



A Comparison of Implant Stability between Aggressive and Non-Aggressive Dental Implant Design Using Two Different Stability Measuring Techniques: In Vitro

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Abstract

Recently, implant thread design has been developed for purpose of achieving the proper primary stability. Also, a new device for evaluating implant stability has been introduced. However, the effect of aggressive thread design and the reliability of the device still lack knowledge. The aim of this in vitro study is to investigate the primary stability of aggressive thread design implant (BLX) compared with nonaggressive thread design implant (BLT) and to evaluate the correlation between implant stability quotient (ISQ) values and implant stability test (IST) values. Thirty-two implants were used in this study; sixteen implants were for each group. All implants were digitally planned and placed in 3D printed model with two edentulous premolar spaces using computer-assisted guided surgery. Postoperative implant stability measurement was performed immediately after implant insertion. Implant stability was measured by Osstell ISQ for ISQ value and AnyCheck for IST value. The data was analyzed using the Spearman correlation and Mann-Whitney U test. The mean ISQ value was 71.86 and 68.00, for BLX and BLT, respectively, while the mean IST value was 69.50 for BLX and 48.50 for BLT. In conclusion, the aggressive thread design implant (BLX) showed superior stability to the nonaggressive thread design implant (BLT) in both ISQ and IST groups. Moreover, there was a correlation between ISQ and IST in both implant designs.

Keywords: *implant stability, implant stability test, implant stability quotient, aggressive thread implant, non-aggressive thread implant*

1. Introduction

Implant stability is one of the most crucial factors for successful dental implant treatment. The satisfying stability during the healing period might prevent excessive micromovement and disruption of bone formation (Aspenberg et al., 1992). Primary stability is the stability of the implant at the time of implant placement, which is a critical factor for achieving osseointegration. Several possible aspects that have an influence on primary implant stability are bone-related factors, implant characteristics, and surgical technique (Atsumi, 2007; Meredith, 1998).

Since bone density or bone quality can determine the success in obtaining primary stability. Various bone assessments have been proposed, they were commonly classified into four bone types based on the compact bone to a trabecular bone ratio (Lekholm et al., 1985). According to Misch (1990), bone density can be categorized into D1 to D4, in which D1 comprised the majority of dense compact bone, D2 bone is composed of dense to the porous compact cortical bone on the outside and coarse trabecular bone on the inside, D3 bone is composed of porous, thinner cortical bone and fine trabecular bone, and D4 bone is composed of fine trabecular bone with very low density and little or no cortical crestal bone. The volume of available bone and its density are significantly correlated with the surgical intervention and implant type, and these factors are fundamental to the successful outcome of dental implant surgery. Recently, material which commonly use to replicate jaw bone for a mechanical-test in laboratory experiment is polyurethane foam block (Sawbones®; Pacific Research Laboratories Inc., Washington, USA). Polyurethane foam is generally accepted as the standard for mechanical testing of orthopedic implants. Furthermore, the physical properties of this biomechanical test material are uniform and consistent, preventing the variation which can occur when



testing with human cadaver bone (Devlin et al., 1998). In addition, some in vitro study has been striving to achieve the utmost simulation of the intraoral implant surgery and decrease the limitations. The three-dimensional printing models with the edentulous area were used and attached to the phantom head, to mock a real intraoral surgery, also position and visualization of the operator (Sittikornpaiboon et al., 2021; Yeung et al., 2020).

Regarding surgical technique, optimal implant placement is critical for providing a prosthesis design that is suitable for long-term success and maintenance. The conventional guide technique provided an acceptable outcome by using a surgical stent that was converted from a radiographic stent with an opaque radiographic marker. The stents enable the surgeon to observe the appropriate prosthesis location intraoperatively. This technique is frequently referred to as a free-hand technique. However, the exact implant position is highly dependent on the surgeon's ability and expertise in this technique. Lately, new digital technology called static computer-assisted implant surgery (CAIS) has been used to plan implant position and design surgical guided stent before surgery, considering the bone quality and quantity, the location of important anatomical structures, soft tissues, and teeth, and the final prostheses. A 3D-printed surgical guide is used to transfer the planned implant location to the surgical site. Through a metal sleeve placed in the surgical guide, guided surgical drills control the angulation and depth of the implant osteotomy. Moreover, it has been stated that guided implant surgery has higher precision and accuracy than conventional surgical guides or free-hand implant surgery (Smitkarn et al., 2019; Yeung et al., 2020).

