A Comparison of implant stability between two implant systems using guided Surgery in inexperienced surgeons

Miss Pinmuk Supachaiyakit

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การเปรียบเทียบความเสถียรของรากเทียมสองระบบโดยใช้แผ่นจำลองทางการผ่าตัดโดยใช้คอมพิวเตอร์ในทันตแพทย์ผู้ ไม่มีประสบการณ์

น.ส.ปิ่นมุก สุภาไชยกิจ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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วัตถุประสงค์: เพื่อศึกษาความเสถียรของรากเทียมของรากเทียมชนิดปลายตัดเกลียวเดียว และรากเทียมชนิดปลายสอบเกลียวคู่ โดยการวัดเสถียรภาพด้วยค่าความถี่เรโซแนนซ์ ในช่วง 8 อาทิตย์แรกหลังการใส่รากเทียม *วิธีการทดลอง*: รากเทียม 28 ตัวได้รับการทดลองแบบสุ่มโดยใช้คอมพิวเตอร์ โดยถูกแบ่งเป็น สองกลุ่ม เพื่อทดแทนซี่ฟันใน บริเวณฟันกรามหลัง เครื่องถ่ายภาพรังสีซีบีซีทีจะนำมาวัดความหนาแน่นของกระดูกและวางแผนการผ่าตัด การฝังรากเทียมกระทำโดยใช้แผ่นจำลองทางการผ่าตัดโดยใช้คอมพิวเตอร์ ในทันตแพทย์ผู้ไม่มีประสบการณ์ ซึ่งได้รับการวางแผนด้วยโปรแกรมวางแผนรากเทียมสามมิติโดยทันตแพทย์ผู้เชี่ยวชาญ การวัดความเสถียรของรากฟันเทียมทำด้วยวิธีการวัดค่าความถี่เรโซแนนซ์เป็นค่าไอเอสคิว ทันทีหลังการฝัง และติดตามความเสถียรของรากฟันเทียม ที่สัปดาห์ที่ 4 และ 8 หลังการผ่าตัด รวมเป็น 3 ช่วงเวลา ค่าเฉลี่ยของค่าไอเอสคิวได้ถูกนำมาบันทึกและวิเคราะห์ในแต่ละช่วงเวลา โดยค่าไอเอสคิวแรกที่วัดได้ทันทีหลังการผ่าตัดรากเทียม ถือว่าเป็นค่าอ้างอิงเริ่มต้น หรือเรียกได้ว่าคือค่าความเสถียรปฐมภูมิ *ผลการทดลอง*: ระหว่างรากเทียมทั้งสองกลุ่ม พบว่าค่าไอเอสคิวมีแนวโน้มไปในทิศทางเดียวกันทุกช่วงเวลาการทดลอง ค่าไอเอสคิวของรากเทียมทั้งสองชนิดมีค่าลดลงอย่างมีนัยสำคัญในช่วง 4 อาทิตย์แรกหลังการฝังรากเทียม ก่อนค่าจะกลับมาสูงขึ้นอย่างมีนัยสำคัญ ณ สัปดาห์ที่ 8 ระหว่างรากเทียมทั้งสองชนิด พบว่ากลุ่มทีเอส/ดีที มีค่าไออิสคิวที่มากกว่ากลุ่ม ซีเอส/เอสที ในทั้ง 3 ช่วงเวลา แต่ไม่มีผลอย่างมีนัยสำคัญ ด้านความหนาแน่นของกระดูก กลุ่มทีเอส/ดีที พบค่าเฉลี่ยไอเอิสคิวที่แตกต่างอย่างมีนัยสำคัญในกลุ่มความหนาแน่นกระดูกระดับ 4 *สรุป*: คุณลักษณะที่แตกต่างของการออกแบบรากเทียมทั้งสองชนิด ไม่มีผลอย่างมีนัยสำคัญต่อค่าเสถียรภาพของรากเทียม แต่รากเทียมกลุ่มดีเอส/ดีที พบว่ามีคุณสมบัติเหนือกว่ากลุ่ม ซีเอส/ดีที เมื่อฝังรากเทียมในความหนาแน่นกระดูกระดับ 4

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
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KEYWORD: DENTAL IMPLANT/ IMPLANT STABILITY/RESONANCE FREQUENCY ANALYSIS/ IMPLANT DESIGN/ BONE DENSITY

Pinmuk Supachaiyakit : A Comparison of implant stability between two implant systems using guided Surgery in inexperienced surgeons. Advisor: Assoc. Prof. PRAVEJ SERICHETAPHONGSE, D.D.S., M.S. Co-advisor: WAREERATN CHENGPRAPAKORN, D.D.S., Ph.D.

Aim: To investigate the implant stability in relation to two different implant designs, a cylindrical shaped single threaded design (CS/ST) and a tapered shaped double threaded design (TS/DT) using RFA over the first 8 weeks. *Materials and Methods*: 28 implants were randomly allocated into two groups and were placed as single tooth implant in the posterior arch. CBCT scan was used to determine the bone density and the implants were placed with guided surgical template by inexperienced surgeons which were prepared with the same implant planning software. The implant stability was measured using the RFA over the first 8 weeks at 3 points intervals. A mean ISQ value was recorded at each time points. The first ISQ of each implant recorded at the time of implant placement were the so-called primary stability. *Results*: A similar pattern of implant stability changes was observed. A significant decreased was found at the first four weeks after implantation ($P<0.05$) before ascending to maximum cumulative stability by the 8th week ($p<0.05$). Between the 2 groups, TS/DT group had a higher mean ISQ values at all three observation periods but did not reach statistical significance ($P=0.69$). Regarding different types of bone, TS/DT showed a significant difference in mean ISQ values in D4 bone. *Conclusions*: The difference in implant design did not significantly influence the implant stability however, TS/DT shows superiority over CS/ST when placed in D4 bone.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....
		Co-advisor's Signature ....

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Pinmuk Supachaiyakit

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Chapter I

Background and Rationale

Over half the century, dental implants have become an increasingly popular oral rehabilitation method, whether for fully or partially edentulous patients. The long-term function and success of dental implants are heavily dependent upon successful osseointegration to maintain implant stability and withstand the dynamic of functional loading.[1, 2]

Implant stability plays a critical role for successful osseointegration. Therefore, measuring implant stability is an important method for evaluating the success of an implant. Implant stability can be classified into Primary stability and Secondary stability. At the start, Primary stability comes from the mechanical engagement with the cortical bone when the implant is placed in a position that allows the implant to adapt to the bone of the host.[3] In contrast, Secondary stability is associated with biological stability gained through the process of bone regeneration and remodeling which are dynamic and occur over time.

In the beginning, primary stability accounts for the overall stability of the implant. It occurs from the mechanical retention between the implant and the bone. Soon after the biological response of the bone tissue take place, resulting in the regeneration and remodeling of the bone. During this time as the primary stability decreases and the new bone formation or the secondary stability is starting to increase, this time point is referred to as the “stability dip”. [4]

It is imperative for clinical success that the implant maintain a relatively adequate stability to allow for proper healing. As during this critical time of stability dip as mentioned above, micromotion of the implant may occur if the implant is not sufficiently stable during the transition period between the primary and secondary stability.[5] This micromotion may result in a disrupted healing process, leading to the fibro-osseous integration instead of osseointegration thereby leading to subsequent clinical failure of the dental implant.[6]

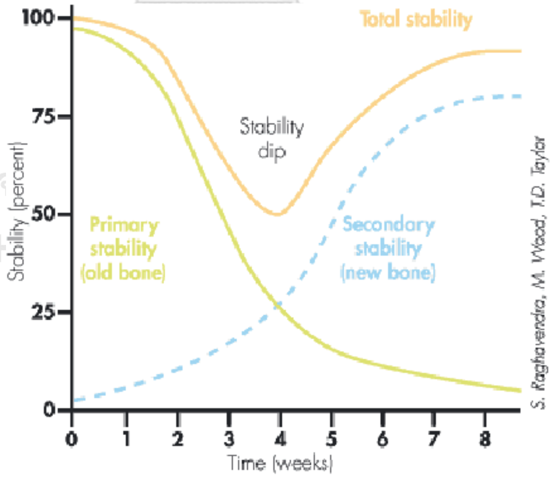


Figure 1: The stability dip [4]

Implant stability depends on several factors. The first factor is the density and dimension of the bone surrounding the implant. In other words, this will determine the amount of bone-to-implant contact (BIC). Bone quality and quantity has a positive relation to implant stability and is a key factor in predicting implant stability. Many clinical studies have found a greater implant survival in areas such as the mandible than the maxilla due to its soft bone quality [3, 7].

The second factor influencing implant stability is the implant design. Implant design can simply be further divided into two major categories: Macro-design and Micro-design. Micro-design of implants refers to the surface morphology and surface treatment which focuses on the biological aspect and host response and plays a part in favorable osteoblastic response. Thus, it may have little effect on the primary stability of the implant immediately after placement but have more influence on the secondary stability enhancing the osseointegration during the healing period. [8]

In this study, the focus is mainly on implant macro-designs and the effect it has on primary stability. Marco-design includes the thread geometry (shape, pitch, lead, depth, width and crestal module) which focus mainly on the relativity between the mechanical features of the implant design and osseointegration. [9] Therefore, the macro-design of an implant highly influences the primary stability and force transmission. Hence, it should be designed to maximize the surface contact area to the bone while minimizing the extreme adverse stresses by favorable stress distribution. Review of literatures have found that square thread shape provided the best primary stability while thread with smaller pitch increases the BIC. Thread depth is also essential in mitigating the stresses within the bone and a microthread configuration at the neck of the implant might increase stress distribution and decrease marginal bone loss. On the other hand, tapered implants were found to have higher primary stability due to the fact that they exert more lateral compressive force in the surrounding bony walls. [9, 10 11 12]

Another factor that might influence the implant stability is the surgical technique and condition of the implant bed. This includes the clinician’s skill, which might also play a role in affecting the implant stability. A study by Romanos et al. found that both experienced and inexperienced surgeons achieved primary stability, although higher ISQ values were observed with surgeons who were more experienced.[13] However, a more recent study in 2019 conducted a study to assess the role of clinical experience on primary stability and found that no significant differences in ISQ values were detected between the clinicians with different experiences.[14]

Measuring implant stability is of utmost importance since it’s a predictor of osseointegration, hence being able to measure implant stability at different time points can help determine a long-term prognosis of the implant individually and is useful in predicting the “optimum healing period” which consequentially lead to the suitable loading time[15, 16].

Implant stability can be measured by a variety of methods. The two most popular method are classified under non-destructive methods - Periotest and

Resonance Frequency Analysis. Due to the difficulty in controlling the angle, position and force of the rod , Periotest remains an uncertain prognostic tool for implant stability for its poor susceptibility to operator variables.[15, 17] Hence, the Resonance Frequency Analysis was chosen in this study which measures implant stability in the quantitative method and can be monitor over the healing period, therefore it can be a valuable tool in assessing the implant to bone interface. It is important to note one major disadvantage of the RFA method which includes unscrewing the healing abutment for measurement of the ISQ values since this may be critical to the implant healing phase.

In today's world, the spotlight of implant surgery has shifted from the conventional (free hand) technique to the computer assisted surgery (CAS) for dental implant placement[18]. The launch of the computed tomography (CT), implant software, computer-aided design/ computer-assisted manufacturing (CAD/CAM) provides the clinician with a virtual 3D realistic view of the treatment area hence, an ideal implant position can be designed in a precise prosthetically driven manner.[19]

In a recent systemic review by Chen et al in comparing the accuracy between the free-hand and surgical guide technique. They found that for both angular deviation and deviation at the apex and coronal, surgical guide had significantly less deviation than free-hand technique.[20]

Although, a variety of factors have been reported to contribute to the accuracy of the static template-based guidance system including the type of tissue support, type of arch, guide type, surgical technique, image acquisition and the clinician’s skill.

To date, the comparative clinical studies on the changes of RFA values in two different implant system using the computer assisted surgery is very limited. In addition, studies in inexperienced clinicians in terms of RFA values using the computer assisted surgery is also very scarce.

Research Question

Do different implant systems effect the implant stability when using the same implant planning software in inexperienced surgeons?

Statement of hypothesis

Null hypothesis

1. There was no significant difference on implant stability based on implant systems
2. There was no significant effect between the implant systems and inexperienced surgeons in terms of the RFA value.

Research Objectives

The aim of this study was to investigate the longitudinal changes in the stability of posterior implant regions between two implant systems using guided surgical technique with the same implant planning software in inexperienced surgeons by examining RFA over the first 8 weeks.

Keywords

Dental implant, Implant stability, Resonance Frequency Analysis, Bone density, Implant design

The Expected Benefits

1. Information regarding implant stability in the span of 2 months between 2 implant systems with different macro-design using guided surgery will be compared.
2. If there are differences in the RFA between the two systems, this information will provide useful information to implant surgeons in deciding implant system used.

Chapter II

Implant Stability

Implant stability plays a critical role for successful osseointegration. Therefore, measuring implant stability is important for evaluating the success of an implant. Implant stability can be classified into Primary stability and Secondary stability. At the start, Primary stability comes from the mechanical engagement with the cortical bone when the implant is placed in a position that allows the implant to adapt to the bone of the host this is often referred to as the “primary bone contact” [3]. Histologically, lamellar plastic deformation, elongated Haversian systems and micro-fractures are seen on the bone. Additionally, a compression of the cortical bone can also be observed. [21] In contrast, secondary stability is associated with bone regeneration and remodeling. Osborn and Newesley in 1980 first described the term Distance and Contact Osteogenesis which refer to the relationship between the forming bone and the surface of the implanted material.[22] Since bone tissues are dynamic, regeneration and remodeling occur over time.

