Effect of Implant Thread Design on Biological Stability based on Resonance Frequency Analysis

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Abstract

Biological stability greatly influences osseointegration, which ultimately affects the success of implant treatment. Though implant thread design is one important factor influencing implant stability, not many studies have analyzed its impact on biological stability. This experimental study involving 44 implants evaluated the biological stability of threaded implants with cylindrical (bone-level; BL) and tapered (bone-level tapered; BLT) designs. Implant stability was evaluated for each implant at 3 time parameters using resonance frequency analysis. A mean implant stability quotient (ISQ) value was calculated for each measurement time. A significant increase in the ISQ value was found at each time parameter consecutively at the time of implant placement one month and 2 months after implant placement in both implant design groups ($P < 0.05$). No significant difference was noted in ISQ value between the groups at all 3 time parameters ($P = 0.05$). There was also no significant difference in the ISQ value at all 3 time parameters between implants with diameters of 4.1 mm and 4.8 mm in the BL and BLT implant groups ($P = 0.71$). The implant thread designs of BL and BLT implants did not affect the biological stability. Other factor such as implant diameter also did not affect the biological stability in either implant group.

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Introduction

The replacement of missing teeth using dental implants has been widely conducted for more than 50 years and has been proven able to restore function, esthetics, speech, and patient confidence.[1–3] Since the concept of oseointegration was introduced and established by Branemark et al. in 1965, dental implants have experienced continual revision and progress.[4–6] One of the factors that contributes to the success of dental implant treatment is the achievement of osseointegration and stability of dental implants. Osseointegration is defined as a direct connection between the bone and implant surface. The concept of stability of the dental implant is divided into primary stability and secondary stability. Primary stability is obtained by friction and mechanical fixation of the implant with surrounding bone immediately after insertion of the implant and is related to the quality and quantity of bone, surgical technique, implant surface area, and design (i.e., shape, diameter, length, and thread profile). A high level of primary stability guarantees a high resistance of the implant to micromovements. Implant should not be subjected to micromovements of more than 50 to 150 μm because such can induce fibrous tissue formation around the implant, which causes clinical failure. Primary implant stability is crucial to achieve at the time of implant placement to determine the right time for implant loading. Meanwhile, secondary stability is generated secondarily by bone formation and bone remodeling in the process of osseointegration due to biological fixation in the interface between bone and implant without the interposition of connective tissue and is directly dependent on the primary stability.[1,4,6–12]

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There are several factors that affect the success of osseointegration, including quality and quantity of the bone, oral hygiene, patient-related medical risk factors (e.g., systemic diseases or habits such as smoking), implant design, and operator skills.[1,3,6–9,11–17] Nowadays, there are approximately 1,300 different implant systems available that vary in shape, dimension, bulk and surface material, thread design, implant–abutment connection, surface topography, surface chemistry, wettability, and surface modification. The most common implant shapes are cylindrical or tapered.[15] Implant modification, implant thread design (i.e., shape, thread, diameter, length, and thread profile depth), increase in implant surface roughness with sand-blasting techniques, acid etching, anodization, grit-blasting, coating procedures with certain materials, lasers, and hydrophilic surface modifications of the implant aim to accelerate osseointegration and ensure a good degree of contact between implants and bones (bone–implant contact; BIC) in the long-term.[1,3,5,6,9,13,15,18,19]

The degree of osseointegration can be evaluated through the measurement of changes in the implant stability. Several studies have shown that the resonance frequency value has a high correlation with the level of BIC. Such findings support the use of resonance frequency analysis (**RFA**) to evaluate the changes in the process of osseointegration and bone healing after implant placement. The RFA device can measure implant stability clinically and noninvasively and also estimate the degree of osseointegration. The implant stability quotient (**ISQ**) is a measurement unit recorded as a number between 1 and 100, with 100 representing the highest stability.[4,7,10,12,20–22]