Another potential factor that can influence the stability of the implant and long-term success rate is implant characteristics. The main features of the implant are such as implant material, implant micro-design, and macro-design (Bolind et al., 2005; Huang et al., 2008). Currently, new material has been developed, which is a hybrid of titanium and zirconia. According to the study by Kobayashi et al. (1995), it provides greater strength and biocompatibility. As a result, the risk of fracture is reduced, allowing the dentists to choose a smaller diameter implant in case of anatomical limitations. Moreover, most implant companies offer taper implants, due to the advantage of lateral compression in poor bone implant sites and situations with anatomical limitations. Currently, the aggressive thread design was introduced. This implant design provides a special ability to cut the bone during insertion and obtain better primary stability after implant placement (Irinakis & Wiebe, 2009).

To determine or predict the outcome of implants, various techniques for evaluating implant stability have been developed, including invasive and non-invasive clinical test methods. Insertion torque (IT) is one of the objective and non-invasive measurement techniques. Some studies have previously reported implant stability using IT measurements (Akca et al., 2010; O'Sullivan et al., 2004). Implant stability could be determined by a high torque number (Ncm). However, following implantation, this procedure could not be reproduced. Consequently, Resonance frequency analysis (RFA) was introduced. RFA is a non-invasive electronic instrument that has excellent repeatability and reliability for monitoring changes in implant stability (Meredith, 1998). The implant-bone complex's stiffness was determined and reported as an implant stability quotient (ISQ) value ranging from 1 (least stability) to 100 (highest stability). In the last decade, the RFA has been employed increasingly to provide a quantitative assessment of implant stability. ISQ measurements were taken periodically throughout the healing period to detect changes in implant stability as a result of successful osseointegration. (Bischof et al., 2004; Huwiler et al., 2007; Meredith et al., 1997; Nedir et al., 2004). However, in the process of ISQ measurement, the healing abutment must be unscrewed and the transducer of a metal rod (a peg) must connect to the implant. As a result, the routine of unscrewing the healing abutment and a peg back and forth may affect implant stability and osteointegration during a critical period.

Consequently, an implant stability test (IST) device (AnyCheck: Neobiotech, Korea) has been developed to detect the stiffness between alveolar bone and implant by means of slightly tapping at the healing abutment. AnyCheck can also be utilized without having to unscrew the healing abutment. It strikes the healing abutment six times over three seconds and converts the time into IST values. As a result, this device provides a safety measure for detecting initial implant stability, however, research on AnyCheck is limited, and more studies are needed (J. Lee et al., 2020).



However, none of the studies that have assessed primary stability using the ISQ and IST values have investigated the impact of the aggressive thread implant. The advantages of identifying factors affecting implant stability are substantial. It will enable clinicians to select an implant that minimizes or eliminates implant instability during the early stages of bone remodeling, allowing a greater number of cases to meet the criteria for immediate or early loading while maintaining a high degree of predictability and a successful treatment outcome.

2. Objectives

1. To investigate the primary stability of aggressive thread design implant (BLX) compared with the nonaggressive thread design implant (BLT)
2. To evaluate the correlation between implant stability quotient (ISQ) values and implant stability test (IST) values.