As shown in figure 1 [4], In the beginning, primary stability accounts for the overall stability of the implant. It occurs from the mechanical retention between the implant and the bone. Soon after the biological response of the bone tissue take place, resulting in the regeneration and remodeling of the bone. During this time as the primary stability decreases and the new bone formation or the secondary stability is starting to increase, this time point is referred to as the “stability dip”. [4]

It is imperative for clinical success that the implant maintain a relatively adequate stability to allow for proper healing. As during this critical time of stability dip as mentioned above, micromotion of the implant may occur if the implant is not sufficiently stable during the transition period between the primary and secondary stability[5].

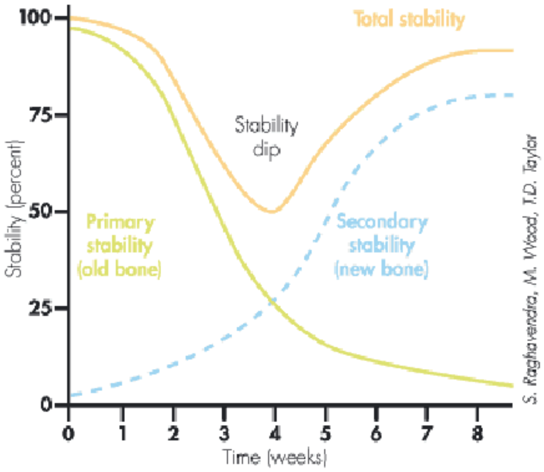


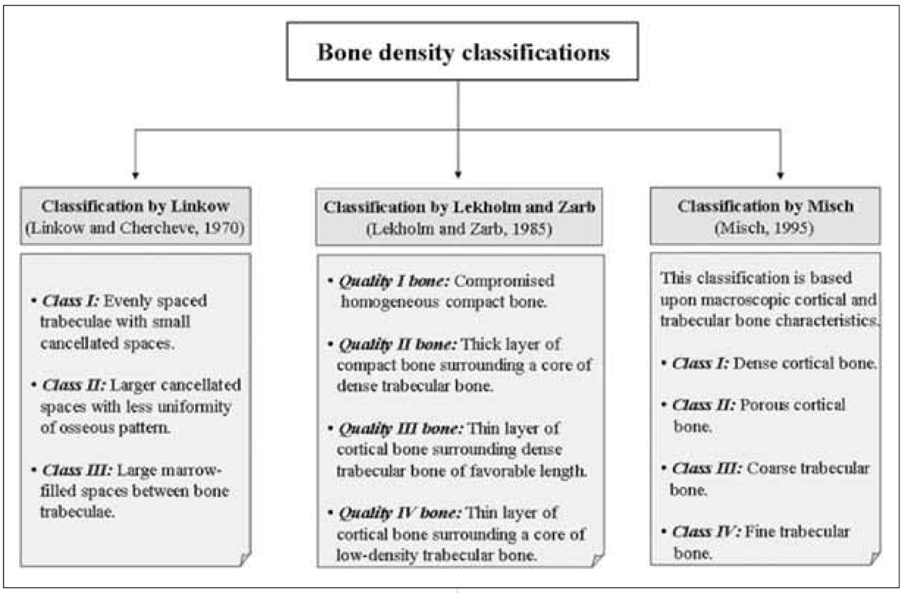
Figure 1. The decreasing primary stability and increasing secondary stability between week 2 and 4 of implant placement, resulting in a stability dip[4]

This micromotion may result in a disrupted healing process, leading to the fibro-osseous integration instead of osseointegration thereby leading to subsequent clinical failure of the dental implant[6].

Factors Affecting Implant Stability

Implant stability depends on several factors. The first factor is the density and dimension of the bone surrounding the implant. In other words, this will determine the amount of BIC or bone-to-implant contact. Bone quality and quantity has a positive relation to implant stability and is a key factor in predicting implant stability. Many clinical studies have found a greater implant survival in areas such as the mandible more than the maxilla due to its soft bone quality [3, 7].

The classification of bone density and its relation to dental implant treatments have been evaluated for half the century.[23] The bone density classifications can be seen in figure 2 [3].



Bone density classifications

Classification by Linkow (Linkow and Chercheve, 1970)

- ***Class I:*** Evenly spaced trabeculae with small cancellated spaces.
- ***Class II:*** Larger cancellated spaces with less uniformity of osseous pattern.
- ***Class III:*** Large marrow-filled spaces between bone trabeculae.

Classification by Lekholm and Zarb (Lekholm and Zarb, 1985)

- ***Quality I bone:*** Compromised homogeneous compact bone.
- ***Quality II bone:*** Thick layer of compact bone surrounding a core of dense trabecular bone.
- ***Quality III bone:*** Thin layer of cortical bone surrounding dense trabecular bone of favorable length.
- ***Quality IV bone:*** Thin layer of cortical bone surrounding a core of low-density trabecular bone.

Classification by Misch (Misch, 1995)

This classification is based upon macroscopic cortical and trabecular bone characteristics.

- ***Class I:*** Dense cortical bone.
- ***Class II:*** Porous cortical bone.
- ***Class III:*** Coarse trabecular bone.
- ***Class IV:*** Fine trabecular bone.

Figure 2: Bone Classifications

First, in 1970, Linkow and Chercheve classified bone into three classes. In 1985, Lekholm and Zarb[24] reported four bone qualities based on their the radiographic assessment, and the sensation of resistance encountered by the surgeon when preparing the implant placement. Finally, Carl E Misch [25] further classified bone into 4 types based on the cortical and trabecular bone characteristics. From Misch’s classification in 1988, D1 bone has dense cortical bone while D2 bone has dense to porous cortical bone with a coarse trabecular bone. D3 bone has thinner porous cortical bone with fine trabecular bone while D4 almost has no cortical bone. The mean bone density of the implant area can be measure in Houndsfield units (HU) with an imaging software from the CBCT. The mean HU values of the implant area can be classify into each bone type according to Misch's criteria in *Table 1*[26]. Several studies found that implants placed in bones with a thick cortical bone tend to have a better primary stability than areas with an open trabecular network. A study by Ostman and colleagues reported that decreasing implant stability was seen with decreasing bone quality[27]. Therefore, areas with Class I, II or D1 and D2 seems to favor primary stability. However, bones that are dense tend to cause adverse effect during implant preparation and can cause overheating to the bone. Ironically, viable cellular component is required as secondary (biological) stability commence with the bone regeneration and remodeling phenomena. Thus, bone class IV or D4 provide a higher number of viable cells even though it has poor bone density.

Bone Type	*Houndsfield Unit*
D1	>1,250 HU
D2	850-1250 HU
D3	350-850 HU
D4	150-350 HU

Table 1: Bone density classification of Houndsfield units (HU) by Misch's criteria[12]

An analysis of correlation between the HU of CBCT scans and implant primary stability was conducted by Montenegro et al. A study in 29 patients in the posterior mandible was performed and the values of HU units and ISQ values were obtained. In conclusion they did not find a correlation between the HU values and primary stability.[28] On the other hand, Coutant et al. conducted a study in NobelActive implants and found a correlation between a bone density of 350 HU with an ISQ value of 50 or greater. Therefore, CT images can be a useful predictor of primary stability prior to the surgery. [29]

The second factor influencing implant stability is the implant design. Implant designs are the three-dimensional structure of the implant whether it be their surface typography, chemistry, surface energy and surface wettability which has been reported to attribute to the implant’s biologic capacity.[30] Implant design can simply be further divided into two major categories: Macro-design and Micro-design.

Implant Macro-design

Macro-design includes the thread geometry (shape, pitch, lead, depth, width and crestal module) which focus mainly on the relativity between the mechanical features of the implant design and osseointegration. Therefore, the macro-design of an implant highly influences the primary stability and force transmission. Hence, it should be designed to maximize the surface contact area to the bone while minimizing the extreme adverse stresses by favorable stress distribution.[9, 10] The implant geometry mentioned is shown in figure 3.[9]

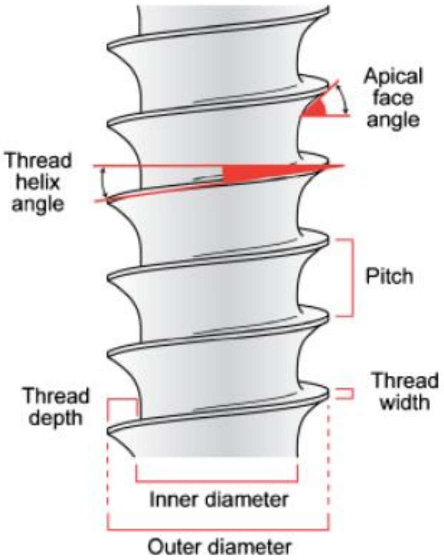


Figure 3: Basic implant macro-design features[9]

As shown below in figure 4, several thread shapes can be found in commercial implants. To date, a number of studies have reported the influence of thread shape on the surrounding bone. For most studies, the square thread shape seems to have the most favorable response in terms of stress distribution and micromotion value.[31, 32] However, it is important to note that these studies utilize the Finite Element Analysis (FEA) for the stress distribution analysis which are computer-based mechanical design and might not give forth the true result in the oral cavity.[9, 10]

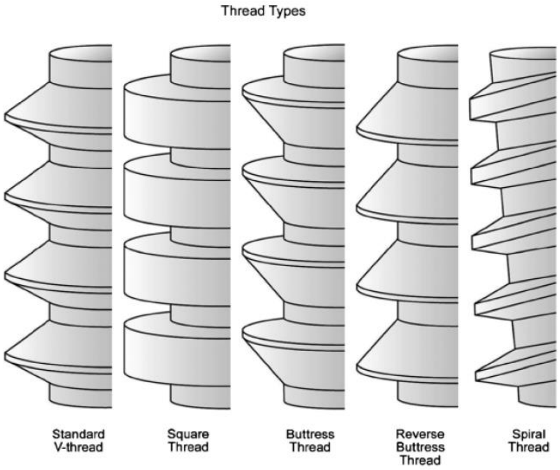


Figure 4: Different thread shapes of implant [9]

Thread pitch refers to the distance between one thread to the other, measured parallel to the long axis of the implant. On the other hand, lead is the distance within the same thread after one complete revolution. Thus, for double or triple threaded implants, lead doubles or triples the pitch (Figure 5). [9] This determines the speed in which an implant is inserted into the bone. Gonzalez-Serrano et al. compared single thread and double thread design in D3 type bone and found that higher ISQ value was found for the double thread implants due to better bone to implant contact. [33] Moreover, several studies have reported that narrow pitch (more threads) have a higher percentage of bone to implant contact thereby reinforcing the primary stability of an implant and were more effective in distributing stress when compared to implants with wider pitch. Studies have also found that thread pitch plays a greater role in increasing the primary stability in poor bone quality than in high bone quality. [9, 10]

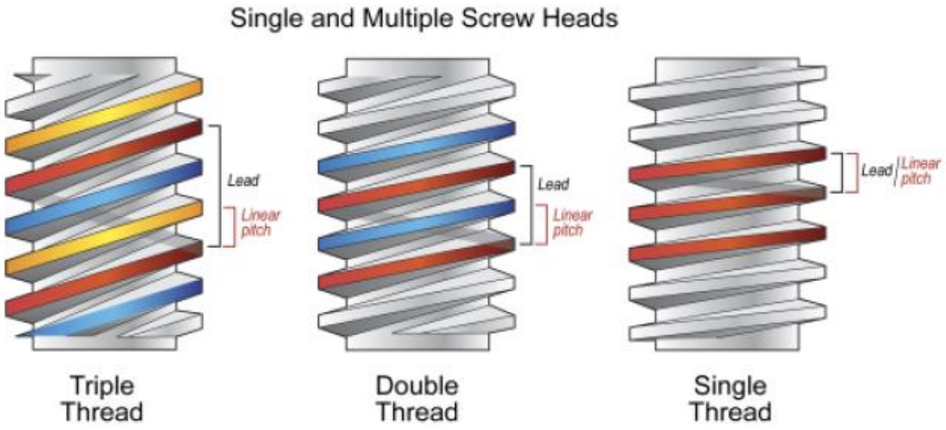


Figure 5: The thread configurations [9]

Thread depth is the distance from the outer rim to the inner rim of the thread while thread width is the distance measured of a single thread from the upper to the lower tip. FEA studies show that shallow thread depth grants an easier implant insertion process. However, deeper threads have greater surface area of the bone to implant interface and might be beneficial in poor quality bone where an increase in primary stability is needed.[10] In addition, a FEA study by Kong et al. found that thread depth had a higher impact on reducing the stress on the bone than thread width. [34]

The area at the neck of the implant is referred to as the crestal module. It is a crucial part of an implant since it is the area where it is expose to the open oral cavity. The concept of microthread was introduced to the crestal portion of the implant to minimize marginal bone loss and maintain the soft tissue surrounding the bone. Amid R et al. found that stress was often situated at the cortical bone next to the neck of the implant and by adding a microthread design, the stress at the cortical bone was reduced. [11] A recent study by Jin et al. in 2019, found that the microthread design of implant reduces the shear stress in the peri-implant bone thereby reducing the marginal bone loss. However, with the decline of marginal bone level, this effect is gradually mitigated. [35]

Implant design is another important aspect of the implant macro-design and has undergone various changes over the years. Dos Santos et al. analyze the influence of implant design on primary stability and found no statistically difference in ISQ values between tapered and cylindrical implants.[8] Similarly, A split-mouth prospective study by Waechter et al. found no significant difference in ISQ and IT values when comparing between tapered and cylindrical implants. [12] On the other hand, Carrascal et al. conducted a clinical study comparing between the cylindrical and tapered implants and found that tapered implants achieved greater primary stability when measuring through the ISQ and IT values. This might be explained by the fact that tapered implants permit a higher lateral compression force against the crestal and surrounding bone of the implant. Thus, this might be valuable in poor bone quality areas to achieve a better primary stability. [36]

In addition, the effect of implant length and diameter on the primary stability was assessed in many studies. A clinical study by Barikani et al, reported that implant length influenced the primary stability when they are placed in bone with low quality (D3, D4) type[37] .In contrast with this study, Ostman et al, found that implant stability plummeted with the increased implant length. The primary stability decreased at 15 and 18 mm when compared to 7-13mm in length. The author proposed that it might be due to increased heat when placing longer implants. [27] In the implant diameter aspect, Ostman's research found wide implants were more stable due to the fact that the larger the surface, the more it engages the cortical bone walls. In accordance with this Barikani and colleagues found that narrow platform implants (NP) demonstrated the lowest primary stability value when compared with Regular platform (RP) and Wide platform (WP) implants. However, the result was more prominent in low bone quality. Therefore, avoiding the use of NP implants in low quality bone was suggested. In addition, the primary stability value in RP and WP were not significantly different. Considering that, RP implants were recommended since it will help preserve the thickness of the bony walls[27, 37].

