Effect of Implant Length and Insertion Depth on Primary Stability of Short Dental Implant

Hsiang-Chun Wu, DDS[1]/Heng-Li Huang, PhD[1,2]/Lih-Jyh Fuh, DDS, PhD[1,3]/Ming-Tzu Tsai, PhD[4]/Jui-Ting Hsu, PhD[1,2]

Purpose: To evaluate the effect of insertion depth, bone type, and implant diameter on the primary stability of short implants. ***Materials and Methods:*** Commercial dental implants with different lengths (6 and 8 mm; BLX, Straumann) were inserted into artificial bone specimens of good and poor quality at three different depth positions: equicrestal, 1-mm subcrestal, and 2-mm subcrestal. Insertion torque values were recorded spontaneously during the implant procedure. Both maximum insertion torque values (MITVs) and final insertion torque values (FITVs) were recorded. Subsequently, Periotest values (PTVs) and implant stability quotients (ISQs) were measured for all specimens. ***Results:*** The mean MITVs of all groups ranged from 31.8 to 46.2 Ncm. However, the mean FITVs of all groups ranged from 8.8 to 29 Ncm. Torque values decreased significantly when the implants were inserted into their final positions. When insertion depth was increased, the PTV and ISQ decreased. Long implants and implants inserted into good-quality bone yielded greater primary stability, and bone quality appeared to have a greater effect on primary stability. ***Conclusion:*** When 6-mm short implants are inserted in a subcrestal position, low primary stability may be yielded, particularly in poor-quality bone. *Int J Oral Maxillofac Implants 2023;38:62–70. doi: 10.11607/jomi.9769*

Keywords: artificial bone, implant stability quotient, insertion depth, insertion torque value, Periotest value, primary stability, short dental implant

Advancements in dental implant technology have made dental implants the mainstream method for replacing missing teeth. Numerous studies have noted favorable outcomes in terms of the appearance, strength, and long-term stability of dental implants. Osseointegration between dental implants and jawbone is an essential factor that influences the implant success rate.[1–6] The primary stability of an implant after insertion into jawbone has been demonstrated to be among the most crucial indicators for assessing whether an implant can achieve excellent osseointegration. The success rate of osseointegration is higher when the dental implant in the jawbone has higher primary stability, and thus, the related postsurgery implant survival rate is also higher.[7,8] In clinical practice, multiple factors can affect the primary stability of an implant, including the design, size, and surface treatment of dental implants; patient bone quality and quantity; and the surgery methods performed by clinicians.[7,9,10] At present, three key methods are used for measuring the primary stability of implants in clinical practice: the implant stability quotient (ISQ), Periotest value (PTV), and maximum insertion torque value (MITV).[11,12] The ISQ and PTV are noninvasive measurement methods that can be used repeatedly to observe changes in implant stability after insertion, whereas the MITV can be measured directly during an insertion procedure; these three variables are often compared in clinical settings.[13–15]

Ideally, inserting an implant with a longer length and wider diameter allows for better primary stability. However, a patient's anatomical limitations (eg, the anatomy of the maxillary sinus and inferior alveolar nerve or edentulousness that resulted in insufficient bone quantity) can prevent the insertion of optimally sized implants, particularly in the posterior mandible and maxilla. Although a bone augmentation technique (eg, maxillary sinus elevation procedure and mandibular vertical augmentation) can be performed to solve the aforementioned problems,[16,17] short implants have provided patients with new options. Several studies have suggested that short implants are associated with fewer

---

[1]School of Dentistry, College of Dentistry, China Medical University, Taichung, Taiwan.
[2]Department of Bioinformatics and Medical Engineering, Asia University, Taichung, Taiwan.
[3]Department of Dentistry, China Medical University and Hospital, Taichung, Taiwan.
[4]Department of Biomedical Engineering, Hungkuang University, Taichung, Taiwan.

Correspondence to: Prof Jui-Ting Hsu, School of Dentistry, College of Medicine, China Medical University, 91 Hsueh-Shih Road, Taichung 404 Taiwan. Email: jthsu@mail.cmu.edu.tw; richard@ms32.url.com.tw

Submitted November 8, 2021; accepted June 28, 2022.

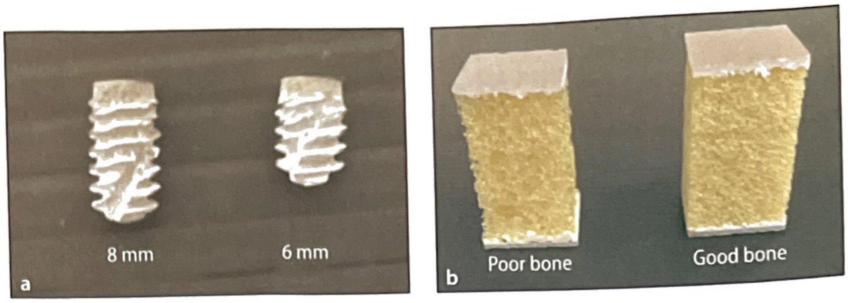

Fig 1 Specimens: *(a)* dental implants and *(b)* artificial foam bones.

postoperative complications, lower surgical costs, and shorter operation time, and no differences in survival rate were observed when they were compared with long implants in the early- to mid-term follow-up.[18–20] The definition of a short implant differs among studies, and earlier studies have defined implants that are < 10 mm as short implants.[21,22] Nonetheless, because of advancements in implant design, recent studies have started to define short implants as having a length of 6 or 8 mm.[18,23] A more rigorous classification of short implants was proposed by Nisand and Renouard,[24] who considered not only implant length but also the aspect of submerged bone quality.

The position of the implant-abutment junction may affect subsequent marginal bone loss and cause implant exposure. Studies have suggested that bone-level implants should be inserted in a subcrestal position to prevent implant exposure–related problems.[25,26] However, few studies have discussed the exact depth for appropriate insertion. In addition, the primary stability of an implant is dependent on the upper cortical bone.[27,28] When an implant is inserted into the range beyond cortical bone, it may lose its primary stability. Therefore, when a short implant is inserted to accommodate a patient's anatomical structure, it has lower primary stability relative to a long implant; for this reason, sufficient primary stability can only be achieved by maximizing the contact area between an implant and cortical and trabecular bone.[29,30] Existing literature rarely discusses the effects of equicrestal or subcrestal implant placement on primary stability, especially on short implants.