3. Materials and Methods

Materials

Polyurethane blocks

Rigid polyurethane blocks (Sawbones®; Pacific Research Laboratories Inc., Washington, USA) were utilized at various densities to represent bone in a laboratory setting. The American Society for Testing Materials recommends using synthetic polyurethane foams as a standard material for mechanical testing of orthopedic devices and equipment because they have a density and mechanical qualities comparable to human bone. Following Misch's classification of bone density, polyurethane blocks at a density of 40 pounds per cubic foot (PCF) were represented as D1 bones, polyurethane blocks at a density of 30 PCF were represented as D2 bones, polyurethane blocks at a density of 20 PCF were represented as D3 bones, and polyurethane blocks at a density of 10 PCF were represented as D4 bones. All blocks were standardized using the same batch and weighed accurately. To imitate mixed cancellous bone at the implant insertion site, each density of polyurethane blocks was cut into a cylindrical shape and randomly stacked.

Implants

The implant used in this study is BLT Straumann® dental implant system and BLX Straumann® dental implant system (Straumann®, Switzerland). Every single placed implant is Roxolid® with SLActive® surface. All implants were placed by using digital guided surgery, according to a standardized surgical protocol following the manufacturer's instructions.

Methods

Model preparation

The method was adapted from a previously published study by Sittikornpaiboon et al. (2021); Yeung et al. (2020). This research used a subject with bilateral edentulous sites at the maxillary first premolar. To create a suitable digital U shape full-arch model with a bar, an intra-oral scan file (Standard Tessellation Language; STL) was created and uploaded into Meshmixer software version 3.5.474 (Autodesk Inc., California). At both edentulous sites, a cylindrical hollow space of 7 mm in diameter and 16 mm in length was designed to conform to the implant implantation locations. Thirty-two digital models were produced using a 3D printer (Straumann CARES P30+, Straumann AG, Basel, Switzerland) using a model resin solution (P Pro Master Model Gray, Straumann AG, Basel, Switzerland) with a layer thickness of 0.05 mm. Afterward, the models were completely cleaned with isopropyl alcohol and treated with UV light to cure. To replicate mixed cancellous bone at the implant insertion site, the hollow area at each site was packed with a computer-generated randomized pattern of four different kinds of polyurethane blocks (Sawbones, Washington, United States); each density of polyurethane blocks was cut into a cylindrical form of 7 mm in diameter and 4 mm in length, according to the total height of the hollow space. Each polyurethane piece was randomly stacked up into four layers, to mimic diverse bone densities in different areas of the human bone jaw. The polyurethane was ensured to fit completely in the hollow space and secured to the model by using cyanoacrylate glue. A computer-generated randomization list was carried out by a statistician who was not



engaged in implant planning design or placement and each model was given a number from 1 to 32. All 32 models were chosen for the procedure in order from 1 to 32.



Figure 1 Sample of U shape full-arch model with bilateral edentulous sites at the maxillary first premolar

Implant planning procedure

Each implant was digitally planned and a surgical guide was created on a software (coDiagnostiX software version 9.7, Dental Wings GmbH, Chemnitz, Germany) using Digital Imaging and Communications in Medicine (DICOM) file and STL file. To create a DICOM file, all models' imaging data were taken using a cone-beam CT (CBCT) machine (X- mind Trium, de Götzen S.r.l.-Acteon Group, Varese, Italy). The CBCT machine was set to 6 mA, 86 kV, 54 seconds exposure time, 0.15 mm voxel size, and 80 x 80 mm field of view. Moreover, the models were then scanned for 3D files, using a desktop scanner (Cares 7 SERIES, Dentalwings, Montreal, Quebec, Canada) to create an STL file. Thirty-two implants were determined a final planned position on the software. All implants were planned by one investigator. The optimal position placed at the center of the polyurethane block: 1.5 mm of the surrounding area, measured from implant shoulder to outer margin of the block and 2 mm deeper from the top of the block. 16 implants for each of the two drilling protocols. Each protocol specifies the particular surgical kit, the sleeve height, the sleeve location, and the implant design. All 32 surgical guides were designed with an embedded guide sleeve, to achieve the optimal implant position and angulation in all subjects and to control the error from the 3D printing process of the model. Additionally, implant diameters varied slightly between the two groups, owing to the variance in implant diameter available throughout various systems. The implant length was set to ensure that all groups had the same free-drilling-distance length. As a result, two distinct procedures were used: group A used a 4.1 x 12 mm bone level tapered implant (Straumann AG, Basel, Switzerland), while group B used a 4.0 x 12 mm BLX implant (Straumann AG, Basel, Switzerland).