Micro-Design of implant

Micro-design of implants refers to the surface morphology and surface treatment which focuses on the biological aspect and host response and plays a part in favorable osteoblastic response. Thus, it may have little effect on the primary stability of the implant immediately after placement but have more influence on the secondary stability enhancing the osseointegration during the healing period. [8]

Many in vitro studies found that surface typography, especially the surface roughness increases the spreading, proliferation, differentiation of osteoblastic lineage cells and protein synthesis. These changes alter the growth, metabolism and migration of these osteogenic cells thus leading to improved bone integration with increased osteoconduction and osteogenesis. [30, 38, 39]

There are various methods in altering the surface of the implant. It is important to note that the surface typography is dependent on surface orientation and roughness and different machining procedures will produce different orientation, reported by Stout et al.[40] The commonly used techniques on altering the surface can be classified into subtractive processes and addictive processes. Examples of subtractive processes are Blasting, etching, mechanical polishing and oxidation. On the other hand, examples of additive processes are hydroxyapatite (HA) and other Calcium phosphate coatings, Titanium plasma-sprayed (TPS) and Ion deposition[38].

Apart from the factors mentioned above, another factor that might influence the implant stability is the surgical technique and condition of the implant bed. A precise drilling technique should be used to optimize bone density. It is recommended that an undersized drilling technique will increase the density of the surrounding bone of the implant which will in turn increase the primary stability of the implant[3]. However too tight-fitting implants can also cause adverse effect to the osseointegration. In addition, avoid overheating the bone, studies have found that continuous heating of the bone over 47 degrees causes detrimental effect to the bone as such local ischemia and osteonecrosis of the bone.[41, 42]. The clinician’s skill might also play a role in affecting the implant stability. A study by Romanos et al. found that both experienced and inexperienced surgeons achieved primary stability, although higher ISQ values were observed in low bone quality with surgeons who were more experienced.[13] A more recent study in 2019 conducted a study to assess the role of clinical experience on primary stability and found that no significant differences in ISQ values were detected between the clinicians. An aggressive threaded implant was used in this study and they concluded that implant geometry is more crucial than the clinical experience in achieving good primary stability. [14]

Measurement of Implant Stability and Osseointegration

Implant stability have been suggested by many authors to be a useful predictor for the long term success of osseointegration[15]. It occurs in two stages, the primary stability and the secondary stability. As is mentioned above, primary stability comes from the mechanical engagement with the surrounding bone while the secondary stability is a biological stability gained through the bone remodeling and regeneration process [5]. Secondary stability has been shown to increase around 4 weeks after the insertion of the implant and is dependent on the primary stability [4] The factors that influence implant stability is summarized in Table 2 below. [43]

Measuring implant stability is of importance since it’s a predictor of osseointegration, hence being able to measure implant stability at different time points can help determine a long-term prognosis of the implant individually and is useful in predicting the “optimum healing period” which consequentially lead to the suitable loading time[15, 16].

Factors Affecting Primary Stability	*Factors Affecting Secondary stability*
Bone quantity and quality	Primary stability
Implant (e.g. Geometry, length, diameter, surface characteristics)	Bone remodeling and regeneration
Surgical technique	Implant surface characteristics

Table 2: Factors that influence Implant Stability[43]

To date, a various of methods was introduced for the measurement of implant stability. The methods can be widely categorized into 2 categories. Non-destructive and Destructive method. The destructive methods include the Tensional Test, Push-out/Pull-out Test, Histomorphologic test and Removal torque test while the non-destructive methods were radiography, Cutting resistance, Periotest and RFA [17].

The Histomorphologic test is considered a gold standard test since its highly objective, however it can only be done in vitro and is considered highly invasive.[43, 44] One of the most common tests to measure implant stability and has been performed since the early days is the percussion test. This test is based on the tapping of the implant/ abutment with a metallic instrument and an audible ringing sound is produced from the resonance and damping of the implant. The drawback to this test is, however, that it is very subjective and have poor sensitivity. It is hard to distinguish the resonance frequency, damping and amplitude of the tone produced.

In addition to this radiography was also commonly used. It is non-invasive and can be taken at any time before treatment and during any stage of healing. Nevertheless, to make the test reliable and repeatable, a customized template to ensure standardized radiographs are necessary but considered impractical and radiographs are often 2 dimensional and changes in the bone mineral were only detectable after 30% of the demineralization has occurred. Therefore, the use of radiography alone was not an accurate method in assessing the implant stability, rather it should be used in conjunction with other tests and as a follow up predicament[17, 43, 45].

Other test as such the Tensional Test, Push-out/Pull-out Test and Removal torque test are all highly destructive test and has many limitations. For the Removal Torque test, it provides result in an all or none manner as during the second stage of the implant, a counterclockwise (reverse) torque of 20Ncm is applied to an implant with the notion that osseointegrated implants can resist this torque while implants that fail will unscrew. Additionally, Push-out/Pull-out test have the limitation of being only applicable to non-threaded cylinder type implants while the available fixtures are usually threaded designs[17, 46].

Due to the lack of subjectivity and destructiveness, the development of diagnostic methods that were more objective, non-invasive and clinical effective was introduced – the Periotest and the Resonance Frequency Analysis[47, 48].

Originally, the Periotest has been widely used to measure tooth mobility which was first advocated by Dr. Schulte.[49] In measuring implant stability, it is an electronic device with a metallic rod that measures the damping characteristics or dynamic tissue recovery after loading to assess the osseointegration. The contact time between the implant and the tapping rod is measured and converted into Periotest value (PTV) -8 (low mobility) to +50 (high mobility). Though many studies have reported that Periotest is a reliable method in measuring implant stability[50, 51] Meredith et al, found that the striking point, angulation of the tapping rod, the height of the abutment and the force in generates on the implant can alter the accuracy of this method. Therefore, until the difficulty in controlling the angle, position and force of the rod is solved, Periotest remains an uncertain prognostic tool for implant stability for its poor susceptibility to operator variables.[15, 17] A commercially marketed implant stability called Anycheck was recently introduced combining the advantages of the damping method and RFA. Its most valuable attraction is the elimination of unscrewing the healing abutment which is critical during healing process. The results are displayed in the standardized ISQ values. However as with the drawback of the Periotest, the force that is generated on the implant cannot be controlled and may be detrimental to the implant. In addition, controlling the angle, position and rod in area such as the posterior mandible with intact adjacent tooth may be infeasible.

Resonance Frequency Analysis

In 1996, Meredith et al, [15] introduced the Resonance Frequency Analysis (RFA) that measure implant stability based on vibration and a principle of structural analysis. In the original instruments, RFA uses a small L-shaped transducer which is tightened to the implant or the abutment by a screw. The transducer utilizes stainless steel or titanium and comprised of an offset cantilever beam with piezoceramic elements. It comprised of 2 piezoceramic elements. One of which was vibrated with a typical frequency of 5 to 15 kHz using a frequency response analyzer. The second piezoceramic element measures the response of the transducer to the vibration thus the RFA represent the stiffness of the bone to implant interface resulting from the peak of frequency against the amplitude plot which was converted into a value.[17, 43] At the beginning, the measurements were in Hz but since the experimental RFA was commercially available (Osstell®, Integration Diagnostic AB, Göteborg, Sweden) the implant stability quotient (ISQ) was created as a replacement of Hertz[27]. 100 is represented as the highest implant stability while 1 implies instability. An invitro study by Herro-Climent et al. experimented on the RFA system Osstell ISQ and found an almost perfect repeatability and reproducibility of the ISQ values naming it a reliable method in measuring implant stability.[52] The manufacturer’s propose guideline is that an ISQ < 50 typically indicate an increased risk of failure while and ISQ of more than 65 lead to typically successful implants.[48] With the development, a wireless metal rod (SmartPeg) with a small magnet attached to the top is connected to the implant via screw connection. It is excited with a magnetic pulse and the peg is vibrated in two direction, giving two ISQ values, one high and one low.

Mainly the Resonance frequency (RF) of an RFA is influenced by three factors as shown in figure 6. [2] The design of the transducer, the stiffness of the bone-implant interface and finally the effective length above the marginal bone level.[2]

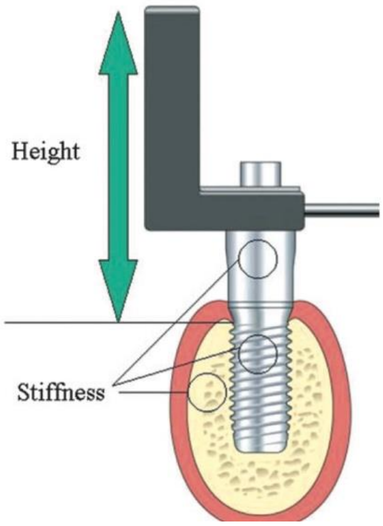


Figure 6 A schematic showing the principles of RF values and the factors that influences it.[2]

A positive correlation was found between cortical bone thickness and ISQ values[17]. A number of studies reported that Type 4 bone showed a lower mean initial ISQ value that other bone types. Although, by the 10 week after implant placement, no significant changes in ISQ was reported among the different bone types.[44]. Sim et al, proposed that implant stability might increase with the healing period with the predominately loose trabecular bone and blood vessels which contribute to a successful osseointegration.[53]

In a systemic review of RFA in assessing implant stability, Chen et al found that from a total of 62 articles, ISQ values increased over time, while, some of the increases were significant, others were not. In addition, some studies found an initial dip in ISQ values between 2 and 4 weeks after implant placement followed by an increased in mean ISQ values[54]. This phenomenon was expected due to many reasons such as stress relaxation after initial bone compression and a remodeling process with the development of osseointegration.

Effective implant length (EIL) was the sum length of the exposed implant height (marginal bone height) and abutment height. A contradictory relationship was found among the various studies. An increase in EIL was found with a decrease in the RF values showing an inverse relationship between ISQ and EIL, in a study by Lachmann et al who did an in vitro study of screw-type oral implants in acrylic blocks. [55] However, a longitudinal study by Meredith et al. who studied maxillary implants in function after 5 years in edentulous and partially edentulous patients, found a positive relation between EIL and the RF values[56].

A difference in ISQs were found between the arches with the mean ISQs of the mandibular implants higher than in maxillary implants.[44] In regard to the influence of implant diameter and implant length on the ISQ values, conflicting results were seen as some of the definition of “short” or “long”, “wide” or “narrow” implant differ among the studies. A variety of studies reported that implant length and diameter did not have adverse effect on the RFA[57]. In a study by Sim et al. when comparing between implant 8mm and 10 mm in length, they found that the ISQ values were higher initially for the 10mm implant but gradually after a healing period of 12 weeks both the 8mm and 10mm yield no significant difference in ISQ values.[53]

Moreover, when failed implants were taken into account, a systemic review by Chen et al. found that low initial ISQ value did not always lead to a failed implant. However, a majority of the failed implants either had a very lower or lower values of ISQ when compared over time.[44]

To date, there are no consensus on the cut-off ISQ value point indicating a success or failure of an implant. However, RFA measures implant stability in the quantitative method and can be monitor over the healing period, therefore it can be a valuable tool in assessing the implant to bone interface. Subsequently, an establishment of a proper healing period can be determined based on the prognosis of a given implant whether it be immediately loaded, early loaded in 6-8 weeks or left for uneventful healing period of 3-6 months. A safe level of the stability of the implant may differ in each system, for the Branemark type, an ISQ of 65-75 and for Straumann type an ISQ of 55-65 are indicated[2]. In addition, if a lower or decreasing ISQ values is detected, various measured can be taken for a close follow up which may prevent the implant from failing.

Computer Assisted Surgery (CAS)

In today's world, the spotlight of implant surgery has shifted from the conventional (free hand) technique to the computer assisted surgery (CAS) for dental implant placement.[18] Conventional surgical technique requires meticulous planning which involves taking a conventional CT/ CBCT with a radiographic template integrated foil / metal at the center of the prosthodontic wax up. However, the template is made on diagnostic cast without the knowledge of the unique boundary conditions and does not provide an exact 3-dimensional guidance during the implant surgery.[58] The launch of the computed tomography (CT), implant software, computer-aided design/ computer-assisted manufacturing (CAD/CAM) provides the clinician with a virtual 3D realistic view of the treatment area hence, an ideal implant position can be designed in a precise prosthetically driven manner.[19]

Presently, computer-guided systems can be categorized into 2 types, the static template-based guidance system and the dynamic navigation system. The dynamic navigation system uses the CAD/CAM technology to fabricate a surgical template or bur tracking and allow the clinician to track the real-time movement of the drill chairside. [19] On the other hand the static systems incorporate the use of the implant software, CAD/CAM technology with the anatomical and radiographic data collected by digital scanner and CBCT respectively. After virtual planning on the implant planning software, the production of a stereolithographic template is made by a CAD/CAM prototyping system.[19, 20] The digital workflow starts with acquiring data of the patient including the CBCT, the intraoral scan and the digital impression of a full contour wax-up.[59] The multiplanar reformatting (MPR) in the Computed tomography allows a reformatted cut in the axial, coronal and sagittal view which converts 2D images to be visualized in 3 different planes. Together with the anatomical view from the intraoral digital scan these data are processed through the virtual planning software. The location, angle, depth, diameter, abutments and provisional crowns can be virtually planned with precision in regard to the complex anatomic considerations, severely resorbed ridges and multiple implant sites.[58] Therefore, the computer assisted surgery offer prompt visualization and predictable planning in terms of reducing the probability of damage to unique boundary conditions and aids in prosthetic planning where both function and esthetic requirements must be met.[59]

Planning Software

At the moment, there are a number of third-party implant planning software programs available. 3shape Implant Studio from the TRIOS software has claimed to be user-friendly, easy planning and efficient for the digital workflow of the dental implant treatment.