Studies have often used the MITV to represent primary stability because it can be measured during an insertion procedure. However, the torque value of an implant inserted into the jawbone varies, and the MITV does not necessarily occur at its final inserted position.[31,32] Therefore, in addition to recording MITVs, the present study also measured the final insertion torque value (FITV). After inserting an implant, the present study measured the implant's ISQ and PTV to compare the primary stability of four groups. The present study explored two implant lengths (6-mm short implant and 8-mm standard implant) with three varying depths (equicrestal, 1-mm subcrestal, and 2-mm subcrestal positions); the implants were inserted into artificial bone with varying bone quality (good- and poor-quality bone) to measure the effects of implant length and insertion depth on primary stability.

MATERIALS AND METHODS

Artificial Foam Bone Specimen and Dental Implant Preparation

Two implant dimensions were selected (4.5-mm diameter, 6- and 8-mm length; BLX, Straumann) for the present study. The parameters were set according to Nisand and Renouard's definition of implant length; that is, a short implant was defined as an implant with a designed intrabony length of ≤ 8 mm (Fig 1a).[24] Artificial foam bone specimens that consisted of rigid cellular polyurethane blocks (Sawbones) were prepared for the present study. For the good-quality bone specimen, 1.5-mm synthetic cortical shells (model 3401–01) with a density of 1.64 g/cm^3 were attached to trabecular bone blocks with a density of 0.32 g/cm^3 (model 1522–12). For the poor-quality bone specimen, 1.0-mm synthetic cortical shells (model 3401–01) with a density of 1.64 g/cm^3 were attached to trabecular bone with a density of 0.16 g/cm^3 (model 1522–10; Fig 1b).[29,33–35]

Arrangement of Groups According to Parameter Settings

In the present study, four groups were established according to bone type and implant diameter, and each group was further divided into three subgroups according to insertion depth (equicrestal, subcrestal 1-mm position, and subcrestal 2-mm position; Fig 2). Each subgroup comprised five samples (n = 5):

- Group 1: 6-mm implant was inserted into good-quality bone at the equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions.
- Group 2: 8-mm implant was inserted into good-quality bone at the equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions.
- Group 3: 6-mm implant was inserted into poor-quality bone at the equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions.
- Group 4: 8-mm implant was inserted into poor-quality bone at the equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions.

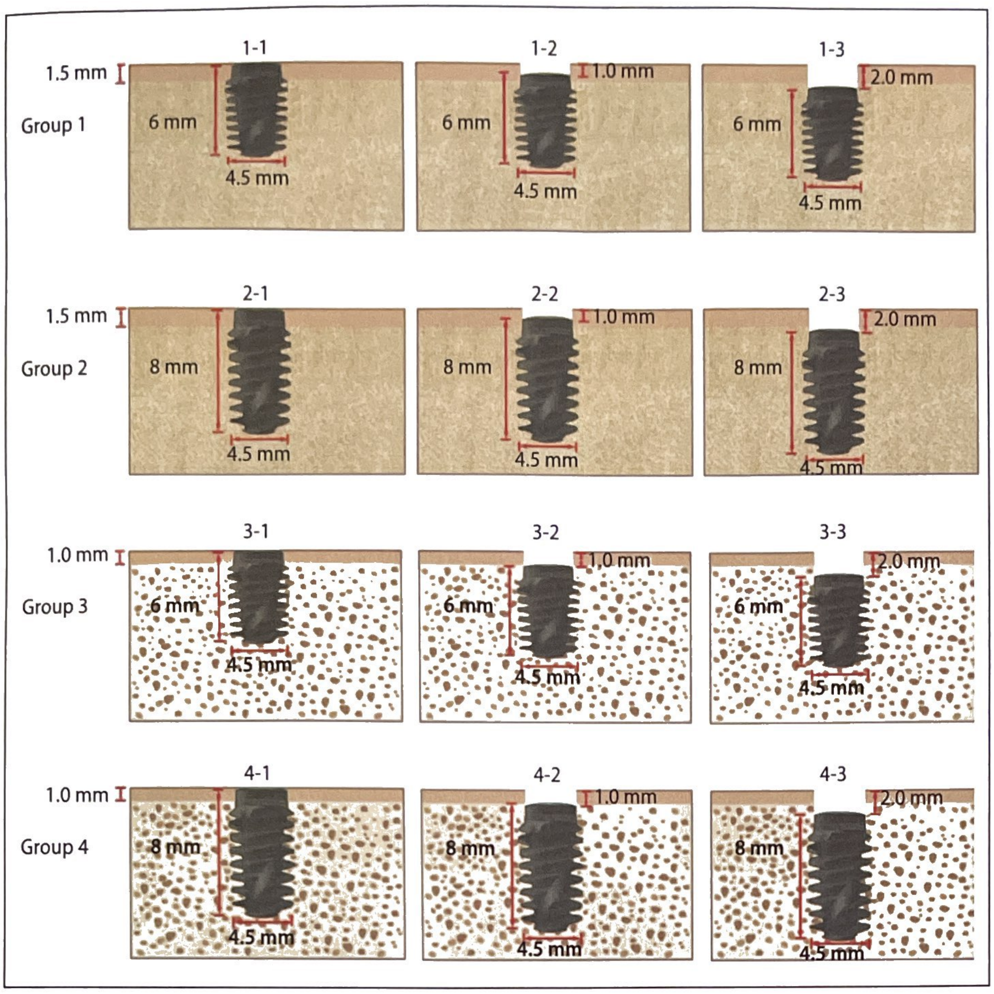

Fig 2 Parameter settings. Group 1: 6-mm implant inserted into good-quality bone at equicrestal (subgroup 1-1), subcrestal 1-mm (subgroup 1-2), and subcrestal 2-mm (subgroup 1-3) positions. Group 2: 8-mm implant inserted into good-quality bone at equicrestal (subgroup 2-1), subcrestal 1-mm (subgroup 2-2), and subcrestal 2-mm (subgroup 2-3) positions. Group 3: 6-mm implant inserted into poor-quality bone at equicrestal (subgroup 3-1), subcrestal 1-mm (subgroup 3-2), and subcrestal 2-mm (subgroup 3-3) positions. Group 4: 8-mm implant inserted into poor-quality bone at equicrestal (subgroup 4-1), subcrestal 1-mm (subgroup 4-2), and subcrestal 2-mm (subgroup 4-3) positions.