Several studies suggest that the primary stability of tapered screw–type implants is significantly higher than that of straight screw–type implants when measured by the Periotest (Medizintechnik Gulden, Modautal, Germany) and Osstell device (Osstell AB, Gothenburg, Sweden) in bovine rib blocks.[20,23] Another study showed that there were no significant differences in maximum torque value; ISQ value; and qualitative and quantitative histologic, histomorphometric, and radiographic measures when a new tapered screw implant was compared with a cylindrical screw implant with exactly the same surface area after 4 weeks of unloaded healing or 8 weeks of loaded healing in the minipig.[24] Dard et al. proved that the use of a bone-level tapered (**BLT**) implant together with an optimized drill procedure was able to obtain good primary stability in variable-density **PUR** foam blocks simulating bone types 1 through 4 as well as ex vivo in pig ribs and in vivo in pig mandibles.[25] However, not many studies exist that have analyzed the effect of implant thread design on biological stability. Biological stability is one of the important factors in the success of implant treatment. This study focuses on examining biological stability because the formation of such illustrates the beginning of osseointegration, which is characterized by the apposition of bone to the implant after implant placement.[26] It is essential to conduct the evaluation of osseointegration during the healing process of bone tissue and the results of such can become clues in the initial diagnosis of implant failure. The present study aimed to evaluate the effect of implant thread design on biological stability. We hope in the future that the results of this study can provide recommendations for further treatment planning.

Materials and methods

This study was approved by the Ethics Committee of the Faculty of Dentistry, University of Indonesia (no. 13/ethical approval/FKGUI/III/2019). This was an experimental study with a sample size of 44 implants, including 22 bone-level (BL) implants and 22 bone-level tapered (BLT) implants**.** This study was performed by 2 prosthodontist operators at 2 private clinics from June to November 2019. The implant placements were all carried out with the same standard operating procedure. The inclusion criteria were: (1) minimum age of 18 years old, (2) had tooth loss in the posterior mandible indicated for single dental implant placement, (3) possessed good oral hygiene, (4) had no history of systemic diseases that could affect the alveolar bone remodeling process and bone healing, (5) had no history of heavy smoking (i.e., more than 10 cigarettes per day), (6) had good local (bone and soft tissue) condition with no requirement for bone grafting and soft tissue manipulation procedure, and (7) was able to attend follow-up visits at one month and 2 months after implant placement. The exclusion criterion was refusal to participate in this study.

The study treatment protocols were explained to all patients and written informed consent was obtained prior to their participation in the study. Before implant treatment, all patients were screened based on an interview sheet and diagnosis chart by an experienced clinician. They filled in a questionnaire that documented their general and dental health conditions. Clinical and radiological examinations were then carried out to assess local bone and soft tissue conditions (e.g., the size of the alveolar ridge or inflammatory signs).

Two different implant thread designs were placed using standard surgical protocols: the Straumann sandblasted large grits and acid etching (SLA) BL implant (Straumann, AG, Basel, Switzerland) or the Straumann SLA BLT implant (Straumann, AG, Basel, Switzerland) (Figure 1). Both were made of a titanium–zirconium alloy (Roxolid; Straumann, AG, Basel, Switzerland) with surface treatment conducted via SLA treatment. The BL implants were totally parallel-walled while BLT implants were parallel-walled only at the coronal half of the implant body and then tapered for the apical half with the presence of self-cutting features. The implant measured 10 mm long and the diameters ranged from 4.1 to 4.8 mm. Postsurgical instructions consisted of amoxicillin (500 mg 3 times daily for one week), acetaminophen (500 mg 4 times daily) and chlorhexidine digluconate mouthwash (0.12% twice daily for 2 weeks). No provisional prostheses were used during the observation period. Implant stabilities were measured at the time of implant placement and at one and 2 month(s) after implant placement, using the RFA method. For this purpose, the Osstell device was used. The scale of measurement was ISQ with a value from 1 to 100. Measurements were made in the buccolingual and mesiodistal directions. The 3 times measurements were performed. Mean ISQ values of the 3 measurements were taken at each observation time point.