The surgical guides were generated identically using the coDiagnostiX program. All 32 surgical guide templates were created with four inspection windows. Between the surgical guide and the tooth, a gap of 0.05 mm was established. All surgical guides were printed using a 3D printer (Straumann CARES P30+, Straumann AG, Basel, Switzerland) with a layer thickness of 0.1 mm from a 2 mm thick medical grade surgical guide resin material (P Pro Surgical Guide, Straumann AG, Basel, Switzerland).

Surgical protocol

The models were attached to a phantom head in a supine position, in order to simulate the real procedure in the patient. The operator is seated in the right rare position. The surgical guide was placed on a model and evaluated the fitting through the inspection window before the implant placement procedure. All guided implant surgeries were conducted by one operator. The two drilling systems were applied in this experiment. The same design of implant used the same protocol. The drilling procedure was carried out following the manufacturer's instructions. Using each system's guided adapter, the implants were inserted fully guided. The BLX was placed at the upper left premolar area while the BLT was placed at the upper right premolar area.



Outcome measurement

All measurements were performed by one trained evaluator. After implants were placed, the final insertion torque value (Ncm) was recorded immediately. Implant stability was measured by an Osstell ISQ. A standardized SmartPeg was hand-screwed into the implant fixture with an amount of 4-5 Ncm of torque which means 'finger tighten' or 'finger torque' as the manufacturer's recommendation. The probe of the device was held close as much as possible to the peg in the buccal and mesial direction. The space between the probe's tip and the top of the SmartPeg should be a few millimeters without touching. Another measurement of implant stability was used by using AnyCheck IST device with a standard height of healing abutment of 4 mm (AnyCheck: Neobiotech, Korea). This device needs to maintain the contact angle between 0 to 30 degrees downward based on the ground level (Figure 2). The measurement was performed at the buccal and lingual aspects of the healing abutment. The ISQ and IST measurement was performed 3 times separately on each side.



Figure 2 AnyCheck device needs to maintain the contact angle between 0 to 30 degrees downward based on the ground level

Statistical analysis

The data were analyzed with IBM SPSS Statistics software version 22 (SPSS Inc., Chicago, Illinois). Shapiro-Wilk test verified the non-normality of the data distribution. Thus, the Spearman correlation test was used to analyze the correlation between the ISQ value and IST value. P values $<.05$ were set as statistically significant. Mann-Whitney test was used to compare the implant stability of BLX and BLT.

4. Results and Discussion

4.1 Results

A total of 32 implant sites in 16 models were included in this study. 16 BLT Straumann® dental implants and 16 BLX Straumann® dental implants were placed in each model. The mean implant stability value and standard deviations were shown in Table 1. The mean ISQ value was 71.86 and 68.00, for BLX and BLT respectively. Also, the mean IST value was 69.50 for BLX and 48.50 for BLT (Figure 3).

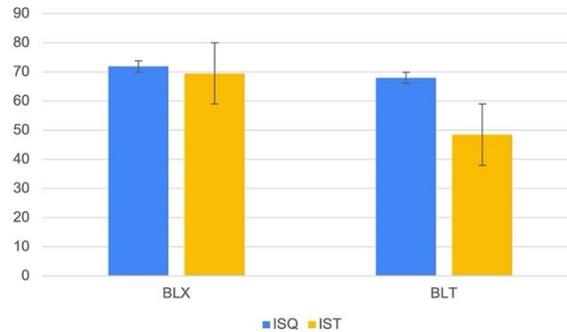


Figure 3 Mean ISQ and IST value of BLX and BLT implant

Regarding the implant type, the implant stability between BLX and BLT was analyzed by the Mann-Whitney test and found statistical differences in both ISQ value and IST value (p-value <0.001) (Table 1).