Measurement of Three Primary Stability Indexes of Short Dental Implant

All the drilling protocols were performed according to Straumann BLX implant instructions. Before inserting a dental implant, pilot holes were drilled into each artificial bone specimen using the Nobel Biocare OsseoSet implant motor (Fig 3). The implant motor could record immediate torque value (Ncm) during drilling. Notably, for the subcrestal 1-mm position, drilling depths of 7 and 9 mm were used for the 6-mm and 8-mm implants, respectively; for the subcrestal 2-mm position, drilling depths of 8 and 10 mm were used for the 6-mm and 8-mm implants, respectively.

The PTV was measured after the abutment was placed. The Periotest device (Medizintechnik Gulden) was used to measure the primary stability of an implant (Fig 4a). The tip of the Periotest device was placed perpendicularly to the abutment at a distance of 2 mm. The resonance frequency analyzer Osstell ISQ (Osstell) was used to measure ISQ values (Fig 4b). The specific smart peg for the internal hex connection of an implant (Type 38, Osstell) was fixed to the top of the implant.

Statistical Analysis

All statistical analyses were performed using SPSS Version 19 (IBM), and the significance level was set to $P < .05$. Three statistical methods were used to perform the assessments required to achieve the objectives of the present study.

To assess the effects of different insertion depths (equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions) on the MITV, FITV, ISQ, and PTV of implants, Kruskal–Wallis test was used to identify differences in the results pertaining to the four primary stability parameters and three insertion depths, and Dunn test was used to conduct a post hoc pairwise comparison whenever a difference was identified.

To assess the effects of bone types (good- and poor-quality bone) on the MITV, FITV, ISQ, and PTV of implants with varying insertion depths, Mann-Whitney *U* test was used to compare group 1 with group 3 and group 2 with group 4.

To assess the effects of implant lengths (6 and 8 mm) on the MITV, FITV, ISQ, and PTV of implants with varying insertion depths, the Mann-Whitney *U* test was used to compare group 1 with group 2 and group 3 with group 4.

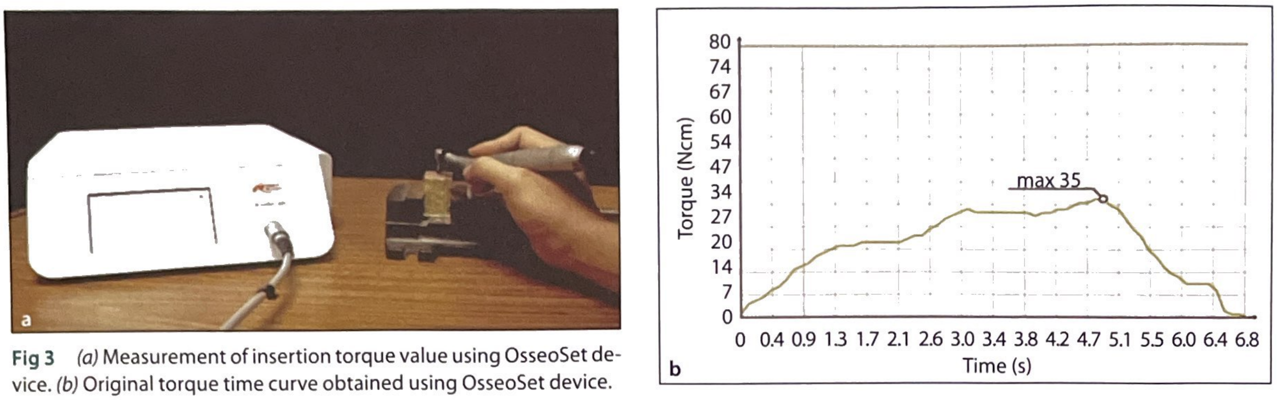

Fig 3 *(a)* Measurement of insertion torque value using OsseoSet device. *(b)* Original torque time curve obtained using OsseoSet device.

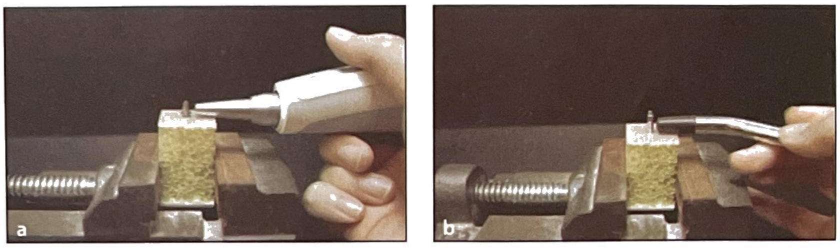

Fig 4 *(a)* Measurement of PTV using Periotest device. *(b)* Measurement of ISQ using Osstell ISQ device.

Table 1 MITV, FITV, ISQ, and PTV of the Four Groups

		Group 1			Group 2			Group 3			Group 4		
Subgroup		**1-1**	**1-2**	**1-3**	**2-1**	**2-2**	**2-3**	**3-1**	**3-2**	**3-3**	**4-1**	**4-2**	**4-3**
MITV	Mean	46.20	44.00	45.00	45.80	41.00	44.40	35.60	31.80	38.20	39.20	39.80	36.40
	SD	5.36	8.06	4.42	7.05	4.85	2.70	5.50	2.86	3.56	3.11	6.18	6.43
FITV	Mean	29.00	19.40	10.60	27.40	17.20	8.80	18.40	10.40	8.80	20.20	11.00	9.40
	SD	3.54	1.95	1.82	5.18	2.59	0.84	4.72	1.14	1.48	3.56	1.58	3.36
ISQ	Mean	70.60	68.35	61.05	67.35	64.45	50.15	59.90	55.35	53.50	58.45	54.90	45.10
	SD	0.96	1.15	1.62	1.17	2.99	5.95	2.14	2.23	4.43	2.93	3.83	4.63
PTV	Mean	3.85	4.35	6.74	4.64	5.29	8.16	9.16	11.25	11.40	8.40	10.83	14.41
	SD	0.32	0.31	0.52	0.97	1.45	2.53	1.69	2.46	0.72	1.47	1.26	0.85

Group 1: 6-mm implant inserted into good bone. Group 2: 8-mm implant inserted into good bone. Group 3: 6-mm implant inserted into poor bone. Group 4: 8-mm implant inserted into poor bone.

