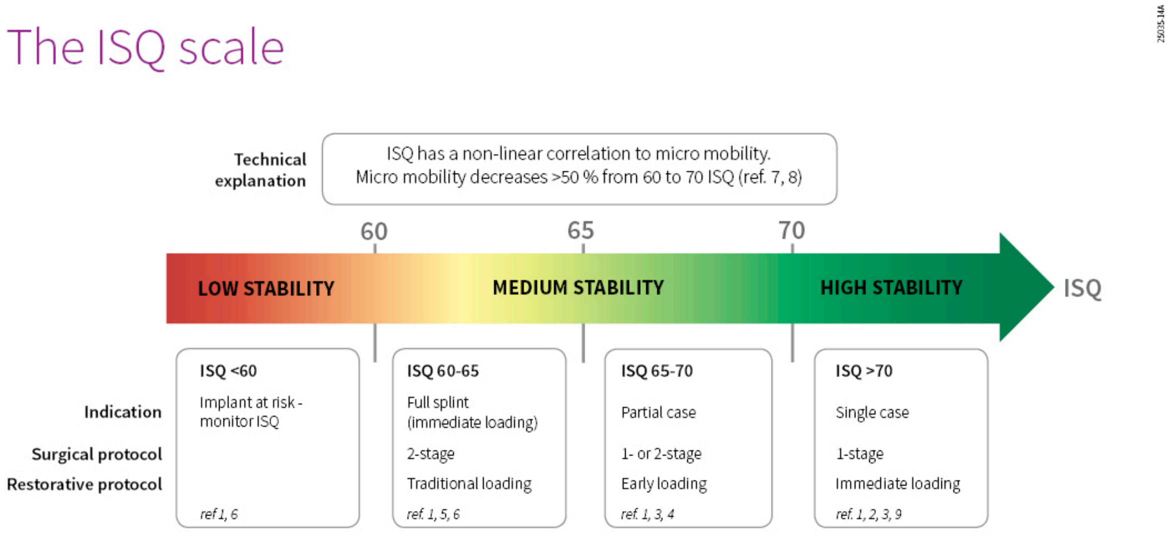

Figure 7: ISQ scores recorded by RFA along with resulting implant stability [194]

3.2 Importance of Primary Stability

3.2.1 Immediate Loading

Immediate loading of dental implants has gained popularity due to the reduction in treatment time and trauma, as well as aesthetic and psychological benefits to the patient.[195] A prerequisite for long-term success in cases of immediate implant placement is adequate primary stability at the time of implant placement and following initial loading of the implant.[196] Primary stability is paramount to implant success throughout the normal healing processes.[197] If an implant exhibits poor initial stability (mobility > 150 um), the excessive pressure of immediate loading forces may compromise normal healing. Poor primary stability is one of the most common causes for implant failure.[198] If the normal healing process is altered, a fibrous tissue interface results leading to failure of osseointegration.[199] Elias et. al. stated that primary not secondary stability, is the most critical factor in cases of immediate loading. [200] Friberg et. al. has reported an implant failure rate of 32% for implants with inadequate initial stability. [201]

Ivanoff et. al. investigated the influence of primary stability on osseointegration in rabbits by placing implants where some were primarily stable, some had rotational mobility, and some were totally mobile. Although all implants experienced some osseointegration, upon removal there was significantly less bone surrounding the implants that had initial mobility. They concluded that high primary stability reduced the risk of micromotion and adverse tissue responses such as fibrous tissue formation.[202] Brunski found that when implants are immediately loaded, a micromotion up to 100 um is tolerated and does not affect the osseointegration of the implant.[203]

3.2.2 Success in Poor Quality Bone

The importance of achieving adequate primary stability is greatly increased in cases of poor quality bone. A balance between cancellous and cortical bone is desired.[204] Lateral forces can potentially induce a micromotion up to 250 um in D4 bone.[205] [206] Failure rates up to 35% have been reported in type 4 bone [207] attributed to the difficulty in achieving primary stability and maintaining the bone-implant interface. [208]

In 1991, Jaffin et.al. reported a 35% failure rate in 102 implants placed in D4 bone. Of the 952 implants placed in D1, D2, and D3 bone, only 3% failed. They concluded that presurgical determination of D4 bone may help reduce failures and alter surgical treatment modalities.[209] In a similar study, Farre et. al. concluded that implants placed in D1, D2, D3 bone resulted in better implant stability, whereas those placed in D4 bone had higher failure rates.[210]

Thus, implant failure rates are greater in poor quality bone and the importance of primary stability is exacerbated.