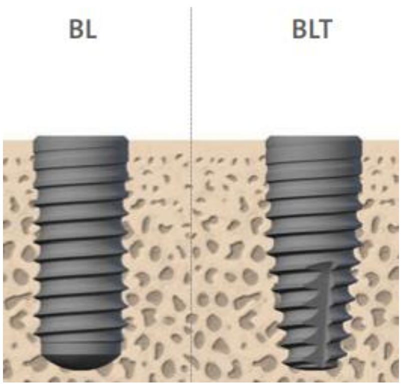

Figure 1. Implant thread designs. **A. BL**: bone level. **B. BLT**: bone-level tapered [27]

Statistical analysis

Univariate analysis was performed to observe the distribution of the subjects. The Statistical Package for Social Sciences version 22.0 software program (IBM Corp., Armonk, NY, USA) was used to analyze the data. General linear model (GLM) repeated measures were used to compare the stability of the 2 different implant thread designs at the time of implant placement and one and 2 month(s) after implant placement, with *P* value less than 0.05 is considered to be statistically significant.

Results

Among the 44 single dental implants placed at 2 prosthodontist private clinics from June to November 2019, clinically, there were no postoperative complications. Treated areas showed no alterations, and good wound-healing was observed at 7 days postsurgery.

The 2 implant thread designs used in this study were spread evenly with a percentage of 50.0% each. Most implants used in this study had a diameter of 4.1 mm (72.7%) relative to 4.8 mm (27.3%) (Table 1).

Variable	Frequency	Percentage (%)
Implant Thread Design		
- BL	22	50.0
- BLT	22	50.0
Implant Diameter		
- 4.1 mm	32	72.7
- 4.8 mm	12	27.3

Table 1. Frequency and distribution of the study subjects based on implant type and diameter.
BL: bone level; **BLT**: bone-level tapered.

The results of this study showed that the ISQ value for BL implants increased significantly both at the time of initial examination (62.28 ± 4.66), then at one month after (71.45 ± 5.10) and 2 months after (75.91 ± 3.39) implant placement. The results of this study also suggested that the ISQ value for BLT implants increased significantly at the initial examination (64.06 ± 4.78), at one month after (74.44 ± 3.74) and at 2 months after (80.27 ± 3.21) after implant placement (Table 2).

Intergroup tests (between subjects) revealed no significant differences in the ISQ values that existed between BL and BLT implant system groups, with *P* = 0.05 (Table 3).

	n	MD ± SD	95% CI (Min–Max)	p-value
BL	22			
- Implant placement vs 1st month		-9.17 ± 0.64	-10.76 - -7.59	0.00*
- Implant placement vs 2nd month		-13.63 ± 0.88	-15.83 - -11.43	0.00*
- 1st month vs 2nd month		-4.46 ± 0.69	-6.17 - -2.74	0.00*
BLT	22			
- Implant placement vs 1st month		-10.38 ± 0.64	-11.96 - -8.80	0.00*
- Implant placement vs 2nd month		-16.21 ± 0.88	-18.41 - -14.01	0.00*
- 1st month vs 2nd month		-5.83 ± 0.69	-7.55 - -4.12	0.00*

Table 2. ISQ values within groups of BL and BLT implant types.
BL: bone level; **BLT**: bone-level tapered
* statistical test results using the GLM repeated measures test; significance at p < 0.05

	BL (n=22) Mean ± SD	BLT (n=22) Mean ± SD	p-value
Implant placement	62.28 ± 4.66	64.06 ± 4.78	0.05
1st month	71.45 ± 5.10	74.44 ± 3.74	
2nd month	75.91 ± 3.39	80.27 ± 3.21	

Table 3. ISQ values between groups of BL and BLT implant types.
BL: bone level; **BLT**: bone-level tapered.

The results of multivariate statistical analysis with GLM repeated measures showed that there was no significant difference in the ISQ value between 4.1- and 4.8-mm diameter implants in both the BL and BLT implant groups at the time of implant placement when compared with at one month and 2 months, with *P* = 0.71 (Table 4).