RESULTS

Effect of Insertion Depth on Primary Stability

The experimental results are presented in Table 1 and Fig 5. In all four groups, MITVs did not show a significant difference between the subgroups with different insertion depths. Therefore, the mean of the three subgroups was used for the intergroup comparison in the present study. The results revealed that the MITVs of all groups were not attained at the final insertion position (Fig 6). For the FITV, ISQ, and PTV at three depths (equicrestal, subcrestal 1-mm, and subcrestal 2-mm positions), a comparison of the four groups revealed no significant difference between the equicrestal and subcrestal 1-mm positions and between the subcrestal 1-mm and subcrestal 2-mm positions; however, a significant difference between the equicrestal and subcrestal 2-mm positions was observed (except for the PTV in group 4, which was nonsignificant).

Effect of Implant Length and Bone Type on Primary Stability

For implants with the same length that were inserted into bones of different quality, the comparisons of group 1 with group 3 and group 2 with group 4 revealed that at the equicrestal (subgroups 1-1 and 3-1 and subgroups 2-1 and 4-1) and subcrestal 1-mm (subgroups 1-2 and 3-2 and subgroups 2-2 and 4-2) positions, the values of the four primary stability parameters were all higher in good-quality bone ($P < .05$). At the subcrestal 2-mm position, the PTVs of subgroups 1-3 and 3-3 were significantly different ($P < .05$), and the ISQs and PTVs of subgroups 2-3 and 4-3 were significantly different ($P < .05$).

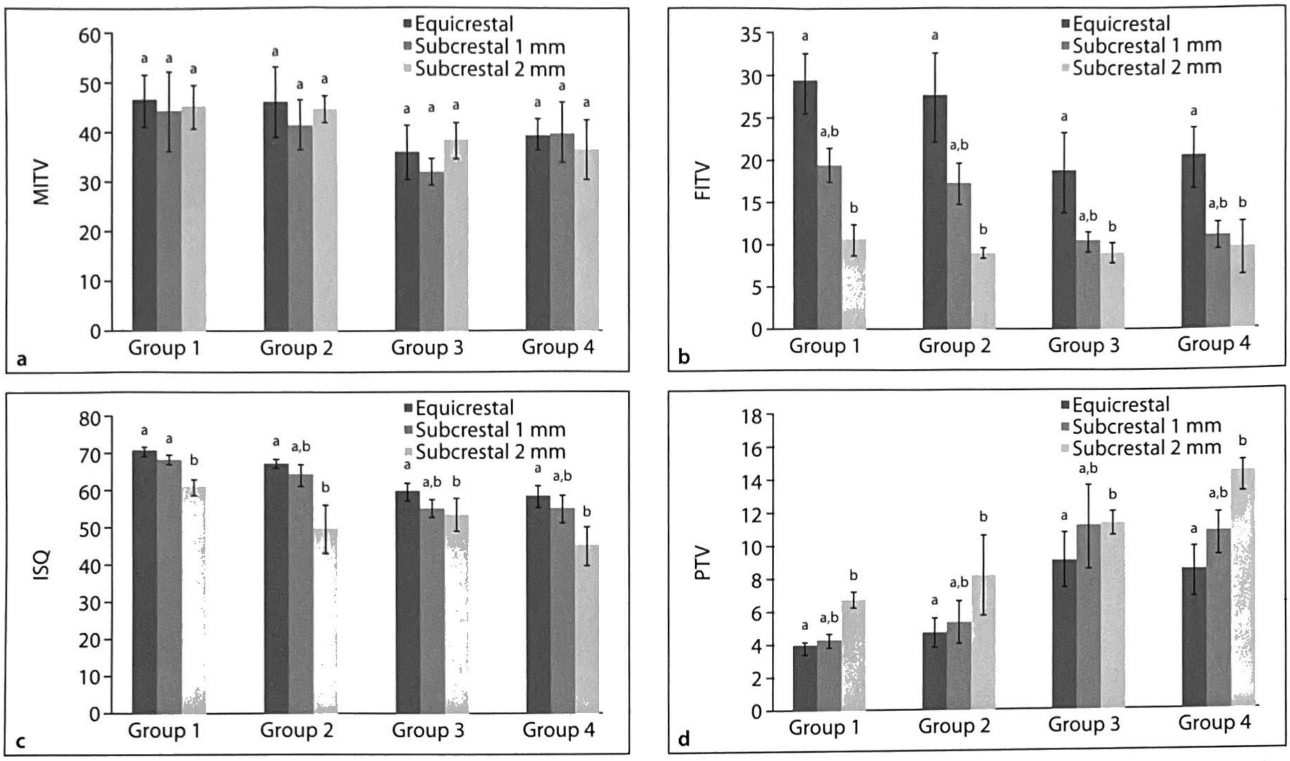

Fig 5 Comparison of *(a)* MITV, *(b)* FITV, *(c)* ISQ, and *(d)* PTV for different insertion depths. For the subgroup bars in each group, having the same letter indicates a nonsignificant difference. Group 1: 6-mm implant inserted into good-quality bone. Group 2: 8-mm implant inserted into good-quality bone. Group 3: 6-mm implant inserted into poor-quality bone. Group 4: 8-mm implant inserted into poor-quality bone. The bar chart presents the results for the four primary stability parameters of the three insertion-depth subgroups of each group. Post hoc pairwise comparisons were conducted using Dunn test; for each group, having the same letters indicates nonsignificant differences between means at a significance level of .05.