3.3 Research Objectives

Achievement of long-term success in implant therapy is compromised in cases of poor bone quality and immediate loading. It has been shown that the primary stability of an implant immediately following placement is essential in allowing the osseointegration process to occur.[211] The goal of this study was to determine whether tapered or parallel walled dental implants provided greater primary stability in poor quality bone. Historically, the posterior maxilla has had the poorest quality bone and consequently the worst location for successful implant placement. Because dental implants placed in poor quality bone (as in posterior maxilla) are more susceptible to implant failure, it has been hypothesized that placement of tapered implants in poor quality bone could be expected to demonstrate a higher degree of initial stability, which in turn could lead to greater osseointegration and implant success.

3.4 Research Hypothesis

Tapered implants will NOT have a greater primary stability than parallel walled implants in poor quality bone.

4.0 CHAPTER 2

4.1 Methods/Materials

4.1.1 Implants

The Hahn™ tapered implants (Glidewell Dental Laboratories, Newport Beach, CA) (4.3mm x11.5mm), which is currently commercially available, was compared to a Parallel walled prototype implant (4.3mm x 11.5mm) fabricated by Glidewell Dental Laboratories (Newport Beach, CA). The prototype was fabricated with the same Titanium alloy, same length (11.5 mm) and diameter (4.3mm), same thread design, same self-tapping grooves and threads, and same collar as the Hahn™ Tapered implant. The only difference between the two implants was the taper of the walls, which was the only variable evaluated in this study. Twenty-four tapered and parallel walled dental implants were used in this study.

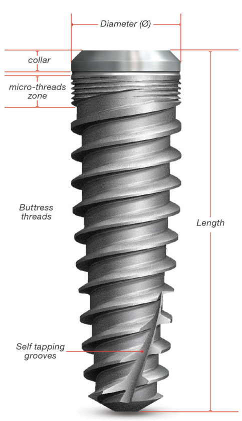

Figure 8: Hahn Tapered Implant Design (Glidewell Dental Laboratories, Newport Beach, CA)

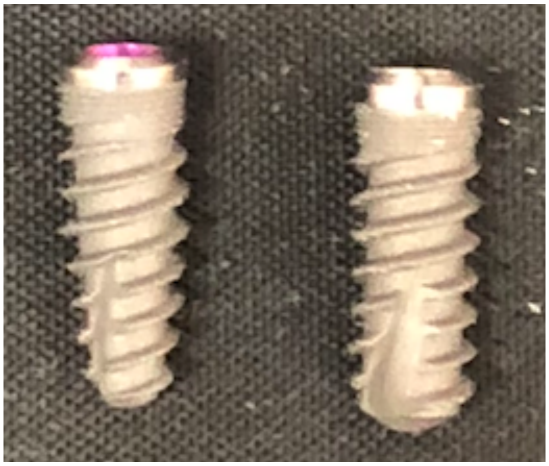

Figure 9: A comparison of Hahn Tapered Implant (left) (Glidewell Dental Laboratories, Newport Beach, CA) and parallel walled prototype (right)(Glidewell Dental Laboartories, Newport Beach, CA) compared in this study

4.1.2 Low-Density Material

5 artificial acrylic materials (polyeurethane blocks), 3 types of wood (oak, white pine, balsa), and Styrofoam were initially tested to determine which would best simulate poor quality bone. A CBCT (GENDEX) (Carestream Dental; Atlanta, GA) was taken of all materials and uploaded to Simplant (Dentsply Sirona; York, PA) to determine the Hounsfield Units (Hu) reported in the table below. A pilot study was conducted where implants were placed in all 9 testing mediums. Based on the CBCT image and clinical observations, it was determined that Balsa wood would best simulate the poor quality bone most likely encountered in the posterior maxilla. A 1 inch x 1 inch x 12 inch Balsa wood block was used as the test material for this study. Below is a table of the HU for the materials that were tested:

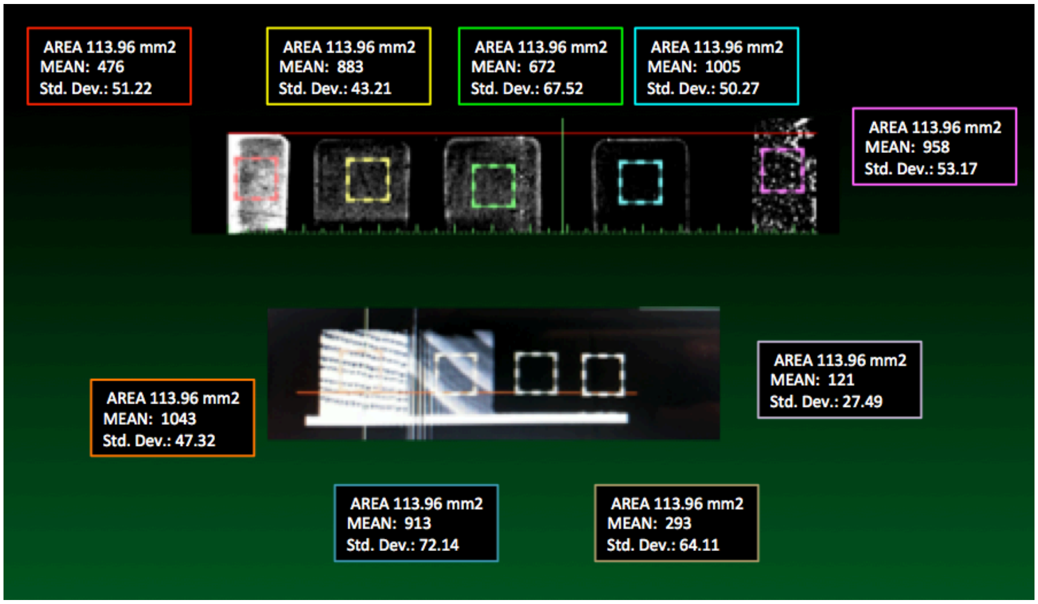

Figure 10: Average Hounsfield Units (HU) calculated of each testing medium in Simplant (Dentsply Sirona, York, PA)

Table 2: Table of Hounsfield Units (HU) of each testing medium

Material	PU1	PU2	PU3	PU4	PU5	Oak	White Pine	Balsa	Styrofoam
HU's	476	883	672	1005	958	1043	913	293	121

4.1.3 Surgical Technique and Implant Placement

In order to limit the amount of variability and error during implant placement, a guided surgical template was fabricated for the placement of all dental implants in this study. This template will ensure that all implants were positioned at the same angle and limited the amount of placement error. A drill press (KFF ¼" Drill Press)(King Feng FU Machinery; Taiwan) set to run at 800 RPM was used to prepare the osteotomy. The manufacture has recommended that individual drills should be replaced after 10 uses. To further limit variability in this study, a new drill was used for each osteotomy for each implant. A soft bone protocol was followed as is done in cases of poor quality of bone. The final drill for a 4.3mm x 11.5mm implant was a 3.5mm twist drill. Once the final drill was used, an air water syringe was employed to remove any debris accumulation. Implants were then inserted using the guide and torqued to 45ncm using a 20:1 implant hand piece. A decision was made prior to conducting the study, that if an implant would bottom out, it would be torqued by hand until the neck of the implant was at the crest of the wood.