Table 1 The implant stability in each group

Group	BLX	BLT	P-value*
ISQ			<0.001
Mean	71.68	68.00	
Median	71.50	69.50	
Std. Deviation	3.36	3.97	
Min-Max	66.00-77.00	59.00-72.00	
Range	11	13	
95% CI	69.90,73.48	65.89,70.11	
IST			<0.001
Mean	69.50	48.50	
Median	70.00	48.50	
Std. Deviation	3.43	6.39	
Min-Max	63.00-74.00	40.00-57.00	
Range	11	17	
95% CI	67.61,71.33	45.10,51.90	

*Differences between BLX and BLT were analyzed using the Mann-Whitney U test

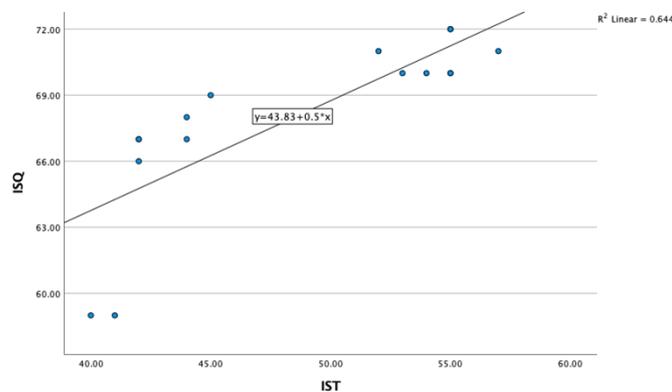


Figure 4 Correlation between ISQ and IST in BLT

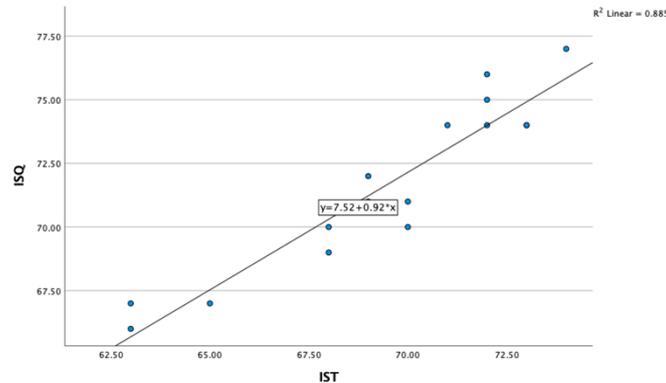


Figure 5 Correlation between ISQ and IST in BLX

The correlation between ISQ value and IST value was found in both implant types (p -value < 0.001) as shown in figure 4, and Figure 5. Besides, the ISQ value has been found to have a higher number than the IST value in both implant designs.

4.2 Discussion

This study aimed to investigate the primary stability of aggressive thread design implant (BLX) compared with the non-aggressive thread design implant (BLT) and evaluate the correlation of implant stability quotient (ISQ) values and implant stability test (IST) values. Resonance frequency analysis (RFA) was introduced by Meredith et al. (1996) and has been commonly used as a non-invasive electronic device that is a reliable and repeatable tool for assessing implant stability during the healing process. The RFA analyzes the implant-bone complex stiffness and displays it as an implant stability quotient (ISQ) value. The ISQ value is determined by three key factors: the transducer design, the stiffness of the implant-bone junction (implant characteristics, cancellous to cortical bone ratio, and implant-tissue interface stiffness), and the total effective length (Sennerby & Meredith, 1998).