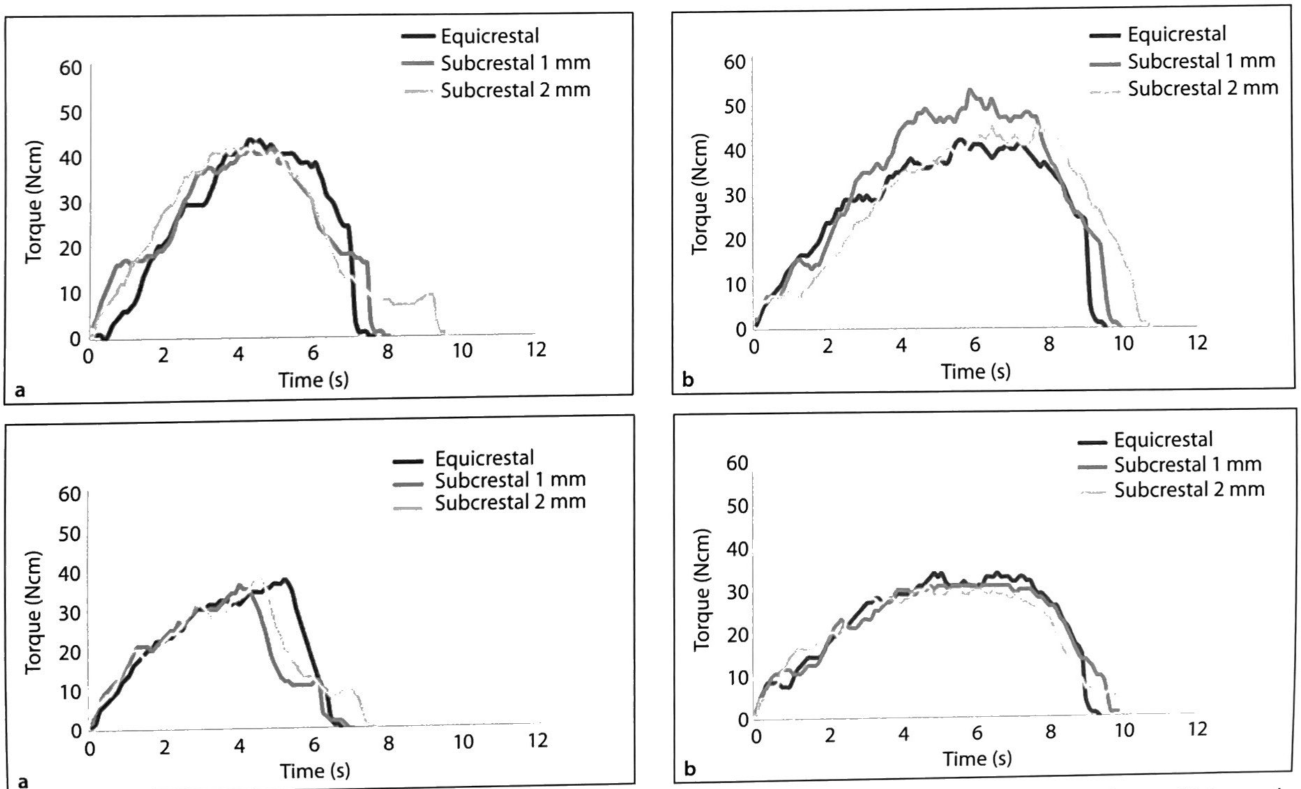

Fig 6 Torque–time curves for each group. Each curve represents a randomly chosen sample. Group 1: 6-mm implant inserted into good-quality bone. Group 2: 8-mm implant inserted into good-quality bone. Group 3: 6-mm implant inserted into poor-quality bone. Group 4: 8-mm implant inserted into poor-quality bone.

For implants of different lengths that were inserted into bones of the same quality, the comparisons of group 1 with group 2 and group 3 with group 4 revealed that at the equicrestal position, the ISQs of subgroups 1-1 and 2-1 were significantly different ($P < .05$). At the subcrestal 1-mm position, the differences in primary stability parameter values were nonsignificant ($P > .05$). At the subcrestal 2-mm position, significant differences in the ISQ and PTV were observed between subgroups 1-3 and 2-3 and between subgroups 3-3 and 4-3 ($P < .05$).

DISCUSSION

In the past, insufficient alveolar bone quantity due to edentulousness or other factors prevented the insertion of optimally sized implants, particularly in the posterior mandible and maxilla. Moreover, the presence of anatomical limitations, such as the maxillary sinus and inferior alveolar nerve, often require the performance of complex bone augmentation techniques to enable the insertion of implants of sufficient length.[16,17] Advancements in dental implant design and surface treatment in recent years have led to substantial improvements in the primary stability of implants, such that short implants can now be used in patients with anatomical limitations to avoid complex surgery.[36–38] Nevertheless, few studies have discussed the primary stability of short implants, and even fewer have examined the effects of varying insertion depths on primary stability. The present study is the first to use four primary stability parameters as references: ISQ, PTV, MITV, and FITV. The results revealed that the implant insertion torque value fluctuated throughout the insertion procedure and that the MITV and FITV were not necessarily attained at the same insertion depth. The FITV may be more suitable for assessing the primary stability of an implant after insertion. Furthermore, experiments have verified that when an implant is inserted beyond cortical bone, the loss of cortical engagement leads to a considerable decrease in the ISQ, PTV, and FITV, indicating the crucial role of cortical bone in maintaining the primary stability of implants.

Recent studies on short implants have reported no significant difference in short-term success rates relative to long implants. In a multicenter randomized controlled trial conducted by Guljé et al in 2012, the success rates of long and short implants (inserted in the posterior mandible and maxilla) were compared. In the aforementioned study, 49 and 46 patients received short (6 mm) and long (11 mm) implants, respectively, and the findings obtained after a year of follow-up indicated that both types of implants were equally reliable.[39] A pilot randomized controlled trial conducted by Esposito et al in 2015 compared 15 patients with short implants (5.0 to 8.5 mm) and 13 patients with long implants (> 11.5 mm; inserted in the maxillary edentulous area with autogenous bone augmentation); both types of implants had similar success rates during a 1-year observation period, and postoperative complications only occurred in the autogenous bone augmentation group.[36] Weerapong et al[38] conducted a randomized controlled trial in 2019 to test the immediate loading performance of 23 short implants (6 mm) and 23 standard implants (10 mm) in the posterior mandible; at the 1-year follow-up, the study reported that two short implants were affected by loss of integration, and one standard implant had failed. In the aforementioned study, no significant difference in the success rates of both types of implants was observed, and the 6- and 10-mm implants achieved similar outcomes with respect to three indicators (ie, implant survival rate, marginal bone level change, and ISQ).[38] Medium- and long-term studies are relatively rare. In 2014, Felice et al conducted a randomized controlled trial that examined the posterior atrophic mandible and compared the 5-year success rates of directly inserted short implants (6.6 mm) and long implants (> 9.6 mm) inserted after vertical augmentation; the results indicated that the medium-term (5-year) prognosis of short implants was comparable to that of long implants.[40]