Figure 11: KFF 1/4" Drill Press with Osteotomy bur (King Feng FU Machinery, Taiwan)

Figure 12: Balsa wood with Tapered and Parallel walled implants placed

4.1.4 Analyzing stability using RFA

After the implants had been placed, the ISQ score for each was calculated using a Penguin RFA Analyzer (Aseptico®, Woodinville, WA). The ISQ value reflected the micromobility of the implant when a force was applied. This value is directly related to the biomechanical properties of the surrounding bone, tissue, and quality of the bone-implant interface. Since both the tapered and parallel walled implants have the same interface, the same RFA transducer ("smart peg") was used for all implants.

The ISQ value was calculated in two different directions. These values were uploaded into an Excel spreadsheet. The average of the two ISQ values represented the ISQ score for that sample implant.

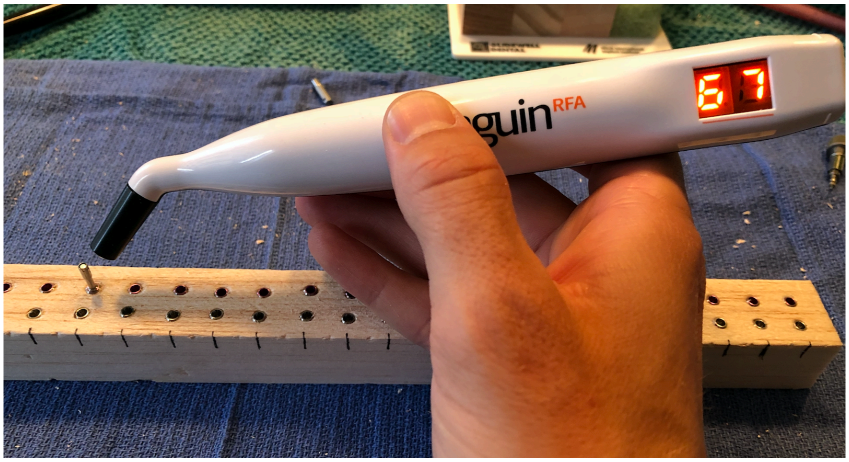

Figure 13: RFA recording using Penguin RFA Analyzer (Aseptico, Woodinville, WA)

4.1.5 Statistical Analysis

Once all data had been collected on an Excel spreadsheet, the values were uploaded into Stata 16 (StataCorp, College Station, TX) to be analyzed. Analysis of the differences in ISQ values between tapered and parallel wall implants was evaluated using a 2-sample t-test because both variables in this study were independent. The test provided information as to whether a difference existed between the variables and if the p-value if this difference was statistically significant.

5.0 CHAPTER 3

5.1 Results

Data for the 48 implants tested in the study are expressed below in table 1. The mean ISQ value for tapered implants was 67.125 +/- 1.974 and for parallel walled implants was 64.813 +/- 0.93. The 2-sample t test was used to determine if a difference existed between the ISQ values. The 2-sample t test yielded a p-value = 0.0000. Since the p-value < 0.05, there was a statistically significant difference between the ISQ scores of the tapered and parallel walled implants. This study concluded that tapered dental implants do reach a statistically significant greater primary stability in poor quality bone than parallel walled implants and rejected the original null hypothesis.

	A	B	C	D	E	F	G
1	**TAPERED (n=24)**				**PARALLEL (n=24)**		
2	**1st reading**	**2nd reading**	**Average**		**1st reading**	**2nd reading**	**Average**
3	68	71	69.5		64	65	64.5
4	69	66	67.5		66	66	66
5	64	66	65		67	64	65.5
6	71	69	70		65	64	64.5
7	67	65	66		65	63	64
8	71	69	70		64	66	65
9	70	67	68.5		64	64	64
10	65	66	65.5		66	67	66.5
11	70	70	70		65	64	64.5
12	69	68	68.5		65	64	64.5
13	68	65	66.5		63	66	64.5
14	66	66	66		65	67	66
15	68	70	69		66	65	65.5
16	68	67	67.5		64	67	65.5
17	66	65	65.5		66	65	65.5
18	67	64	65.5		66	65	65.5
19	67	69	68		64	62	63
20	62	66	64		66	64	65
21	64	68	66		62	66	64
22	68	71	69.5		63	64	63.5
23	66	64	65		64	62	63
24	70	67	68.5		65	66	65.5
25	64	64	64		66	63	64.5
26	65	66	65.5		65	66	65.5
27	**AVERAGE**		**67.125**		**AVERAGE**		**64.8125**