Accuracy of the static CAS system.

Widman et al. stated that the accuracy of a guided surgery is defined as the cumulative and interactive deviation in the location and angle of the implant when compared with the plan and includes all possible errors that might occur from image acquisition to the surgical implant position.[58]

A number of studies have reported a deviation of the actual implant position from the virtual planned position when using the static CAS system. In a systemic review by Schneider et al. they found that the overall mean error in angulation in 3 clinical human studies (155 sites) were 5.73 degrees. The mean deviation point at entry and apex was at 1.16mm and 1.96mm respectively. However when analyzing all 8 articles found in the systemic review, a 1.07 mm of overall mean at deviation point, 1.63mm at the apex, a mean vertical deviation of 0.43mm and an overall mean angular deviation of 5.26 degrees was reported. [60]

George et al. conducted a study using 3shape Implant Studio, a digital intraoral scan from a Trios scanner and cone-beam computed tomography. Ten stereolithographic guides were made in-office with a desktop stereolithographic 3D-printer. The result found the mean mesiodistal angulation deviation was 0.84 degrees (range 0.08-4.48) and the mean facio-lingual angulation deviation was 3.37 degrees (range 1.12-6.43). [61]They concluded that the in-office printer demonstrates similar results than laboratory prepared guides.

In clinical split mouth study by Farley et al. on the accuracy of implant placement between the traditional surgical guide and computer-generated surgical guide in 10 patients who received 2 implants each in symmetric location. Using CAD/CAM surgical guides proved to have less variability and greater accuracy in the lateral direction than traditional guides.[62]

In a recent systemic review by Chen et al in comparing the accuracy between the free-hand and surgical guide technique. They found that for both angular deviation and deviation at the apex and coronal, surgical guide had significantly less deviation than free-hand technique. However, when assessing the survival rate, in a total number of 899 implants, they found no significant differences between the two technique.[20]

Despite the fact that the result in accuracy of the guided surgery varied among the studies, there is limited weak evidence suggesting that a CAD/CAM surgical template offer a higher accuracy than the traditional free-hand technique. With the information of deviation in mind, a safety distance of at least equivalent to the maximum deviation might be necessary to ensure a safe and predictable treatment outcome. CAS system still grant the advantage of the protection of critical anatomical structure and the function and esthetic of a prosthetically driven manner in mind.[20, 58]

Factors influencing the accuracy of the static CAS system

A variety of factors have been reported to contribute to the accuracy of the static template-based guidance system including the type of tissue support, type of arch, guide type, surgical technique, image acquisition and the clinician's skill.

Type of tissue support (Tooth-supported, Bone-supported,Mucosa-supported)

Raico Gallardo et al, conducted a systemic review on the accuracy of guided surgery according to the tissue of support and concluded that the tissue of the guide support influences the accuracy of the guided surgery. From a meta-analysis of 4 included studies, they found that bone supported guides showed a statistically greater deviation when compared to the mucosa-supported guides. However, when the outcome of all eight studies were analyzed, they found a statistically higher accuracy for the tooth-supported guides at all the deviation (the angle, the apex, and at the entry point).[59] Concurring with this is another systemic review by Van Assche et al. who also reported a statistically significant difference between the tooth and bone supported and between the bone and mucosa supported guides.[63]

Type of Arch (Maxillary/ Mandible)

From a systemic review by Zhou et al. in 2007, a statistically higher mean deviation was seen on the maxilla arch from a total of four studies in this systemic review. However, the global meta-analysis showed no difference in the coronal deviation between both archs. They discussed that from the result, the mandible has a more angular accuracy than on the maxilla. This may be due to the bone anatomy and bone density and structure of the mandible. The upper jaw has a lower bone density and therefore makes it easier to transfer accuracies than on the mandible.[64]

Type of Guide (Fully guided placement / Partially guided placement)

Two studies from a systemic review showed statistically accuracy when comparing the angle of deviation in the totally guided group that the partially guided group. Moreover, a higher degree of deviation at the point of entry and at the apex was seen in the partially guided group. [64]

Surgical technique (Flap/ Flapless approach)

The flapless approach was shown to be more accurate than an open-flap approach since a more extensive flap were needed in the guided surgery and this may cause a possible interference of the positioning of the guide due to the reflected tissue. Zhou et al. found a greater reduction in angle and coronal deviation when the flapless approach was used.[64] Despite this, the drawback to flapless approach is that it may compromise the more limited attached gingival tissue with the circumferential supracrestal fiberotomy. [20] On the other hand, flapless approach may unequivocally have the slight advantage in that it might reduce the patient's discomfort and postoperative pain.

Image acquisition

Zhou et al. studied the influence of radiographic techniques in a total of 15 studies in their systemic review. 6 studies used CBCT whereas the other 9 studies used CT. For the CT group, a mean angular deviation on 4.02 degrees and 3.86 for CBCT was reported. They suggested that there is no significant difference in the accuracy between the CBCT and CT technique.[64]

Clinician's skill (Experienced/ Inexperienced)

A number of studies have reported a positive relation between the operator's experience and the implant survival rates. A study by Lambert et al. found twice amount of failure rates in implants which was placed by surgeons who had a little experienced (less than 50 implants). [65]

In the same way, the surgeon's experience is also a determinant that influences the accuracy of implants placed with the static CAS system.

Van de Velde et al. conducted a study on the different experience level (specialists, general dentists and students) when placed in the conventional method with the flapless approach and compared it to a virtual implant plan. They found that implant positioning was inaccurate regardless of the level of experience. However, in terms of horizontal deviation, specialists were statistically significantly better than the students. The authors concluded that due to the inaccuracy found in the implant position to the virtual planning, additional use of guiding systems was recommended since, in clinical situations, these deviations would lead to complications such as implant stability, esthetics and functional consequences.[66]

Another in vitro study by Rungcharassaeng et al. investigated the role of an operator’s skill in third year dental students and post graduate students who placed more than 20 implants. The study was done in a mandibular model and each operator placed 1 implant that had been planned with a planning software and transferred to a surgical guide. The results found no significant differences in angular, linear and vertical deviations. However though not statistically difference, amount of vertical deviation in the coronal direction was twice as much in the inexperienced group. The authors discussed that the contact between the flange of the drill and the guiding sleeve of the template controlled the depth/ vertical position of the implants and premature contacts caused by the angular deviation would result in a more coronally placed implant. Another reason might be that inexperienced surgeons are more cautious of the depth of the implants than the experienced operators. [67]

Cushen et al. also did an invitro study between inexperienced and experienced surgeons. 100 implants were placed by 4 operators (2 of which placed more than 100 implants and 2 who placed less than 20 implants) Statistically significant difference were found between the two groups in the angular and horizontal errors at the implant entry point and apex. [68]

A vivo study by Van de Wiele et al studied 75 Osseospeed implants placed in 16 patients by an inexperienced postgraduate student who were supervised by an experienced dentist and compared it with a study by Vercruyssen et al. who conducted a similar study with the same material and method in experienced surgeons. Their study was done in 12 jaws and overall, 52 implants were placed. The result found no major influence on accuracy when compared with the experienced which they discussed that having a supervisor played a significant role in this result. [69, 70]

Chapter III

Materials and Methods

Research Design

Experimental Research

Sample Description

This study was approved by the Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU 2020-076). Sample size of the study was calculated using the G*Power version 3.1.9.4. based on a large effect size f of 0.5, 5% Type I Error,80% study power resulting in 24 subjects. A 15 percent compensation was taken into consideration in case of patient drop out, resulting in a sample size of 28. Study participants were patients seeking dental implant in the posterior region at the Special weekend clinic at the Esthetic and Implant clinic, Chulalongkorn

University. All patients understood the objectives of the study, treatment protocol and their obligations to the study. All informed consent were obtained.

Table 3: Patient inclusion Criteria
A. Age 21 years or older
B. Ability to understand and sign the informed consent prior to starting the study
C. Ability and willingness to comply with all study requirements
D. Systemically healthy (ASA I or II)
E. Adequate bone volume to accommodate the endo-osseous dental implant (e.g., sufficient height such that the implant would not encroach on vital structures such as the IAN and sufficient width that the implant could be placed within the confines of the existing bone).
F. Healed ridge and present Seibert’s bone classification I to accommodate the primary stability of planned endo-osseous dental implants.
G. Implant placement with one staged protocol
H. All implants will achieve the optimal primary stability measured by number

of torque insertion with torque wrench or implant drill machine which is provide at >20 Ncm

Table 3 Patient Inclusion Criteria

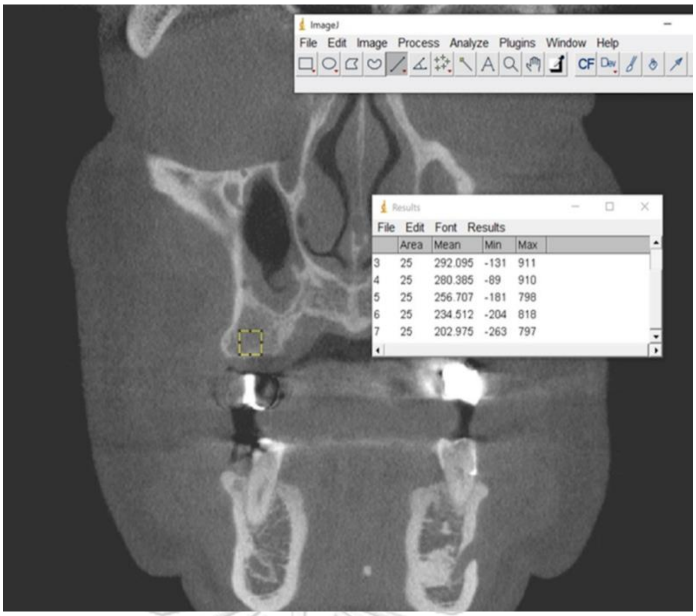
Table 4: Patient Exclusion Criteria
A. Heavy smoking (more than 10 cigarettes per day) or tobacco chewing.
B. History of drug abuse or alcoholism
C. Patients on medications involving bone metabolism such as bisphosphonate
D. Physical handicap that would interfere with the patient’s ability to exercise good oral hygiene on a regular basis
E. Pregnancy, Smoking, DM
F. A need for submersion of the implants
G. Presence of infection at the implant site
H. Systemic Diseases that could alter bone and soft tissue healing

Table 4: Patient Exclusion Criteria

Preoperative Radiographic Evaluation

CBCT scan (iCAT ^{TM} Imaging Sciences International, Hatfield, PA, USA) (FOV 13 x 16cm, 0.25mm voxel, 14.7s, 37.07 mAs and 120 kVp) was used for preoperative evaluation of the jaws for each patient. CBCT scanning of the edentulous area was performed after positioning a prefabricated acrylic resin surgical template, which incorporated a 4mm diameter indicator gutta percha at the center of each proper designated implant area.

Image Analyzing software, ImageJ (Wayne Rasband, NIH USA), was used to measure the mean bone density of the implant area in the unit of grey scale values. The measurements will be performed at seven different cross-sectional images which were at the center of the gutta percha,1,2,3mm mesial and distal to the center of the gutta percha to cover the entire area of the future implants. For each cross-sectional image, the measurements were obtained by defining a 5x5mm square-shaped region of interest (ROI) by using the rectangular selection tool in the ImageJ program. This pre-selected 5x5mm ROI (Figure 7) is then used in every cross-sectional image that were measured. The mean grey values will then bear comparison with the Houndsfield units and were used to classify the bone density of each implant area according to Misch's bone classification.[25]



	Area	Mean	Min	Max
3	25	292.095	-131	911
4	25	280.385	-89	910
5	25	256.707	-181	798
6	25	234.512	-204	818
7	25	202.975	-263	797

Figure 7: The image J software measured the greyscale value of the defined 5x5mm^2 (Region of Interest).

<u>Clinical Protocol</u>

This parallel randomized controlled study had sample size of 28. The samples were allocated following simple randomization procedures using computerized random numbers by the researcher to 1 of 2 treatment groups resulting in 15 cylindrical shaped with single threaded design which is a non-aggressive thread design with a wide thread pitch and width of thread; Straumann® Bone Level implants (Straumann, Switzerland) and 13 tapered shaped with a double lead threaded design which is a mixture of an aggressive thread design with steep, variable thread pitch and vertical sulcus around the body of the implant that enables gradual bone condensing;NobelActive® implants (NobelBiocare, Switzerland)(Figure 8). Information of the allocation was recorded by the researcher and were kept from the independent investigator who was responsible for measuring the ISQ values. Preoperatively, CBCT scans were acquired through the iCAT ™ and intraoral digital impressions were made with the 3D oral scanner(3shape®). The surgery was planned via the 3shape Implant Studio (3Shape, Copenhagen, Denmark) by an experienced surgeon. All implants were placed by inexperienced surgeons (experience of less than 5 implants), using a non-submerged technique, according to a strict surgical protocol following the manufacturer’s instructions. The choice of the implant size and length were left to the decision of the surgeons and depending on available bone volume and quality. Immediately after the implant was placed, the ISQ values were determined using an Osstell® ISQ (Osstell AB, Gamlestadvä-gen 3B, Göteborg, Sweden). The standardized SmartPeg for the Straumann and NobelBiocare implants with fixed length was screwed into the internal connection of the implant with mounting instrument via hand tightening by the researcher. The ISQ readings were obtained by the independent investigator on the buccal, lingual, and mesial to ensure the repeatability of the measurement and the mean values were recorded. The researcher oversaw all the recordings of the measurement as to keep the investigator blinded to the allocation. Aside from the day of implant placement, the measurements were further taken on the 4th and 8th week post-operatively. One individual investigator did all the measurements and to reduce the selection bias, the previous recordings, patient information and their implant systems were not accessible prior to the ISQ value measurement. The data from day 0 were served as the baseline and each visit involved assessment of pain level, clinical palpation, removal of the healing abutment, and the ISQ values measurements. In case any implant presented any clinical mobility, a post-surgical infection or abnormal pain, the implant would be excluded from the study.