Studies have reported that artificial bone is a suitable material for conducting biomechanical tests of dental implants.[27,30,41,42] Therefore, the present study referred to the experimental protocols of related studies[27,32,43] and experiments were conducted by inserting commercial dental implants into cellular polyurethane artificial bone. Although some studies used fresh animal bones to perform biomechanical experiments involving dental implants,[44] the material properties of each bone test piece were different. By contrast, artificial bone is stable and thus suitable for use as a material for testing primary stability. In the present study, the good-quality bone specimen had a cortical bone thickness of 1.5 mm and cancellous bone density of 0.32 g/cm^3, whereas the poor-quality bone specimen had a cortical bone thickness of 1.0 mm and cancellous bone density of 0.16 g/cm^3. The cortical bone thickness data of the specimens were obtained from relevant studies. Ko et al noted that the thickness of cortical bone in the posterior maxilla and posterior mandible areas was 0.72 ± 0.19 mm and 1.15 ± 0.42 mm, respectively.[34] Another study demonstrated that the average thickness of cortical bone in the mandible and maxilla was 2.22 ± 0.47 mm and 1.49 ± 0.34 mm, respectively.[35] The density of cancellous bone was obtained from previous studies.[29,33]

Clinically, three principal methods are commonly used to measure the primary stability of implants: ISQ, PTV, and MITV. The results obtained through these three measurement methods are often compared to aid the verification of implant primary stability.[13–15] The present study revealed that when implant lengths were similar, bone quality affected primary stability more significantly. Because the implant lengths examined in the present study differed by only 2 mm, the values pertaining to primary stability could be statistically nonsignificant. This finding is consistent with that of a study conducted by Aragoneses et al.[45] By contrast, other studies have proposed that bone quality has a significant effect on primary stability.[46,47]

Several studies have noted that an appropriate insertion torque can affect the survival rate of implants. In a 2015 study, Ottoni et al[48] reported that an insertion torque of > 32 Ncm was necessary for implants. The results of the present study revealed that a torque value of 10 Ncm (measured when inserting a short implant into poor-quality bone) may indicate a lack of primary stability. In a 2015 clinical study conducted by Rossi et al,[49] 40 SLActive (Straumann) implants with a length of 6 mm were tested and divided into two groups with diameters of 4.1 mm (n = 19) and 4.8 mm (n = 21); bone classification (8 were type 1 [20%], 24 were type 2 [60%], 7 were type 3 [17.5%], and 1 was type 4 [2.5%]) was performed according to the standards established by Lekholm and Zarb in 1985.[50] The results of the aforementioned study indicated that 17, 11, and 10 implants had a mean insertion torque of ≤ 15 Ncm, 15 to 35 Ncm, and ≥ 35 Ncm, respectively; and the ISQ at the time of insertion was 70.2 ± 9.0 Ncm (range: 42 to 84 Ncm). These torque test results were similar to those of the present study, which reported that short implants had a measured torque value of < 15 Ncm. The failure of one of the implants examined in the present study could be because the implant had a torque of < 15 Ncm and an ISQ of 35, which caused insufficient primary stability.

The final position of an implant is operationally regarded as the benchmark when measuring the ISQ and PTV. However, the MITV is commonly used as a parameter for insertion torque. In the present study, the insertion torque value fluctuated throughout the insertion process. Moreover, the MITV and FITV were not necessarily attained at the same insertion depth. When implant length and bone quality were constant, MITV did not differ significantly by insertion depth. This indicated that the MITV was not attained at the final insertion position. In a 2015 study, Wang et al[32] reported that an implant that is thicker in the middle section resulted in the MITV being attained before the FITV. This finding is consistent with the findings of the present study (Fig 6). Because the FITV was lower than the MITV, the FITV should be used as the parameter of implant primary stability.

Studies have discussed that bone-level implants should be inserted at the subcrestal position to prevent problems such as marginal bone loss. A meta-analysis by Valles et al[51] revealed that subcrestal implants resulted in less marginal bone loss relative to equicrestal implants. Linkevicius et al[52] compared 1.5-mm subcrestally and epicrestally placed implants in a meta-analysis; after 2 years of observation, the study discovered that subcrestal and epicrestal implants had a bone loss of 0.18 ± 0.32 mm and 0.51 ± 0.4 mm, respectively. Therefore, the aforementioned study suggested that subcrestal implants can significantly reduce crestal bone loss.

However, few studies have focused on insertion depth under anatomical limitations. In 2019, Palacios-Garzón et al[26] conducted a meta-analysis of 150 articles and discovered that the clinical insertion depth was between −0.5 and −3.4 mm, but the study did not propose an optimal depth. In 2017, Gualini et al[53] compared the marginal bone loss and success rate for implants with an insertion depth of 0.5 or 1.5 mm, and no significant difference was observed between the two depths within a 1-year period. Nonetheless, the results of the present study indicated that when an implant was inserted into a deeper position, its FITV was significantly reduced because of the loss of cortical engagement. Moreover, compared with trabecular bone, whether an implant can contact the upper cortical bone was the crucial factor affecting its ISQ, PTV, and FITV. Cortical bone has been described by numerous studies as an essential factor that contributes to primary stability. The results of the present study are consistent with those of Ferraro-Bezerra et al.[31] In addition, Al-Hashedi et al[54] compared the PTV of two brands (Bicon [6 or 8 mm] and Ankylos [8 mm]) after the implants were inserted into the posterior mandible area; the study reported that the Bicon and Ankylos implant manufacturers recommended implant insertion depths of 1.5 mm and 0.5 to 1 mm, respectively, and the PTVs for Ankylos and Bicon implants were −1.61 (2.02) and 2.15 (2.52), respectively, indicating that Ankylos implants provide more primary stability. The aforementioned study[54] suggested that this discrepancy was probably caused by differences in implant design. Nevertheless, based on the results of the present study, in addition to implant design, a deeper insertion depth may result in reduced primary stability due to the lack of contact with cortical bone.

The present study had several limitations. First, because of the difficulty of obtaining fresh human jawbones with consistent bone quality, this study used artificial bones for its experiments. Second, this study only evaluated the effect of the depth of the dental implant in the bone on implant stability. However, the insertion depth is also influenced by the proposed mucosal margin of the restoration. Third, the study only simulated two types of bone quality, which did not demonstrate the inhomogenous characteristics of actual human bones. Fourth, this study only examined dental implants from one brand and three insertion depths. Fifth, this study only measured four primary stability parameters for dental implants and did not consider the stress and strain distribution on the marginal bone.