Figure 14: ISQ values for tapered and parallel walled implants compared in this study

```
. ttest Tapered == Parallel, unpaired

Two-sample t test with equal variances
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
 Tapered |      24      67.125    .4029443    1.974016    66.29145    67.95855
Parallel |      24     64.8125    .1899001    .9303167    64.41966    65.20534
---------+--------------------------------------------------------------------
combined |      48    65.96875    .2774816    1.922449    65.41053    66.52697
---------+--------------------------------------------------------------------
    diff |              2.3125    .4454505                1.415855    3.209145
------------------------------------------------------------------------------
    diff = mean(Tapered) - mean(Parallel)                         t =   5.1914
Ho: diff = 0                                     degrees of freedom =       46

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

Figure 15: 2-sample t-test results in State 16 (StataCorp, College Station, TX)

6.0 CHAPTER 4

6.1 Discussion

The importance of adequate primary stability has been directly linked to osseointegration and the long-term success of dental implants[212] Primary stability is dependent on the quality and quantity of bone, the surgical technique, and the implant fixture geometry. Misch stated that following implant placement, bone density is the main determinant for the mechanical stability of dental implants. [213] Advances in implant design and improved surgical techniques have enabled greater primary stability in poor quality bone.

The purpose of this study was to compare the initial stability of tapered and parallel walled dental implants in poor quality bone. The achievement of primary stability in poor quality bone is difficult and failure to do so can lead to implant failure.[214] O'Sullivan stated that "due to the lack of cortical bone in type 4 bone, an implant has minimal or no primary stability. This in turn may result in a lack of osseointegration due to implant micromotion."[215] Micromotion in excess of 150 um has been shown to interfere with the biological process of implant stabilization via bone resorption and apposition. [216]

The implants in this study were inserted into homogenous balsa wood to eliminate the variability of bone parameters on the primary stability of the implants. An in-vivo bone model would have increased the heterogeneity across the samples. Bone can present different density, hardness, and mechanical properties in the same segment, ultimately affecting the primary stability of the implant. CBCT analysis confirmed that Balsa wood was an adequate representation of poor quality bone similar to that found in the posterior Maxilla.

The osteotomy was prepared using a drill press through a surgical guide. This was done to limit the variability in the drilling and placement of each implant.

The primary stability of the implants was calculated using Resonance Frequency Analysis (RFA), which is a noninvasive method to quantify the stability of an implant at time of placement as well as throughout the healing phase.[217] ISQ values provide a reproducible assessment of the bone-implant interface.[218] The stiffer the bone-implant interface, the higher the ISQ score.

Many studies in the literature have compared the stability of in different types of dental implants. However, the majority of these studies had many different variables among the implants tested. In this study, the only variable tested was the tapering body of a tapered dental implant compared to a parallel walled implant. All other variables such as thread geometry and pitch, surface composition and texture, and diameter and width were eliminated. This was done to accurately determine whether the tapered body allowed greater initial stability in poor quality bone.

The present study found ISQ scores for tapered implants to be higher than those for parallel walled implants. The conclusion was that tapered implants achieve greater initial stability than parallel walled implants in poor quality bone. Thus, the null hypothesis for this study was rejected.

These results are important because the implant surgeon has historically had greater implant complications and failures in the posterior maxilla, where the bone quality is the poorest. Additionally, with the increase in the amount of immediate placement and immediate loading, primary stability has become more of a necessity. Due to less surgeries and trauma, reduced overall treatment time, and decreased patient anxiety and discomfort immediate placement and loading has become more popular. With that, the implant surgeon must try to achieve adequate primary stability in sites that are compromised by poor bone density and quality. By using a tapered design implant, the surgeon can increase the primary stability and overall success of dental implant therapy.

7.0 CHAPTER 5

7.1 Conclusion

Within the limits of this *in vitro* study, tapered design implants achieved higher primary stability in poor quality bone than parallel walled implants.

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