	BL (n=22) Mean ± SD		BLT (n=22) Mean ± SD		p-value
	4.1 mm	4.8 mm	4.1 mm	4.8 mm	
Implant placement	60.88 ± 3.69	66.03 ± 5.24	63.83 ± 5.47	64.67 ± 2.34	0.71
1st month	70.44 ± 4.34	74.17 ± 6.37	74.23 ± 4.04	75.00 ± 3.03	
2nd month	75.31 ± 2.55	77.50 ± 4.97	80.38 ± 3.69	80.00 ± 1.55	

Table 4. Effect of implant diameter on ISQ values on BL and BLT implant types.
BL: bone level; **BLT**: bone-level tapered.

Discussion

This study was an experimental study that aimed to analyze the biological stability of 2 different implant thread designs at 3 different time parameters, specifically at the time of implant placement and one month and 2 months after implant placement.

There was a significant increase in the ISQ value between at the time of placement and one and 2 month(s) after implant placement groups consecutively in both the BL and BLT implant systems, with *P* < 0.05 (Table 2)**.** This might indicate that the process of osseointegration that occurs during the healing of bone tissue had begun within 2 months. According to the literature, secondary stability begins to increase within 4 weeks after implant placement and requires 3–6 months for the healing process to be unloaded to achieve optimal stability. This study was performed involving the mandible posterior region. Based on the research of Misch, most of the mandible posterior region presents bone quality types 2 and 3 with percentages of 50% and 46%, respectively. The results of this study were in line with research conducted by Kim et al. (2009), where the quality of bones type 2, 3, and 4 experienced a big change in stability between Weeks 0 and 6.[3,4,28]

The ISQ value in this study continued to increase at both measurement of one month and 2 months after implant placement. Based on previous research from McCullough and Klokkevold (2017), the ISQ value initially decreased from Week 0 to Weeks 3 to 4 after implant placement. This indicates a period of bone remodeling that results in a temporary decrease in implant stability. One of the factors that can affect the level and duration of bone remodeling is the design of the implant thread including several other factors such as pitch, depth, and shape of the thread.[29] In addition to the design of the implant, the surface characteristics of the implant can also affect the stability of the implant. Several methods of surface modification have been carried out to improve implant osseointegration, involving chemical means and the deposition of calcium phosphate layers with fluoride and zinc ions. There are 4 categories of bioactive agents superimposed onto the surface of titanium implants, which are biocompatible ceramics, proteins and bioactive growth factors, ions, and polymers. This bioactive layer forms a substrate for bone deposition and actively interacts with the osseointegration process.[28] The present study used Straumann BL and BLT implants with SLA surface modification. This surface treatment shows high predictability and can accelerate osseointegration.[30] This might cause an increase in the value of ISQ during measurements at one month and 2 months after implant placement.

In this study, the comparison of ISQ values between BL and BLT implant types showed no significant difference (Table 3)**.** The results of this study are in line with research conducted by Cochran and Obrecht (2016) was conducted in minipigs and which stated that due to the identical half-coronal part thread design of BL and BLT implants, the ISQ value has no significant difference between the two implant types. In addition, both implant systems have the same surface characteristics as well as the presence of a very osteoconductive SLA surface, resulting in relatively the same osseointegration in both types of implants.[24,29,30] Although it did not show a statistically significant value, the ISQ value of BLT implants presented a higher mean value when compared with BL implants. This might have been caused by the self-tapping effect from the BLT implant design, which eliminates the use of surgical taps during implant-site preparation, thereby increasing primary stability and implant success.[31]

Although this study demonstrated that the ISQ value for 4.8-mm diameter implants tends to be higher than that of 4.1-mm diameter implants in both BL and BLT implant systems, there was no statistical difference found between the diameter (Table 4). Several factors such as the same implant design, the condition of the alveolar bone that is controlled (without bone graft), and standardized treatment procedures may have influenced the results. Previous studies only focused on the effect of implant diameter on primary stability; the effect of implant diameter on biological stability has not been much studied before. Research by Barikani et al. and Bilhan et al. showed that implant diameter did not affect primary stability. Barikani et al. stated that the diameter of the implant will affect stability when combined with the length of the implant, but the results are obtained at an implant length of 15 mm. Implants with a diameter of more than 4 mm did not provide a significant increase in the value of stability, thus, implants with a regular diameter (regular platform) can give a satisfactory result. Further, the use of implants with a diameter that is not too large can leave a thicker alveolar bone in the buccal and lingual parts, having a positive effect on the resistance of the implant.[32,33]

Conclusions

1. This study concluded that the implant thread designs of BL and BLT implants did not affect the biological stability based on RFA ISQ value measurements.
2. Both implant types presented a significant increase in the ISQ value at all 3 time parameters considered.
3. This study also found that the diameter of the implant did not affect the biological stability in both the BL and BLT implant groups.