CONCLUSIONS

Based on the experimental results, the conclusions are as follows:

1. Inserting an implant into bone of better quality can improve primary stability.
2. Implants with a longer length exhibit higher primary stability.
3. Implant insertion torque varies throughout an insertion procedure, and the MITV and FITV are not necessarily attained at the same insertion depth. Therefore, this study suggests that the FITV can be used as a parameter for measuring the primary stability of implants.
4. Cortical bone is a key factor that contributes to primary stability. When an implant is inserted beyond cortical bone, the ISQ, PTV, and FITV (ie, primary stability) decrease significantly because of the loss of cortical engagement. Therefore, when inserting an implant at the subcrestal position, the clinical recommendation is to allow the implant to contact cortical bone to attain adequate primary stability.

ACKNOWLEDGMENTS

All authors have no conflict of interest related to the study. This research was supported by Ministry of Science and Technology, Taiwan (grant number: MOST 110-2221-E-039-005) and China Medical University, Taiwan (grant number: CMU110-S-05).

REFERENCES

1. Alghamdi HS, Jansen JA. The development and future of dental implants. Dent Mater J 2020;39:167–172.
2. Bouchard P, Renouard F, Bourgeois D, Fromentin O, Jeanneret M, Beresniak A. Cost-effectiveness modeling of dental implant vs. bridge. Clin Oral Implants Res 2009;20:583–587.
3. Jokar H, Rouhi G, Abolfathi N. The effects of splinting on the initial stability and displacement pattern of periodontio-integrated dental implants: A finite element investigation. J Med Biol Eng 2020;40:719–726.
4. Karnik N, Bhadri K, Bora U, Joshi S, Dhatrak P. A mathematical model for biomechanical evaluation of micro-motion in dental prosthetics using vibroacoustic RFA. J Med Biol Eng 2021;41:571–580.
5. Pitman J, Christiaens V, Cosyn J, Glibert M. Primary stability of conventionally tapered versus reverse tapered body shift implants under varying bone support conditions—An in vitro study. J Med Biol Eng 2022;42:429–435.
6. Hsu YY, Tsai MT, Huang HL, Fuh LJ, Hsu JT. Insertion speed affects he initial stability of dental implants. J Med Biol Eng 2022;42:516–525.
7. Javed F, Romanos GE. The role of primary stability for successful immediate loading of dental implants. A literature review. J Dent 2010;38:612–620.
8. Lages FS, Douglas-de Oliveira DW, Costa FO. Relationship between implant stability measurements obtained by insertion torque and resonance frequency analysis: A systematic review. Clin Implant Dent Relat Res 2018;20:26–33.
9. 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 Implants 2018;33:824–830.
10. Turkyilmaz I, Aksoy U, McGlumphy EA. Two alternative surgical techniques for enhancing primary implant stability in the posterior maxilla: A clinical study including bone density, insertion torque, and resonance frequency analysis data. Clin Implant Dent Relat Res 2008;10:231–237.
11. Atsumi M, Park SH, Wang HL. Methods used to assess implant stability: Current status. Int J Oral Maxillofac Implants 2007;22:743–754.
12. Swami V, Vijayaraghavan V, Swami V. Current trends to measure implant stability. J Indian Prosthodont Soc 2016;16:124–130.
13. AAl MA, El Far M, Sheta NM, et al. Correlation of implant stability between two noninvasive methods using submerged and nonsubmerged healing protocols: A randomized clinical trial. J Oral Implantol 2020;46:571–579.
14. Alonso FR, Triches DF, Mezzomo LAM, Teixeira ER, Shinkai RSA. Primary and secondary stability of single short implants. J Craniofac Surg 2018;29:e548–e551.
15. Bavetta G, Bavetta G, Randazzo V, et al. A retrospective study on insertion torque and implant stability quotient (ISQ) as stability parameters for immediate loading of implants in fresh extraction sockets. Biomed Res Int 2019;2019:9720419.
16. Bornstein MM, Chappuis V, Von Arx T, Buser D. Performance of dental implants after staged sinus floor elevation procedures: 5-year results of a prospective study in partially edentulous patients. Clin Oral Implants Res 2008;19:1034–1043.
17. Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants 2009;24(suppl):237–259.
18. Lemos CA, Ferro-Alves ML, Okamoto R, Mendonça MR, Pellizzer EP. Short dental implants versus standard dental implants placed in the posterior jaws: A systematic review and meta-analysis. J Dent 2016;47:8–17.
19. Ravidà A, Wang IC, Barootchi S, et al. Meta-analysis of randomized clinical trials comparing clinical and patient-reported outcomes between extra-short (≤ 6 mm) and longer (≥ 10 mm) implants. J Clin Periodontol 2019;46:118–142.
20. Tolentino da Rosa de Souza P, Binhame Albini Martini M, Reis Azevedo-Alanis L. Do short implants have similar survival rates compared to standard implants in posterior single crown?: A systematic review and meta-analysis. Clin Implant Dent Relat Res 2018;20:890–901.
21. Feldman S, Boitel N, Weng D, Kohles SS, Stach RM. Five-year survival distributions of short-length (10 mm or less) machined-surfaced and osseotite implants. Clin Implant Dent Relat Res 2004;6:16–23.
22. Strietzel FP, Reichart PA. Oral rehabilitation using Camlog screw-cylinder implants with a particle-blasted and acid-etched microstructured surface. Results from a prospective study with special consideration of short implants. Clin Oral Implants Res 2007;18:591–600.
23. Fan T, Li Y, Deng WW, Wu T, Zhang W. Short implants (5 to 8 mm) versus longer implants (> 8 mm) with sinus lifting in atrophic posterior maxilla: A meta-analysis of RCTs. Clin Implant Dent Relat Res 2017;19:207–215.
24. Nisand D, Renouard F. Short implant in limited bone volume. Periodontol 2000 2014;66:72–96.
25. Degidi M, Perrotti V, Shibli JA, Novaes AB, Piattelli A, Iezzi G. Equicrestal and subcrestal dental implants: A histologic and histomorphometric evaluation of nine retrieved human implants. J Periodontol 2011;82:708–715.
26. Palacios-Garzón N, Velasco-Ortega E, López-López J. Bone loss in implants placed at subcrestal and crestal level: A systematic review and meta-analysis. Materials (Basel) 2019;12:154.