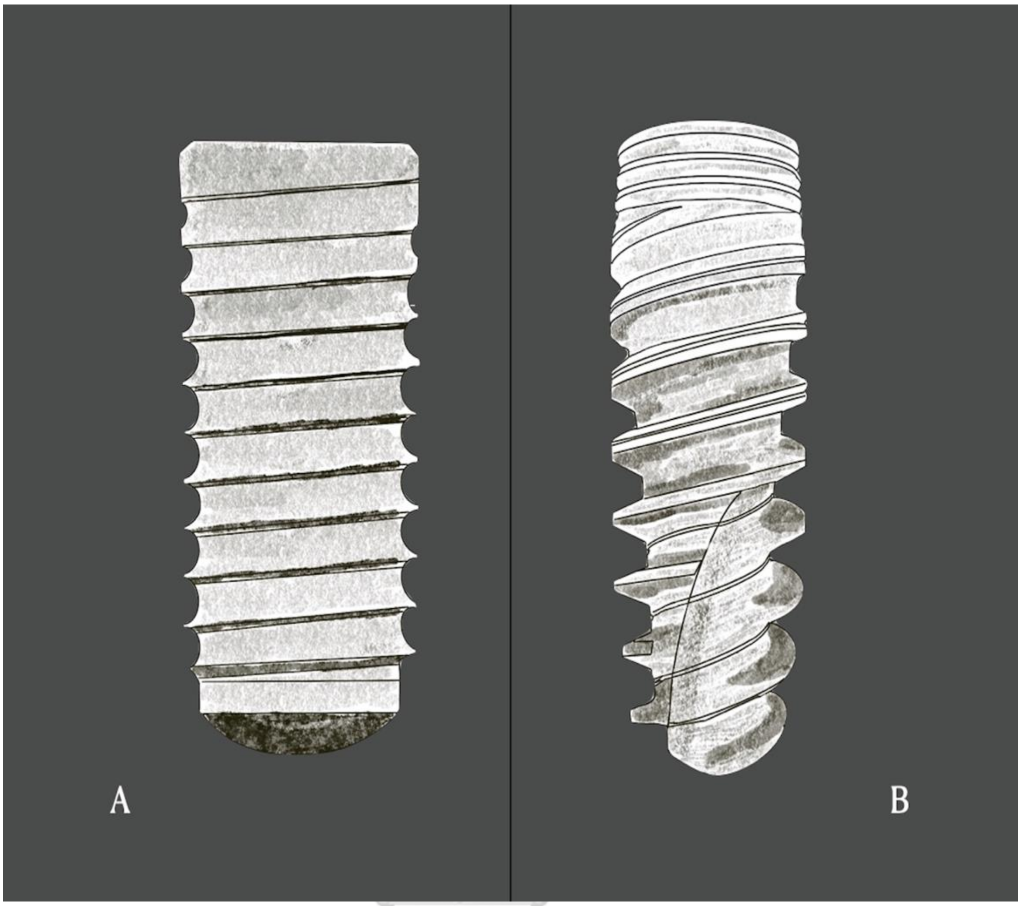


Figure 8: Illustration of the two implant designs. A: Cylindrical shaped, single threaded design (CS/ST) with SLA surface B: Tapered shaped, double lead threaded design (TS/DT) with TiUnite surface.

<u>Statistical Analysis</u>

Data were collected by the author and analyzed using SPSS 22.0 (SPSS, Chicago, IL, USA). The *p*-value <0.05 indicated statistically significant difference. Following descriptive data analysis, the Shapiro-Wilk test was used to test the distribution normality. Two-way ANOVA was employed to identify effect of implant designs in the longitudinal model on mean ISQ values and their interactions. The Independent *t*-test was used to analyze the significant difference in mean ISQ values at each time point of observations between the two implant designs. The within-implant differences in mean ISQ values of each implant design across the time periods were assessed using one-way repeated measures ANOVA with Bonferroni post-hoc analysis.

Two-way ANOVA was also employed to identify effect of bone type in the longitudinal model on mean ISQ values and their interactions. Independent *t*-test was used to analyze the significant difference in mean ISQ values at each time point of observations between the two bone types. Furthermore, within-implant differences in mean ISQ values of each bone type across the time periods were assessed using one-way repeated measures ANOVA with Bonferroni post-hoc analysis.

Regarding each bone type, two-way ANOVA was employed to identify effect of implant design in the longitudinal model on mean ISQ values and their interactions. Moreover, Independent *t*-test was used to analyze the statistically significant difference in mean ISQ values at each time point of observations between the two implant designs. Finally, within-implants difference of each bone type between the reduction and elevation phases was examined with one-way repeated measures ANOVA.

Chapter IV

Results

Sample

The study included twenty-eight patients with a mean age of 52.29 where all the participants received their intended treatment and were analyzed for the outcome. Recruitment period were during September 2020 to May 2021 with a follow-up of 2 months after implant placement. In conclusion, a total of 28 implants were placed in the posterior region (11 in the Maxilla and 17 in the mandible) and most of the implants were placed in the molar region (25% of the implants were placed in the premolar region). Clinically, there were no complications, good wound-healing was seen at the stitch-off, 14-days postoperative visit. Up until the present time, all the implants received prosthodontic rehabilitation and are in function with no complications or failures. Regarding the CS/ST implants, most implants had a diameter of 4.8mm (73%) while 4.1mm accounted for 27% (4 implants). On the other hand, for TS/DT implants, the most frequent implants used were 4.3mm (85%) whereas 5.0mm diameter implants were used in 2 cases. For the CS/ST group, most implants (11 implants) had a diameter of 10mm. In contrast, 69.2% of the TS/DT group used 8.5mm implants in length. The bone density varied from 172.75 to 653.76 in grey scale value with the mean grey scale value of 330.34. According to Misch's bone classification, 15 implants were placed in D3 bone while 13 implants were placed in D4 bone. (Table 5)

Table 5. *Demographic data according to the sex, age, bone type, implant diameter and length of both implant groups. N=28*

	CS/ST group (n=15)	*TS/DT group (n=13)*
Sex	Male: **8**, Female:**7**	Male: **3**, Female: **10**
Age group	21-40: **3** 41-60: **7** 61-80: **5**	17: **1** 41-60: **8** 61-80: **4**
Bone type	D3: **8**, D4: **7**	D3: **9**, D4: **4**
Implant diameter and length	4.1x8mm: **1**, 4.8x8mm: **3** 4.1x10mm: **3**, 4.8x10mm: **8**	4.3x8.5mm: **8**, 4.3x10mm: **3** 5.0x8.5mm: **1**, 5.0x10mm: **1**

Table 5 Demographic Data

Implant Stability and Implant Design

The effect of the implant design on mean ISQ values were depicted in Figure 9. Evidently, the pattern of changes in the mean ISQ values observed between the two-implant designs were consistent in all the 3-time parameters. There was no interaction between implant design and time parameters (*F*=0.370, *p*=0.693). There was statistically significant effect of time parameter (*F*=25.138, *p*<0.001) but no significant effect of implant design (*F*=0.949, *p*=0.339) on mean ISQ values. A significant decrease in ISQ values, similar in both implant design, was seen at 1-month post implantation before rising notably by the 8th week.

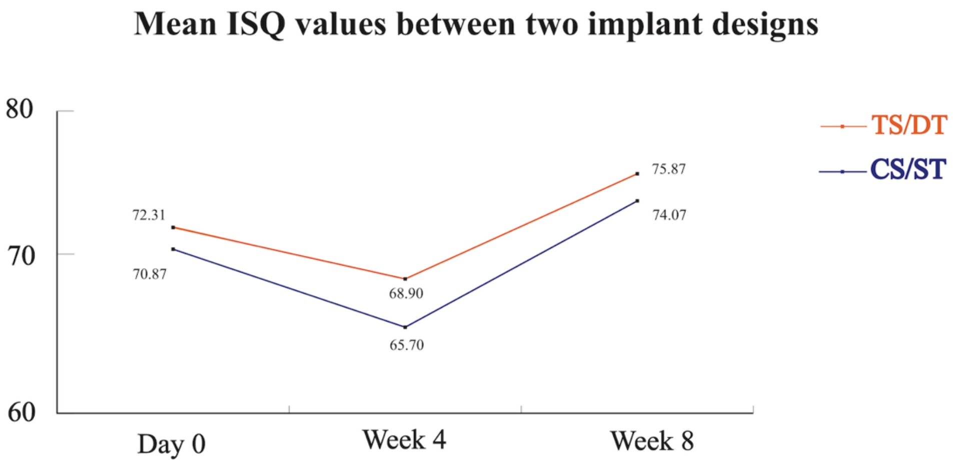


Figure 9: Mean implant stability quotient (ISQ) values for the CS/ST implants (Blue) and the TS/DT implants (Orange); Overall assessment at the 3-time observation points. (n=28)

In closer detail, the mean ISQ values for the CS/ST and TS/DT implant group decreased significantly from the time of implant placement (70.87±7.54) to (65.70±7.83) (*p*=0.007) and from (72.31±6.26) to (68.90±7.03) (*p*=0.015), respectively, at one month after implant placement. Then, the ISQ values increased notably at the 8th week after implant placement. In the CS/ST, the ISQ values rose to

(74.07±5.84) (*p*=0.004) and for the TS/DT implants this figure stood at (75.87±4.98) (*p*=0.001) by the end of the 8th week. There was no statistically significant difference in mean ISQ value between implant installation and 2 months after implantation in both the TS/DT and CS/ST implants (*p*=0.162 and 0.085, respectively). Additionally, result from Independent *t*-test found that at each time point, there was no statistically significant difference in mean ISQ values between the two implant designs at every time point (*p*>0.05). (Table 6)

Table 6. *Descriptive Statistical Analysis (Mean*±SD) showing the ISQ immediately after implant installation and during the 2-months follow up

ISQ	*CS/ST group*	*TS/DT group*
Day 0	70.87±7.54 Aa	72.31±6.26 Aa
Week 4	65.70±7.83 Ab	68.90±7.03 Ab
Week 8	74.07±5.84 Aa	75.87±4.98 Aa

Same capital letter in each row indicated no statistically significant difference between two implant designs in each time point (*p*>0.05), analyzed using independent t-test.

Same lower letter in each column indicated no statistically significant difference between two time points in each implant design (*p*>0.05), analyzed using one-way repeated measures ANOVA with Bonferroni post-hoc analysis. (0x4,4x8,0x8)

Table 6: Descriptive Statistical Analysis (Mean±SD) showing the ISQ immediately after implant installation and during the 2-months follow up

Implant Stability According to Bone Type

The distribution of the implants according to the bone density are 53.6% (n=15) in D3 bone and D4 bone accounted for 46.4% of the implants (n=13). The implant stability in each bone type is shown in Figure 10. There was no interaction between bone type and time parameters (*F*=2.155, *p*=0.139). There was statistically significant effect of time parameter (*F*=26.656, *p*<0.001) and significant effect of bone type (*F*=5.524, *p*=0.027) on mean ISQ values. The changes in implant stability between D3 and D4 bone are consistent in all the 3 observation points.

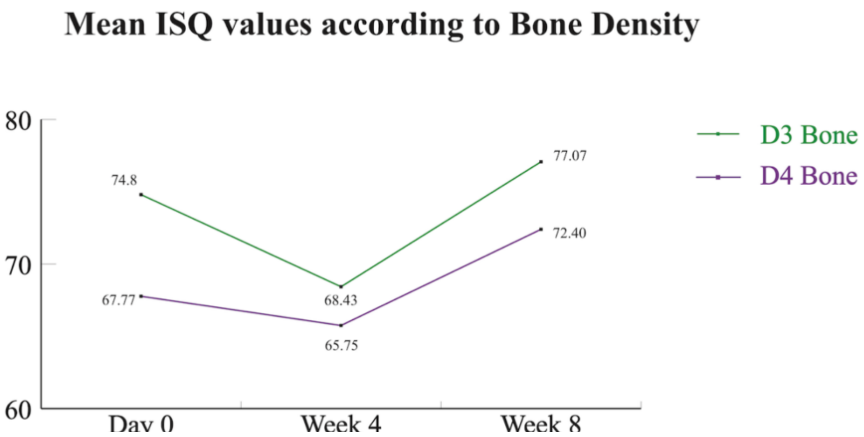


Figure 10: Mean ISQ values for all implants and observation points according to bone density. D3 bone in green, n=15; D4 bone in purple, n=13

At the implant placement visit, the mean ISQ values of D3 bone is 74.80±7.50. Then this value is significantly decreased to 68.43±9.59 before rising to 77.07±5.07 by the end of the observation period. One-way repeated measures ANOVA with Bonferroni post-hoc analysis demonstrated that the mean ISQ values between baseline visit and 1 month after implantation and between 1 and 2 months after implant placement in D3 bone are significantly different (*p*=0.001, and 0.002 respectively).

In D4 bone, it is revealed that the lowest mean stability measurement is at the 4th week observation point in D4 bone at 65.70±3.94, (2.73units) behind D3 bone.

This figure then rose notably to 72.40±4.88 at the 8th week (p=0.006). Moreover, Independent *t*-test showed statistically difference in mean ISQ values between two bone types at the implantation visit and 2 months after implant placement (p=0.005, and 0.020, respectively).