Implant body design and surface modifications have been proposed to increase implant success in low-quality bone by improving anchoring and giving a larger surface area of load to alleviate stress on softer bone types. According to a finite element analysis study, the distributions and magnitudes of bone stress might vary depending on the implant geometry. Additionally, threads are employed to optimize initial contact, enhance stability, increase the surface area of the implant, and facilitate the absorption of interfacial stress. Moreover, according to Lozano-Carrascal et al. (2016), conical implants achieve higher ISQ values and insertion torque values than cylindrical design implants. Rohn et al. (2011) suggested that tapered implants gain more lateral compressive force on the surrounding bone, thus in the area with inadequate bone quality and quantity, the tapered implant is recommended to achieve better primary stability.

Regarding the macro-design of implants, this present study showed the difference between the two implant designs. The aggressive thread design has been determined to have a greater ISQ value and IST value, which agrees with the study by McCullough and Klokkevold (2017). It has been shown that macro-thread design affects implant stability; indicating the novel knife-edge design implant had an overall higher mean ISQ value compared to a standard V-shape design. Moreover, the previous studies reported the highest ISQ value in NobelActive which interestingly created extensive grooves in the apical part, while the imprint was considerably smaller for BLT and Astra (Karl & Irastorza-Landa, 2017). The aggressive thread design implant presented the advantage in fresh socket extraction of non-molar teeth cases resulting in a very high initial stability (Irinakis & Wiebe, 2009).

The result showed that there was a significant correlation between ISQ value and IST value in both BLX and BLT groups. Moreover, a study by D. H. Lee et al. (2020) has reported similar results, the IST



values were strongly correlated with ISQs, suggesting that the IST values follow the tendency of ISQ values. Also, there was no information about appropriate healing abutment diameter for *in vitro* or clinical settings.

Currently, The Osstell ISQ device has been increasingly performed in clinical research to evaluate the development of implant stability during the healing periods. The ISQ tends to vary when the contact of the bone-implant is not strong or certain. On the other hand, when an implant has attained osseointegration and the contact of the bone-implant is firm, this device seems to be rather reliable. Furthermore, while assessing implant stability with the Osstell ISQ, the uppermost part of the fixture (cover screw or healing abutment) must be removed and the SmartPeg connected, which may create difficulty and limitations (Friberg et al., 1999; Nedir et al., 2004). However, since the AnyCheck does not require unscrewing the healing abutment, the procedure is less difficult than with the Osstell ISQ. Also, the measurements of the newly built AnyCheck device were consistent with ISQ values, the AnyCheck device values range from 1 to 99. Moreover, the tapping motion was optimized by using shorter tapping intervals and applying less force to the implant, resulting in a more secure method of determining implant stability.

Besides, computer-assisted implant surgery (CAIS) was utilized in this study for controlling the position of the implant in every model and guaranteed that all implants would be placed in the cylindrical polyurethane block. According to Smitkarn et al. (2019), the static CAIS showed significantly less deviation than free-hand surgery in all parameters. Six out of nine measurements were shown remarkably higher accuracy in the CAIS group. Moreover, in a split-mouth study by Farley et al. (2013), inserted implants using the CAIS technique were found to be more accurate in all dimensions compared to implants placed conventionally. However, the authors stated that a limitation of the research was the fit of the CAD/CAM guides, some of which required relining with the transparent acrylic resin prior to surgery. Therefore, in this study, the surgical guide was individually created and confirmed fitting in advance of the procedure to eliminate the instability of the guide.

The limitation of this *in vitro* study was the research design of this *in vitro* investigation did not allow for comparison of the devices in osseointegrated implants, and more *in vivo* studies are necessary before the devices may be used in clinical settings. The correlation between the devices may reflect tendencies toward implant stability, but it cannot provide precise numbers indicating implant prognosis since the devices are not connected. Further research is needed to determine the reliability of the AnyCheck device in clinical settings.

5. Conclusion

According to the result of this study, the aggressive thread design implant (BLX) showed superior stability to the nonaggressive thread design implant (BLT) in both ISQ and IST groups. Moreover, within the limitation of this study, we conclude that there was a correlation between ISQ value and IST value which the ISQ value was higher than the IST value in both implant designs.

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7. References

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