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Declaration of Interest

The authors have no conflict of interest to declare.

References

1. Gaviria L, Salcido JP, Guda T, Ong JL. Current Trends in Dental Implants. J Korean Assoc Oral Maxillofac Surg 2014;40(2):50-60.
2. Howe MS, Keys W, Richards D. Long-Term (10-Year) Dental Implant Survival: A Systematic Review and Sensitivity Meta-Analysis. J Dent 2019;84:9-21.
3. Misch CE. Contemporary Implant Dentistry. 3rd ed. St Louis: Mosby Elsevier; 2008.
4. Kim JM, Kim SJ, Han I, Shin SW, Ryu JJ. A Comparison of the Implant Stability among Various Implant Systems: Clinical Study. J Adv Prosthodont 2009;1(1):31-6.
5. Albertini M, Fernandez-Yague M, Lázaro P, Herrero-Climent M, Rio-Santos J, et al. Advances in Surfaces and Osseointegration in Implantology. Biomimetic Surfaces. Med Oral Patol Oral Cir Bucal 2015;20(3):316-25.
6. Duraccio D, Mussano F, Faga MG. Biomaterials for Dental Implants: Current and Future Trends. J Mater Sci 2015;50(14):4779-812.
7. Bataineh AB, Al-Dakes AM. The Influence of Length of Implant on Primary Stability: An In Vitro Study Using Resonance Frequency Analysis. J Clin Exp Dent 2017;9(1):1-6.
8. Falco A, Berardini M, Trisi P. Correlation between Implant Geometry, Implant Surface, Insertion Torque, and Primary Stability: In Vitro Biomechanical Analysis. Int J Oral Maxillofac Implant 2018;33(4):824-30.
9. Elias CN, Rocha FA, Nascimento AL, Coelho PG. Influence of Implant Shape, Surface Morphology, Surgical Technique and Bone Quality on the Primary Stability of Dental Implants. J Mech Behav Biomed Mater 2012;16:169-80.
10. Tanaka K, Sailer I, Iwama R, Yamauchi K, Nogami S, et al. Relationship between Cortical Bone Thickness and Implant Stability at the Time of Surgery and Secondary Stability after Osseointegration Measured Using Resonance Frequency Analysis. J Periodontal Implant Sci 2018;48(6):360-72.
11. Pereira DV, Oliveira A, Ribeiro CP, Serafim M. Stability of Dental Implants Prototype in Bone: Thread and Design. Mater Sci Eng Adv Res 2018;2(4):1-8.
12. Manzano-Moreno FJ, Herrera-Briones FJ, Bassam T, Vallecillo-Capilla MF, Reyes-Botella C. Factors Affecting Dental Implant Stability Measured Using the Ostell Mentor Device: A Systematic Review. Implant Dent 2015;24(5):565-77.