Implant Stability on different implant design in each type of bone

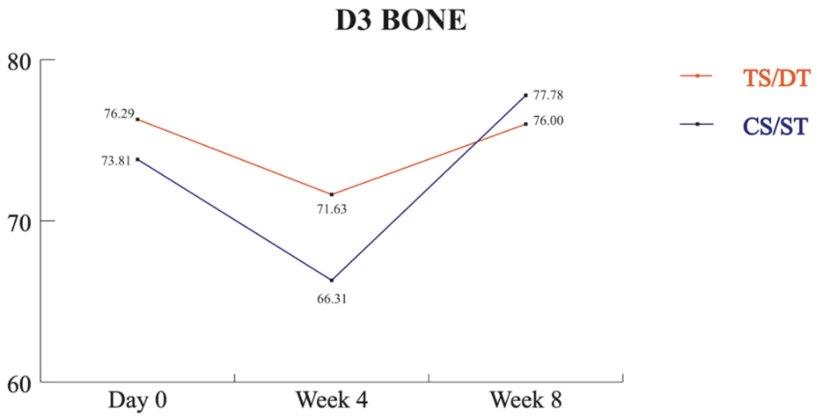


Figure 11: Mean ISQ values for CS/ST implants and TS/DT implants placed in D3 bone according to Misch's bone classification [12]

In D3 bone, (Figure 11) both types of implants showed high mean ISQ values at all the 3-time parameters. Two-way ANOVA revealed no interaction between implant design and time parameters (*F*=2.380, *p*=0.112). There was statistically significant effect of time parameter (*F*=12.827, *p*<0.001) and no significant effect of implant design (*F*=0.316, *p*=0.584) on mean ISQ values. The lowest mean ISQ value is seen at week 4 after implant placement in the CS/ST group at 66.31±9.76. The mean ISQ values of CS/ST is lower than that of the TS/DT group at the time of implant placement and at 1-month after implantation. However, at the last observation point, week 8th, the mean ISQ value of the CS/ST group marginally outdid that of the TS/DT group by 1.78 units (ISQ). Additionally, Independent t-test confirmed that at each time point, there was no significant difference of the mean

ISQ values between the two implant designs in D3 bone (*p*>0.05). (Table 7)

***Table 7**: Descriptive statistics of the mean ISQ values and Two-way ANOVA test at all the 3-time parameters* of the two implant designs and bone density

Table 7: Descriptive statistics of the mean ISQ values and Two-way ANOVA test at all the 3-time parameters of the two implant designs and bone density

	CS/ST group	***TS/DT group***
	Mean±SD	*Mean±SD*
D3		
Day0	71.03±7.39 A	*76.04* ± 5.82 A
Week4	64.63±9.18 A	71.54 ± 8.40 A
Week8	76.03± 4.62 A	75.89± 6.08 A
D4		
Day0	70.68 ±8.30 A	67.96 ±3.37 A
Week4	66.93 ±6.55 A	65.83 ±3.58 A
Week8	71.82±6.60 A	75.83±3.90 B

Same capital letter in each row indicated no statistically significant difference between two implant designs in each time point (*p*>0.05), analyzed using independent *t*-test.

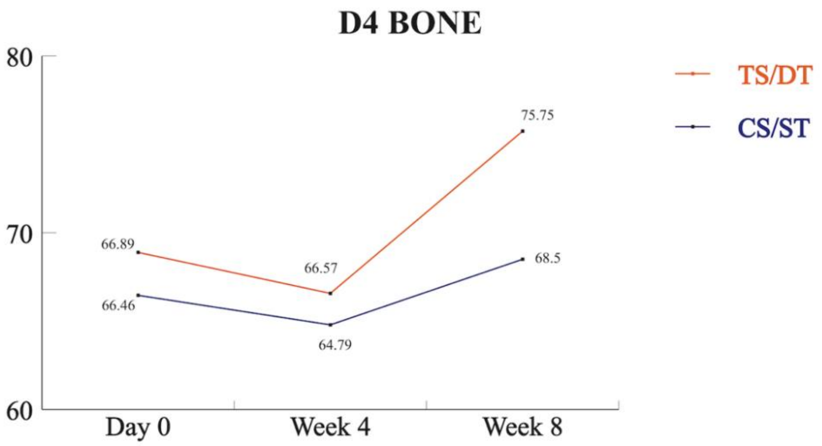


Figure 12: Mean ISQ values for CS/ST implants and TS/DT implants placed in D4 bone according to Misch's bone classification. [12]

Regarding, D4 bone (Figure 12), two-way ANOVA indicated no interaction between implant design and time parameters, (*F*=4.382, *p*=0.050). There was statistically significant effect of time parameter (*F*=21.375, *p*<0.001) and significant effect of implant design (*F*=5.625, *p*=0.037) on mean ISQ values. A closer look shows that at 8th week after implantation, the mean ISQ values of the TS/DT distinctively exceeded that of the CS/ST group by 7.25 units (75.75 vs 68.50) These results are demonstrated in Figure 6. Similar to D3 bone, Independent t-test confirmed that at implantation and 1st month after, there was no significant difference of the mean ISQ values between the two implant designs in D4 bone (*p*>0.05). However, at 8th week post implantation, statistically difference between the two implant design was seen (p=0.002) (Table 7)

Furthermore, descriptive statistics of the mean difference in mean ISQ values between Day 0 and Week 4 (Reduction Phase) and between Week 8 and Week 4 (Elevation phase) within both implant groups in each type of bone are shown in Table 4. Comprehensively, in D4 bone, the TS/DT implant group exhibit only a slight decrease in mean ISQ values in the Reduction phase, by 2.32 ISQ units when comparing to baseline and expresses quite an upsurge of the ISQ values by the end of Week 8 by 9.18 units (highest among all the groups) when comparing to the 4th week. Results of one-way repeated measures ANOVA of within-implant difference between the reduction and elevation phase indicated a significant difference (*p*=0.006) in TS/DT implant in D4 bone but there was no statistically significant difference in in D3 bone (*p*=0.813). On the other hand, the *CS/ST* group shows no significant difference between the reduction and elevation phase in both bone types (*p*=0.147 and 0.107, respectively). (Table 8)

Table 8. *Descriptive statistics of the mean difference in ISQ values between Day0 and Week 4 (Reduction phase) and between Week 8 and Week 4 (Elevation phase) within both implant groups in each type of bone*

Bone type	***CS/ST group***	***TS/DT group***
	Mean±SD	*Mean*±SD
D3		
Reduction	6.41 ± 4.94^{a}	4.50 ± 4.42^{a}
Elevation	11.41 ± 8.95^{a}	4.36 ± 3.37^{a}
D4		
Reduction	3.75 ± 5.97^{a}	2.13 ± 1.86^{a}
Elevation	4.89 ± 5.43^{a}	10.00 ± 4.82^{b}

Same superscript lower letter in each column indicated no statistically significant difference between two time points in each implant design and bone type (*p*>0.05), analyzed using one-way repeated measures ANOVA.

Table 8: Descriptive statistics of the mean difference in ISQ values between Day0 and Week 4 (Reduction phase) and between Week 8 and Week 4 (Elevation phase) within both implant groups in each type of bone

During the un-screwing and screwing of the healing abutment to insert the Smartpeg into the implants to measure the ISQ values, some patients reported a mild level of discomfort which dissipate after a few minutes after re-tightening of the healing abutment. No additional side effects and harm were further reported in this study.

Chapter V

Discussions and Conclusions

Discussions

From the result of this investigation, the *CS/ST* and TS/DT implants demonstrated similar point of implant stability changes. The collective stability displayed significant reduction ($p<0.05$) from the point of implant placement to the 4th week following implantation. On the contrary, by the end of the 8th week after implantation, the ISQ values changed from decreasing to increasing notably ($p<0.05$) for both the implant groups.

An Initial shift in the ISQ values were commonly seen among several studies, in which early signs of a decrease in ISQ values were detected. This result can be explained by the process of bone healing around the implant. According to a research by Raghavendra et al.[4], at week 4 after implant placement is a period referred to as the “stability dip”. This occurs when the mechanical stability (primary stability) decreases, and the new bone formation (secondary stability) have just started to increase. One animal study in the mandible of dogs found a stability dip at 3 weeks post implant placement before gradually increasing to the initial ISQs recorded at the implant placement visit. [71] Other clinical studies[44, 54, 72] reported consistent findings, two of the studies[73, 74] placed Straumann® BL implants in the posterior regions and found similar results regarding the stability dip at 2 weeks after the surgery. These results are in line with our study showing similar pattern in the reduction of the ISQ values before ascending to maximum cumulative stability by the 8th week following implant placement which can be explained by the gradual increase in new bone formation. These findings may be of clinical relevance when adoption of immediate or early loading protocols are implied to the implants.

Regarding the comparison of implant stability between two implant designs, our result found that slightly higher ISQ values were obtained in the TS/DT implants at all three-time parameters that were observed. This result was what we expected since TS/DT implants had macro-designs that were more favorable towards mechanical stability. However, statistically significant difference was not seen among the two implant designs at all 3 times parameters. In contrast to our findings, an in vitro study by Herrero-Climent et al.[75] evaluated implant stability between cylindrical and tapered implant design using the RFA and found that tapered implants always showed higher ISQ values when compared with cylindrical implants. Coinciding with this result, many clinical studies also reported tapered shaped implants achieving higher ISQ values than cylindrical implants [36, 72, 76]. Concerning thread design, implants with more threads, deep threads and micro-thread designs were shown to positively influence the implant stability[9 33]. A split-mouth clinical study by Gehrke et al. [77] also observed greater implant stability in tapered implants with wide pitch compared with cylindrical implants with narrow pitch. The reason why our result differs from the mentioned studies may be that TS/DT group had a higher number of female patient participants (10) while the CS/ST group had 7 females. Turkyilmaz et al.[78] stated that females may be subjected to lower bone density value due to hormonal peculiarities and generally higher bone mass in males. Additionally, 7 implants were placed in the maxilla arch whereas, CS/ST group placed 4 implants in the maxillary arch. Many studies such as Balleri et al.[47] Bischof et al. [79] and Liaje et al. [80], found that the ISQ values of implants placed in the maxilla arch were significantly lower than that of the mandibular arch.

However, there are a solid amount of research which concluded the insignificance effect of implant design on implant stability. One reliable resource is a split-mouth clinical trial on implant stability changes during early healing by Waechter et al.,[12] reporting that both tapered and cylindrical shaped implants have similar biological behavior during the early healing process. A more recent study in 2020 by Winardi et al. [81] conducted an experimental study in 44 implants with an even number of BL and BLT implants from Straumann® implant system. The authors concluded that the different in implant thread designs did not affect the biological stability of the implant.

In this study, all implants were placed in the posterior region and the bone density were measured preoperatively using the CBCT scan and ImageJ software to measure the greyscale value of the region of interest. It should be noted that the grey scale values in this study does not represent the actual Houndsfield units (HU) found in MDCT since the gray density values of the CBCT images (voxel value) are not absolute. However, the recorded greyscale values from this study will bear comparison to HU and classified according to Misch's classification[25, 26] since there are several supporting studies which found a positive correlation between the HU of MDCT and greyscale values of CBCT[82, 83 84, 85]. Recent publications from Razi et al.,[86] compared the HU from CT with the grey level in CBCT in human tissues and found a strong correlation between the two. Similarly, Hakim et al.[87] also suggested that CBCT-based bone density parameter allow for conversion of grey scales into HU. On the contrary, the latest systemic review, published in 2022, reported that greyscale values from CBCT could not be converted into HUs. The article reported that three conversion steps (Equipment calibration, correlation, prediction equation models and standard formula) are needed to obtain the CBCT-HUs.[88] Since the bone density of the present study was obtained from the grey scale values acquired directly from the software, this is a clear limitation and potential source of bias in this study. In hindsight, for research purposes, attaining the HUs directly from MDCT serves as a more accurate source in determining the bone density. However, the use of MDCT for single tooth- implant treatment seems a little too excessive and CBCT yields a lower radiation dose and cost which makes the CBCT more preferable.

Consistently, past studies from Song et al., Isoda et al., and Fariz et al., all showed a high correlation between bone density obtained from CBCT and ISQ values. [89-91] Comparably, Bruno et al., [92] also found a pronounced correlation between the ISQ and HU taken from the MDCT. Regarding the insertion torque, various studies reported a strong correlation between IT and CBCT-HU.[87, 93] Moreover, Turkyilmaz et al.,[78] reported a significant correlation between bone density from MDCT and IT, bone density and ISQ and between IT and ISQ values.

The bone density classification obtained in this study were found to be D3 (53.6%) and D4 (46.4%) bone (Table 5). In the same way, from the present study, the mean ISQ values of D3 bone were significantly higher than that of the D4 bone at the implant installation visit and at 2 months after implantation. From the pattern of changes seen in (Figure 9), a significant reduction in mean ISQ values was seen at week 4 after implant placement. This result is in line with a systemic review by Molly et al.[94] who concluded that implant stability in soft bone demonstrates the lowest ISQ values after 3 weeks of measurement and show a notably rise in values after 6 weeks. This is also consistent with our result showing a significant increase at week 8th post implantation.