27. Hsu JT, Fuh LJ, Tu MG, et al. The effects of cortical bone thickness and trabecular bone strength on noninvasive measures of the implant primary stability using synthetic bone models. Clin Implant Dent Relat Res 2013;15:251–261.
28. de Oliveira Nicolau Mantovani AK, de Mattias Sartori IA, Azevedo-Alanis LR, Tiossi R, Fontão FNGK. Influence of cortical bone anchorage on the primary stability of dental implants. Oral Maxillofac Surg 2018;22:297–301.
29. Di Stefano DA, Arosio P, Pagnutti S, Vinci R, Gherlone EF. Distribution of trabecular bone density in the maxilla and mandible. Implant Dent 2019;28:340–348.
30. Hsu JT, Shen YW, Kuo CW, Wang RT, Fuh LJ, Huang HL. Impacts of 3D bone-to-implant contact and implant diameter on primary stability of dental implant. J Formos Med Assoc 2017;116:582–590.
31. Ferraro-Bezerra M, Rodrigues Carvalho FS, Nogueira Cunto GM, Duarte Carneiro BG, de Barros Silva PG. Does subcrestal position affect insertion torque of different implant designs at different bone densities? An in vitro model study. Int J Oral Maxillofac Implants 2021;36:460–467.
32. Wang TM, Lee MS, Wang JS, Lin LD. The effect of implant design and bone quality on insertion torque, resonance frequency analysis, and insertion energy during implant placement in low or low-to medium-density bone. Int J Prosthodont 2015;28:40–47.
33. Devlin H, Horner K, Ledgerton D. A comparison of maxillary and mandibular bone mineral densities. J Prosthet Dent 1998;79:323–327.
34. Ko YC, Huang HL, Shen YW, Cai JY, Fuh LJ, Hsu JT. Variations in crestal cortical bone thickness at dental implant sites in different regions of the jawbone. Clin Implant Dent Relat Res 2017;19:440–446.
35. Miyamoto I, Tsuboi Y, Wada E, Suwa H, Iizuka T. Influence of cortical bone thickness and implant length on implant stability at the time of surgery–Clinical, prospective, biomechanical, and imaging study. Bone 2005;37:776–780.
36. Esposito M, Barausse C, Pistilli R, Sammartino G, Grandi G, Felice P. Short implants versus bone aumentation for placing longer implants in atrophic maxillae: One-year post-loading results of a pilot randomised controlled trial. Eur J Oral Implantol 2015;8:257–268.
37. Esposito M, Buti J, Barausse C, Gasparro R, Sammartino G, Felice P. Short implants versus longer implants in vertically augmented atrophic mandibles: A systematic review of randomised controlled trials with a 5-year post-loading follow-up. Int J Oral Implantol (Berl) 2019;12:267–280.
38. Weerapong K, Sirimongkolwattana S, Sastraruji T, Khongkhunthian P. Comparative study of immediate loading on short dental implants and conventional dental implants in the posterior mandible: A randomized clinical trial. Int J Oral Maxillofac Implants 2019;34:141–149.
39. Guljé F, Abrahamsson I, Chen S, Stanford C, Zadeh H, Palmer R. Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible: A 1-year multicenter randomized controlled trial. Clin Oral Implants Res 2013;24:1325–1331.
40. Felice P, Cannizzaro G, Barausse C, Pistilli R, Esposito M. Short implants versus longer implants in vertically augmented posterior mandibles: A randomised controlled trial with 5-year after loading follow-up. Eur J Oral Implantol 2014;7:359–369.
41. Elfar J, Menorca RM, Reed JD, Stanbury S. Composite bone models in orthopaedic surgery research and education. J Am Acad Orthop Surg 2014;22:111–120.
42. Wu HC, Tsai MT, Hsu JT. The effect of insertion angles and depths of dental implant on the initial stability. Appl Sci 2020;10:3112.
43. Tabassum A, Meijer GJ, Wolke JG, Jansen JA. Influence of surgical technique and surface roughness on the primary stability of an implant in artificial bone with different cortical thickness: A laboratory study. Clin Oral Implants Res 2010;21:213–220.
44. Romanos G, Damouras M, Veis AA, Hess P, Schwarz F, Brandt S. Comparison of histomorphometry and microradiography of different implant designs to assess primary implant stability. Clin Implant Dent Relat Res 2020;22:373–379.
45. Aragoneses JM, Aragoneses J, Brugal VA, Gomez M, Suarez A. Relationship between implant length and implant stability of single-implant restorations: A 12-month follow-up clinical study. Medicina (Kaunas) 2020;56:263.
46. Gómez-Polo M, Ortega R, Gómez-Polo C, Martín C, Celemín A, Del Río J. Does length, diameter, or bone quality affect primary and secondary stability in self-tapping dental implants? J Oral Maxillofac Surg 2016;74:1344–1353.
47. Marquezan M, Osório A, Sant'Anna E, Souza MM, Maia L. Does bone mineral density influence the primary stability of dental implants? A systematic review. Clin Oral Implants Res 2012;23:767–774.
48. Ottoni JM, Oliveira ZF, Mansini R, Cabral AM. Correlation between placement torque and survival of single-tooth implants. Int J Oral Maxillofac Implants 2005;20:769–776.
49. Rossi F, Lang NP, Ricci E, Ferraioli L, Marchetti C, Botticelli D. Early loading of 6-mm-short implants with a moderately rough surface supporting single crowns—A prospective 5-year cohort study. Clin Oral Implants Res 2015;26:471–477.
50. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark PI, Zarb GA, Albrektsson T. Tissue-Integrated Prostheses. Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985: 199–209.
51. Valles C, Rodríguez-Ciurana X, Clementini M, Baglivo M, Paniagua B, Nart J. Influence of subcrestal implant placement compared with equicrestal position on the peri-implant hard and soft tissues around platform-switched implants: A systematic review and meta-analysis. Clin Oral Investig 2018;22:555–570.
52. Linkevicius T, Puisys A, Linkevicius R, Alkimavicius J, Gineviciute E, Linkeviciene L. The influence of submerged healing abutment or subcrestal implant placement on soft tissue thickness and crestal bone stability. A 2-year randomized clinical trial. Clin Implant Dent Relat Res 2020;22:497–506.
53. Gualini F, Salina S, Rigotti F, et al. Subcrestal placement of dental implants with an internal conical connection of 0.5 mm versus 1.5 mm: Outcome of a multicentre randomised controlled trial 1 year after loading. Eur J Oral Implantol 2017;10:73–82.
54. Al-Hashedi A, Taiyeb-Ali T, Yunus N. Outcomes of placing short implants in the posterior mandible: A preliminary randomized controlled trial. Aust Dent J 2016;61:208–218.