13. Hotchkiss KM, Reddy GB, Hyzy SL, Schwartz Z, Boyan BD, Olivares-Navarrete R. Titanium Surface Characteristics, including Topography and Wettability, Alter Macrophage Activation. Acta Biomater 2016;31:425-34.
14. Pedro RE, De Carli JP, Linden MS, Lima IF, Paranhos LR, et al. Influence of Age on Factors associated with Peri-implant Bone Loss after Prosthetic Rehabilitation over Osseointegrated Implants. J Contemp Dent Pract 2017;18(1):3-10.
15. Smeets R, Stadlinger B, Schwarz F, Beck-Broichsitter B, Jung O, et al. Impact of Dental Implant Surface Modifications on Osseointegration. Biomed Res Int 2016;2:1-16.
16. Ikebe K, Wada M, Kagawa R, Maeda Y. Is Old Age a Risk Factor for Dental Implants? Jpn Dent Sci Rev 2009;45(1):59-64.
17. Heitz-Mayfield LJ, Huynh-Ba G. History of Treated Periodontitis and Smoking as Risks for Implant Therapy. Int J Oral Maxillofac Implant 2009;24(Suppl):39-68.
18. Lang NP, Salvi GE, Huynh-Ba G, Ivanovski S, Donos N, Bosshardt DD. Early Osseointegration to Hydrophilic and Hydrophobic Implant Surfaces in Humans. Clin Oral Implants Res 2011;22(4):349-56.
19. Saini M, Singh Y, Arora P, Arora V, Jain K. Implant Biomaterials: A Comprehensive Review. World J Clin Cases 2015;3(1):52-7.
20. Romanos GE, Ciornei G, Jucan A, Malmstrom H, Gupta B. In Vitro Assessment of Primary Stability of Straumann® Implant Designs. Clin Implant Dent Relat Res 2014;16(1):89-95.
21. González-Jaranay M, Moreu-Burgos G, Gómez-Moreno G, Rubio-Roldan J, Machuca-Portillo G, et al. Changes in Resonance Frequency Analysis Assessed by Osstell Mentor during Osseointegration: Comparison between Immediately Loaded Implants and Control Implants without Load. Journal of Osseointegration 2014;6(3):51-5.
22. Herrero-Climent M, Santos-García R, Jaramillo-Santos R, et al. Assessment of Osstell ISQ's Reliability for Implant Stability Measurement: A Cross-Sectional Clinical Study. Med Oral Patol Oral Cir Bucal 2013;18(6):e877-82.
23. Chrabieh E. Implant Macro-Design and Implant Stability: An Ex Vivo Study. Int Arab J Dent 2017;8(2):49-57.
24. Cochran D, Stavropoulos A, Obrecht M, Pippenger B, Dard M. A Comparison of Tapered and Nontapered Implants in the Minipig. Int J Oral Maxillofac Implant 2016;31(6):1341-7.
25. Dard M, Kuehne S, Obrecht M, Grandin M, Helfenstein J, Pippenger BE. Integrative Performance Analysis of a Novel Bone Level Tapered Implant. Adv Dent Res 2016;28(1):28-33.
26. Monje A, Ravidà A, Wang HL, Helms JA, Brunski JB. Relationship between Primary/ Mechanical Stability and Secondary/ Biological Implant Stability. Int J Oral Maxillofac Implant 2019;34:s7-23.
27. Straumann Bone Level Tapered Implant: Basic Information. Institut Straumann AG; 2019.
28. Hiranmayi KV. Factors Influencing Implant Stability. J Dent Implant 2018;8(2):69-76.
29. McCullough JJ, Klokkevold PR. The Effect of Implant Macro-thread Design on Implant Stability in the Early Post-Operative Period: a Randomized, Controlled Pilot Study. Clin Oral Implants Res 2017;28(10):1218-26.
30. Le Guéhennec L, Soueidan A, Layrolle P, Amouriq Y. Surface Treatments of Titanium Dental Implants for Rapid Osseointegration. Dent Mater 2007;23(7):844-54.
31. Toyoshima T, Wagner W, Klein MO, Stender E, Wieland M, Al-Nawas B. Primary Stability of A Hybrid Self-Tapping Implant Compared to a Cylindrical Non-Self-Tapping Implant with Respect to Drilling Protocols in an Ex Vivo Model. Clin Implant Dent Relat Res 2011;13(1):71-8.
32. Bilhan H, Geckili O, Mumcu E, Bozdag E, Sünbüloğlu E, Kutay O. Influence of Surgical Technique, Implant Shape and Diameter on the Primary Stability in Cancellous Bone. J Oral Rehabil 2010;37(12):900-7.
33. Barikani H, Rashtak S, Akbari S, Fard MK, Rokn A. The Effect of Shape, Length and Diameter of Implants on Primary Stability Based on Resonance Frequency Analysis. Dent Res J (Isfahan) 2014;11(1):87-91.