It has been demonstrated that primary stability is reduced in one or two days after implant placement and during the healing period the secondary stability will come into play slowly after a few weeks and is conditioned by several factors such as implant micro-design (implant surface), loading conditions, individual tissue response, bone density and implant geometry. Throughout the healing phase, the cumulative stability of the implants will encounter a significant decrease before new bone is formed and secondary stability is established to combat against occlusal loading. Interestingly, from the result of our experiment, TS/DT group showed noteworthy dominance in the mean ISQ values during the 8th week period in D4 bone and exhibited a remarkable rebound in ISQ values in D4 bone when comparing between the reduction phase and the elevation phase. (Table 8) The aggressive implant geometry of the TS/DT implants may be the reason behind this result. Supporting this is an in vivo study by Trisi et al.[95] who found that aggressive implant design showed a superior biomechanical performance than classic thread design and that it could enhance the BIC percentage and secondary stability of the implants especially in low-density bone situations. Finally, a more recent study by Romanos et al. also stated that implants with progressive threads can significantly maximize the BIC percentages. [96]

In relation to the difference in micro-design of the two implant designs that were examined in this study (Ti-unite from TS/DT and SLA surface from CS/ST implants). Several studies[71] [74] have supported that both Anodized surface implants (ex: Ti-unite) and Sandblasted surface implants (ex: SLA) have been shown to positively influence the bone healing process and achieved good implant stability. However, it is challenging to review its influence on primary stability as implant surface modification has more effect on the biological stability specifically during the bone remodeling and regeneration process[97, 98]. An in vitro study by Santos et al. found similar ISQ values when comparing between acid etched and anodized surface implants.[8] In addition, another research by Koh et al. suggested that anodic oxidation implants had no advantage over SLA techniques in respect to implant stability.[99] Kim et al., [71] observed implant stability in anodized and SLA implant surface in the span of 10 weeks and found similar trend in implant stability at different time points that were observed. Hence, a sizeable amount of research found similar direction between the two implant surfaces, so its impact on implant stability were not highlighted in this study.

Another key point is the repeated disconnection and reconnection of the healing abutments and the Smartpegs during the RFA measurements period. This raises concern on the deleterious effect it may have on the implant healing process and the implant stability. However, in our study, we purposely shy from making any measurement at week 2 after implantation where it is believed that the bone to implant interface is at its weakest point[100]. On that account, for both the studied implant design, the repeated removal of the healing abutments and peg did not have a palpable injurious effect on the implant healing process.

Regarding the surgeon aspect, the fact that the surgeons were inexperienced did not compromise the treatment outcome in anyway. Furthermore, the use of guided surgical template have been shown to create less variability and greater accuracy than traditional guides[62]. An in-vitro study by Rungcharassaeng et al.[67] investigated the role of an operator’s skill in experienced and inexperienced operators using guided surgical template and found no significant difference in deviation in the angular, linear, and vertical directions between the two groups. In accordance, Romanos et al.,[13] in an ex vivo study in artificial soft bone concluded that both experienced and inexperienced surgeons were able to achieve good primary stability in all the 180 implants placed. To date, all the implants completed the prosthodontic rehabilitation, and the implants are in function for at least 4 months with no failure and/or complications.

As demonstrated, both implant groups obtained an adequate amount of implant stability, with the mean ISQ values at over 65 ISQ units in all the observation points. Preceding research proposed that an ISQ value of more than 60 at the time of implant placement serves as a positive predictor of a good prognosis for immediate loading implant protocol^{2}.

It is worth noting that all the implants in this study were placed in the posterior region with sufficient B-L and M-D bone width and length. Additional bone augmentation or sinus lift procedures were not necessary, therefore, the effect of implant design on implant stability may not be prominent since the implants were placed in a rather health condition with ample amount of bone. A clinical study in 2019, also found that significantly lower implant stability was found in posterior implants placed in bone with dehiscence defects compared to bone without defects at 2 and 4 weeks after implant installation.[101] Consequently, if this study was performed in the anterior region, where bone quality is poorer and supplementary bone augmentations were indicated or in immediate implant placement cases, the impact between the two implant designs maybe more pronounced in which case, future studies should implore into this matter.

Undeniably, our study was conducted under a small sample size per group and only two implant designs were compared. The result of this study should be regarded carefully and cannot be implied to other implant systems. In addition, this study was performed only in the posterior region where bone density is of sufficient amount. That being so, the clinical significance of the implant stability between the two implant designs in other clinical settings have yet to be implored. Moreover, we cannot deny that several other factors such as the condition of the bone, implant bed, implant design and surgical skill may also affect the results. This highlights the need for further research where other influencing factors are better controlled. However, it is worth noting that some factors remain out of our control such as individual host response that might not be predictable even if systemic diseases and environmental factors were excluded out of the study.

Conclusions

Despite the limitations stated above, the following can be concluded.

1. A similar trend can be observed in the overall cumulative stability of both implant designs. An initial decrease was seen at 1st month after implantation before ascending to maximum cumulative stability by the 8th week after implant placement.

2.. This study concluded that the implant design between CS/ST implants and TS/DT implants did not significantly affect the implant stability based on RFA measurements at the 3 times parameters that were examined.

3. In low density bone such as D4 bone, the use of an aggressive thread design in TS/DT deem more beneficial than the CS/ST implants if the early loading protocol were to be implemented, judging from the significant advantage in the mean ISQ values during the 8-week time frame and its positive bounce back of the mean ISQ values by the 8th week after implantation.

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Appendices

Appendix A Descriptive Statistics of all data

	N	Mean	Std. Deviation	Min	Max	Percentiles		
						25th	50th (Median)	75th
ISQd0	28	71.54	6.89	57.8	86	68.06	70	70
ISQw4	28	67.19	7.51	52	80.75	63.13	67.38	75
ISQw8	28	74.90	5.43	63	84.5	70.0	71	79.38

Appendix B The Shapiro-Wilk results in normal distribution of data as grouped by implant design.

	Implant Design	Shapiro-Wilk		
		Statistic	df	Sig.
ISQd0	CS/ST	0.929	15	0.264
	TS/DT	0.956	13	0.694
ISQw4	CS/ST	0.944	15	0.432
	TS/DT	0.975	13	0.947
ISQw8	CS/ST	0.910	15	0.138
	TS/DT	0.973	13	0.923

Appendix C Descriptive Statistics of CS/ST group

	ISQd0	ISQw4	ISQw8
CS/ST-1	84.8	79.75	82.50
CS/ST -2	72.0	64.25	79.00

CS/ST -3	70.0	53.00	71.00
CS/ST -4	70.0	62.25	78.25
CS/ST -5	57.8	52.00	78.25
CS/ST -6	73.3	68.00	78.00
CS/ST -7	72.3	70.50	71.50
CS/ST -8	84.8	68.25	81.00
CS/ST -9	79.5	78.75	80.50
CS/ST -10	68.3	67.25	69.75
CS/ST -11	63.0	57.25	70.00
CS/ST -12	63.0	62.75	63.00
CS/ST -13	68.5	67.00	70.00
CS/ST 14	68.3	68.75	70.25
CS/ST -15	67.8	65.75	68.00
N	15	15	15
Std.Error	1.946	2.022	1.507
Mean	70.867	65.70	74.07
Median	70.00	67.00	71.50
Minimum	57.8	52	63
Maximum	84.8	79.75	82.50
Std.Deviation	7.54	7.83	5.84
Kurtosis	0.228	0.178	-1.107
Skewness	.520	-.021	-0.153

Appendix D Descriptive Statistics of CS/ST group (Cont.)

	N	Mean	Std. Deviation	Min	Max	Percentiles		
						25th	50th (Median)	75th
ISQd0	15	70.87	7.54	57.8	84.8	67.75	62.25	70

ISQw4	15	65.70	7.83	52	79.75	70	67.00	71.5
ISQw8	15	74.07	5.84	63	82.50	73.25	68.75	79

Appendix E Descriptive Statistics of TS/DT group

	ISQd0	ISQw4	ISQw8
TS/DT -1	71.3	67.75	70.00
TS/DT -2	69.0	55.50	67.00
TS/DT -3	74.0	74.75	79.50
TS/DT -4	81.0	79.00	80.25
TS/DT -5	76.5	72.00	74.75
TS/DT -6	86.0	80.75	84.50
TS/DT 7	74.5	71.00	75.25
TS/DT -8	68.0	67.50	70.00
TS/DT -9	69.8	65.25	76.50
TS/DT -10	72.5	71.00	79.00
TS/DT 11	65.8	66.00	74.25
TS/DT -12	62.8	60.00	74.25
TS/DT -13	69.0	65.25	81.00
N	13	13	13
Std.Error	1.946	1.948	1.382
Mean	72.31	68.90	75.87
Median	71.25	67.75	75 .25
Minimum	62.8	55.50	67.00
Maximum	86	80.75	84.50
Std.Deviation	6.126	7.025	4.98
Kurtosis	.733	0.057	-.468
Skewness	.797	-.086	-.134

Appendix F Descriptive Statistics of of TS/DT group (Cont.)

	N	Mean	Std. Deviation	Min	Max	Percentiles		
						25th	50th (Median)	75th
ISQd0	13	72.31	6.126	62.8	86	68.5	65.25	72.13
ISQw4	13	68.90	7.025	55.50	80.75	71.25	67.75	75
ISQw8	13	75.87	4.98	67.00	84.5	75.5	73.38	79.13

Appendix G Two-way ANOVA of ISQ values between the two implant designs in longitudinal model.

Mauchly's Test of Sphericity[a]

Within Subjects Effect	Mauchly's W	Approx.Chi-Square	Df	Sig.	Epsilon [b]		
					Greenhouse-Geisser	Hyunh-Feldt	Lower-bound
isq	0.820	4.958	2	.084	.848	.935	.500

a. Design: Intercept+ Implant Design

Within subjects Design: ISQ

b. Maybe used to adjust the degrees of freedom for the averaged tests of significance.

Corrected tests are displayed in the Tests of Within-Subjects Effects table

Tests of Within-Subject Effects

		Type III Sums of Squares	df	Mean Square	F	Sig.
ISQ	Sphericity Assumed	821.957	2	410.979	25.138	.000
	Greenhouse-Geisser	821.957	1.695	484.914	25.138	.000
	Hyunh-Feldt	821.957	1.870	439.440	25.138	.000
	Lower-bound	821.957	1.000	821.957	25.138	.000
ISQ*Implant Design	Sphericity Assumed	12.094	2	6.047	.370	.693
	Greenhouse-Geisser	12.094	1.695	7.135	.370	.658
	Hyunh-Feldt	12.094	1.870	6.466	.370	.679
	Lower-bound	12.094	1.000	12.094	.370	.548
Error (isq)	Sphericity Assumed	850.136	52	16.349		
	Greenhouse-Geisser	850.136	44.071	19.290		
	Hyunh-Feldt	850.136	48.632	17.481		
	Lower-bound	850.136	26.000	32.698		

Tests of Between-Subjects Effects

Source	Type III Sum of	df	Mean Square	F	Sig

	Squares				
Intercept	424673.004	1	424673.004	4179.467	.000
Brand	96.385	1	96.385	.949	.339
Error	2641.844	26	101.609		

Appendix H Independent T-test of ISQ values at each time point between the two implant designs

		Levene's Test of Equality of Variances		t-test for Equality of Means				
		F	Sig	t	dt	Sig.(2-tailed)	Mean Difference	Std.Error Difference
ISQd0	Equal Variance Assumed	.217	.645	-.545	26	.590	-1.4410	2.6442
	Equal Variance not Assumed			-.552	25.966	.585	-1.4410	2.6086
ISQWeek4	Equal Variance Assumed	.027	.870	-1.132	26	.268	-3.20385	2.83101
	Equal Variance not			-1.141	25.966	.264	-3.20385	2.80833

	Assumed							
ISQWeek8	Equal Variance Assumed	1.751	.197	-.870	26	.392	-1.7872	2.06852
	Equal Variance not Assumed			-.880	25.966	.387	-1.7872	2.04457

Appendix I One-way repeated measures ANOVA with Bonferroni post-hoc analysis of within implant difference in mean ISQ values of each implant design across the time periods.

Implant Design	ISQ (I)	ISQ (J)	Mean Difference (I-J)	Std.Error	Sig[b]	95% Confidence Interval for [b] Lower	Upper
CS/ST	1	2	5.167*	1.399	.007	1.365	8.968
		3	-3.200	1.521	.162	-7.332	.932
	2	1	-5.167*	1.399	.007	-8.968	-1.365
		3	-8.367*	2.066	.004	-13.980	-2.753
	3	1	3.200	1.521	.162	-.932	7.332

		2	8.367*	2.066	.004	2.753	13.980
TS/DT	1	2	3.404*	.990	.015	.652	6.156
		3	-3.558	1.428	.085	-7.526	.411
	2	1	-3.404*	.990	.015	-6.156	-.652
		3	-6.962*	1.357	.001	-10.732	-3.191
	3	1	3.558	1.428	.085	-.411	7.526
		2	6.962*	1.357	.001	3.191	10.732

Based on estimated marginal means

*. The mean difference is significant at the 0.05 level

b. Adjustment for multiple comparison:Bonferroni

Appendix J Descriptive Statistics of Bone Type III, IV group

	Bone Type	Mean	Std.Deviation	N
ISQD0	D3	74.80	7.4989	15
	D4	67.769	3.5229	13
	Total	71.536	6.8866	28
	D3	68.433	9.58676	15

ISQWeek4	D4	65.7500	3.93568	13
	Total	67.1875	7.50975	28
ISQWeek8	D3	77.0667	5.07046	15
	D4	72.4038	4.88145	13
	Total	7.9018	5.43409	28

Appendix K Two-way ANOVA of ISQ values between the two bone types in longitudinal model.

Mauchly's Test of Sphericity ^{a}

Within Subjects Effect	Mauchly's W	Approx.Chi-Square	Df	Sig.	Epsilon ^{b}		
					Greenhouse-Geisser	Hyunh-Feldt	Lower-bound
isq	.729	7.897	2	.019	.787	.861	.500

c. Design: Intercept+ Bonetype

Within subjects Design: ISQ

d. Maybe used to adjust the degrees of freedom for the averaged tests of significance.

Corrected tests are displayed in the Tests of Within-Subjects Effects table

Tests of Within-Subject Effects

		Type III Sums of Squares	df	Mean Square	F	Sig.
ISQ	Sphericity Assumed	816.328	2	408.164	26.656	.000
	Greenhouse-Geisser	816.328	1.574	518.717	26.656	.000
	Hyunh-Feldt	816.328	1.722	474.026	26.656	.000
	Lower-bound	816.328	1.000	816.328	26.656	.000
ISQ*Bone Type	Sphericity Assumed	65.988	2	32.994	2.155	.126
	Greenhouse-Geisser	65.988	1.574	41.931	2.155	.139
	Hyunh-Feldt	65.988	1.722	38.318	2.155	.134
	Lower-bound	65.988	1.000	65.988	2.155	.154
Error (isq)	Sphericity Assumed	796.242	52	15.312		
	Greenhouse-Geisser	796.242	40.917	19.460		
	Hyunh-Feldt	796.242	44.775	17.783		
	Lower-bound	796.242	26.000	30.625		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Intercept	421724.901	1	421724.901	4855.141	.000
BoneType	479.830	1	479.830	5.524	.027

Error	2258.399	26	86.862		

Appendix L Independent T-test of ISQ values at each time point between the two bone types.

		Levene's Test of Equality of Variances		t-test for Equality of Means				
		F	Sig	t	dt	Sig.(2-tailed)	Mean Difference	Std.Error Difference
ISQd0	Equal Variance Assumed	5.670	.025	3.092	26	.005	7.0308	2.2738
	Equal Variance not Assumed			3.242	20.488	.004	7.0308	2.1688
ISQWeek4	Equal Variance Assumed	7.764	.010	.941	26	.355	2.68333	2.85175
	Equal Variance not Assumed			.992	19.130	.334	2.68333	2.70529
ISQWeek8	Equal Variance Assumed	.029	.866	2.469	26	.020	4.66282	1.88864

	Equal Variance not Assumed			2.476	25.685	.020	4.66282	1.88333

Appendix M One-way repeated measures ANOVA with Bonferroni post-hoc analysis of within implant difference in mean ISQ values of each bone types across the time periods.

Implant Design	ISQ (I)	ISQ (J)	Mean Difference (I-J)	Std.Error	Sig^b	95% Confidence Interval for ^{b} Lower	Upper
D3	1	2	6.367*	1.396	.001	2.572	10.162
		3	-2.267	1.613	.545	-6.650	2.116
	2	1	-6.367*	1.396	.001	-10.162	-2.572
		3	-8.633*	1.983	.002	-14.023	-3.244
	3	1	2.267	1.613	.545	-2.116	6.650
		2	8.633*	1.983	.002	3.244	14.023
	1	2	2.019*	.533	.008	.538	3.501
		3	-4.635*	1.185	.006	-7.929	-1.340
		1	-2.019*	.533	.008	-3.501	-.538

D4	2	3	-6.654*	1.484	.002	-10.779	-2.528
	3	1	4.635*	1.185	.006	1.340	7.929
		2	6.654*	1.484	.002	2.528	10.779

Based on estimated marginal means

*. The mean difference is significant at the 0.05 level

b. Adjustment for multiple comparison:Bonferroni

Appendix N Descriptive Statistics of ISQ values in type III, IV bone and implant designs.

Bone type		Implant Design	Mean	Std.Deviation	N
D3	ISQD0	CS/ST	73.806	8.4018	9
		TS/DT	76.292	6.3293	6
		Total	74.800	7.4989	15
	ISQWeek4	CS/ST	66.3056	9.76103	9
		TS/DT	71.625	9.19341	6
		Total	68.4333	9.58676	15
		CS/ST	77.7778	3.99109	

	ISQWeek8				9
		TS/DT	76.0000	6.65019	6
		Total	77.0667	5.07046	15
D4	ISQD0	CS/ST	66.458	2.6899	6
		TS/DT	68.893	3.9498	7
		Total	67.769	3.5229	13
	ISQWeek4	CS/ST	64.7917	4.20837	6
		TS/DT	66.5714	3.80984	7
		Total	65.7500	3.93568	13
	ISQWeek8	CS/ST	68.5000	2.81514	6
		TS/DT	75.7500	3.57071	7
		Total	72.4038	4.88145	13

Appendix O Regarding each bone type, two-way ANOVA of ISQ values between the two implant designs in longitudinal model.

Split file: Bone type

Bone Type	Within Subjects Effect	Mauchly's W	Approx.Chi-Square	Df	Sig.	Epsilon [b]		
						Greenhouse-Geisser	Hyunh-Feldt	Lower-bound

D3	isq	.906	1.184	2	.553	.914	1.00	.500
D4	isq	.337	10.870	2	.004	.601	.696	.500

Mauchly’s Test of Sphericity [a]

a. Design: Intercept+ Brand

Within subjects Design: ISQ

b. Maybe used to adjust the degrees of freedom for the averaged tests of significance.

Corrected tests are displayed in the Tests of Within-Subjects Effects table

Tests of Within-Subject Effects

Bone Type			Type III Sums of Squares	df	Mean Square	F	Sig.
D3		Sphericity Assumed	495.250	2	408.164	247.625	.000
		Greenhouse-Geisser	495.250	1.828	518.717	270.891	.000
		Hyunh-Feldt	495.250	2.000	474.026	247.625	.000
		Lower-bound	495.250	1.000	816.328	495.250	.003
	ISQ*Implant Design	Sphericity Assumed	91.895	2	32.994	45.947	.112
		Greenhouse-Geisser	91.895	1.828	41.931	50.264	.118
		Hyunh-Feldt	91.895	2.000	38.318	45.947	.112
		Lower-bound	91.895	1.000	65.988	91.895	.147
	Error (isq)	Sphericity Assumed	501.947	26	15.312	19.306	
		Greenhouse-Geisser	501.947	23.767	19.460	21.119	
		Hyunh-Feldt	26.00	26.000	17.783	19.306	

		Lower-bound	501.947	13.000	30.625	38.611	
D4	ISQ	Sphericity Assumed	281.256	2	408.164	140.628	.000
		Greenhouse-Geisser	281.256	1.203	518.717	233.831	.000
		Hyunh-Feldt	281.256	1.392	474.026	202.068	.000
		Lower-bound	281.256	1.000	816.328	281.256	.001
	ISQ*Implant Design	Sphericity Assumed	57.660	2	32.994	28.830	.025
		Greenhouse-Geisser	57.660	1.203	41.931	47.937	.050
		Hyunh-Feldt	57.660	1.392	38.318	41.425	.043
		Lower-bound	57.660	1.000	65.988	57.660	.060
	Error (isq)	Sphericity Assumed	144.741	22	15.312	6.579	
		Greenhouse-Geisser	144.741	13.231	19.460	10.940	
		Hyunh-Feldt	144.741	15.311	17.783	9.454	
		Lower-bound	144.741	11.000	30.625	13.158	

Tests of Between-Subjects Effects

Bone type	Source	Type III Sum of Squares	df	Mean Square	F	Sig
D3	Intercept	234230.579	1	234230.579	1695.009	.000
	Implant Design	43.601	1	43.601	.316	.584
	Error	1796.449	13	138.188		
D4	Intercept	181883.309	1	181883.309	7227.773	.000
	Implant Design	141.540	1	141.540	5.625	.037

	Error	276.810	11	25.165		

Appendix P Regarding each bone type, Independent T-test of ISQ values at each time point between the two implant designs.

Bone type			Levene's Test of Equality of Variances		t-test for Equality of Means				
			F	Sig	t	dt	Sig.(2-tailed)	Mean Difference	Std.Error Difference
D3	ISQd0	Equal Variance Assumed	.259	.619	-.615	13	.549	-2.4861	4.0431
		Equal Variance not Assumed			-.652	12.697	.526	-2.4861	3.8105
	ISQ Week4	Equal Variance Assumed	.078	.785	-1.057	13	.310	-5.31944	5.03156
		Equal Variance not Assumed			-1.071	11.337	.306	-5.31944	4.96718

	ISQ Week8	Equal Variance Assumed	3.060	.104	.651	13	.526	1.77778	2.72906
		Equal Variance not Assumed			.588	7.422	.574	1.77778	3.02336
D4	ISQd0	Equal Variance Assumed	.334	.575	-1.274	11	.229	-2.4345	1.9110
		Equal Variance not Assumed			-1.314	10.545	.217	-2.4345	1.8533
	ISQ Week4	Equal Variance Assumed	.095	.764	-.801	11	.440	-1.77976	2.22313
		Equal Variance not Assumed			-.794	10.269	.445	-1.77976	2.24172
	ISQ Week8	Equal Variance Assumed	.340	.572	-4.011	11	.002	-7.25000	1.80765
		Equal Variance			-4.090	10.948	.002	-7.25000	1.77264

		not Assumed							

Appendix Q Descriptive Statistics of Reduction and Elevation phase of each bone type

Bone Type	Implant Design		Mean	Std.Deviation	N
D3	CS/ST	Reduction	7.5000	5.74864	9
		Elevation	11.4722	8.48753	9
	TS/DT	Reduction	4.6667	4.82096	6
		Elevation	4.3750	3.69374	6
D4	CS/ST	Reduction	1.6667	2.18899	6
		Elevation	3.7083	4.51360	6
	TS/DT	Reduction	2.3214	1.77784	7
		Elevation	9.1786	4.90475	7

Appendix R One-way repeated measures ANOVA of within implant difference of each bone types between the reduction and elevation phases.

Split file: Implant Design, Bone type

Bone	Implant	Within	Mauchly's	Approx Chi	Df	Sig	Epsilon ^{b}

							Greenhouse-Geisser	Hyunh-Feldt	Lower-bound
D3	CS/ST	Reduction-Elevation	1.000	.000	0	-	1.000	1.000	1.000
	TS/DT	Reduction-Elevation	1.000	.000	0	-	1.000	1.000	1.000
D4	CS/ST	Reduction-Elevation	1.000	.000	0	-	1.000	1.000	1.000
	TS/DT	Reduction-Elevation	1.000	.000	0	-	1.000	1.000	1.000

Mauchly's Test of Sphericity [a]

a. Design: Intercept

Within subjects Design: Reduction-Elevation

b. Maybe used to adjust the degrees of freedom for the averaged tests of significance.

Bone Type	Imp Lant Design			Type III Sums of Squares	df	Mean Square	F	Sig.
D3	CS/ST	Reduction-Elevation	Sphericity Assumed	71.003	1	71.003	2.585	.147
			Greenhouse-Geisser	71.003	1.000	71.003	2.585	.147
			Hyunh-Feldt	71.003	1.000	71.003	2.585	.147
			Lower-bound	71.003	1.000	71.003	2.585	.147
		Error (Reduction-Elevation)	Sphericity Assumed	219.778	8	27.472		
			Greenhouse-Geisser	219.778	8.000	27.472		

			Hyunh-Feldt	219.778	8.000	27.472		
			Lower-bound	219.778	8.000	27.472		
	TS/DT	Reduction-Elevation	Sphericity Assumed	.255	1	.255	.062	.813
			Greenhouse-Geisser	.255	1.000	.255	.062	.813
			Hyunh-Feldt	.255	1.000	.255	.062	.813
			Lower-bound	.255	1.000	.255	.062	.813
		Error (Reduction-Elevation)	Sphericity Assumed	20.589	5	4.118		
			Greenhouse-Geisser	20.589	5.000	4.118		
			Hyunh-Feldt	20.589	5.000	4.118		
			Lower-bound	20.589	5.000	4.118		
D4	CS/ST	Reduction-Elevation	Sphericity Assumed	12.505	1	12.505	3.842	.107
			Greenhouse-Geisser	12.505	1.000	12.505	3.842	.107
			Hyunh-Feldt	12.505	1.000	12.505	3.842	.107
			Lower-bound	12.505	1.000	12.505	3.842	.107
		Error (Reduction-Elevation)	Sphericity Assumed	16.276	5	3.255		
			Greenhouse-Geisser	16.276	5.000	3.255		
			Hyunh-Feldt	16.276	5.000	3.255		
				16.276	5.000	3.255		
		Reduction-Elevation	Sphericity Assumed	164.571	1	164.571	17.675	.006*
			Greenhouse-	164.571	1.000	164.571	17.675	.006*

	TS/DT		Geisser					
			Hyunh-Feldt	164.571	1.000	164.571	17.675	.006*
			Lower-bound	164.571	1.000	164.571	17.675	.006*
		Error (Reduction-Elevation)	Sphericity Assumed	55.866	6	9.311		
			Greenhouse-Geisser	55.866	6.000	9.311		
			Hyunh-Feldt	55.866	6.000	9.311		
			Lower-bound	55.866	6.000	9.311		

Tests of Within-Subject Effects

Bone Type			Type III Sums of Squares	df	Mean Square	F	Sig.
D3		Sphericity Assumed	495.250	2	408.164	247.625	.000
		Greenhouse-Geisser	495.250	1.828	518.717	270.891	.000
		Hyunh-Feldt	495.250	2.000	474.026	247.625	.000
		Lower-bound	495.250	1.000	816.328	495.250	.003
	ISQ*Implant Design	Sphericity Assumed	91.895	2	32.994	45.947	.112
		Greenhouse-Geisser	91.895	1.828	41.931	50.264	.118
		Hyunh-Feldt	91.895	2.000	38.318	45.947	.112
		Lower-bound	91.895	1.000	65.988	91.895	.147
	Error (isq)	Sphericity Assumed	501.947	26	15.312	19.306	
		Greenhouse-Geisser	501.947	23.767	19.460	21.119	
		Hyunh-Feldt	26.00	26.000	17.783	19.306	
		Lower-bound	501.947	13.000	30.625	38.611	
	ISQ	Sphericity Assumed	281.256	2	408.164	140.628	.000

D4		Greenhouse-Geisser	281.256	1.203	518.717	233.831	.000
		Hyunh-Feldt	281.256	1.392	474.026	202.068	.000
		Lower-bound	281.256	1.000	816.328	281.256	.001
	ISQ*Implant Design	Sphericity Assumed	57.660	2	32.994	28.830	.025
		Greenhouse-Geisser	57.660	1.203	41.931	47.937	.050
		Hyunh-Feldt	57.660	1.392	38.318	41.425	.043
		Lower-bound	57.660	1.000	65.988	57.660	.060
	Error (isq)	Sphericity Assumed	144.741	22	15.312	6.579	
		Greenhouse-Geisser	144.741	13.231	19.460	10.940	
		Hyunh-Feldt	144.741	15.311	17.783	9.454	
		Lower-bound	144.741	11.000	30.625	13.158	

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