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Original Article

Influence of implant length and insertion depth on primary stability of short dental implants: An in vitro study of a novel mandibular artificial bone model

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KEYWORDS
Short dental implant;
Primary stability;
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Implant stability quotient;
Insertion torque value

Abstract *Background/purpose:* Dental implants are a mainstream solution for missing teeth. For the improvement of dental implant surface treatment and design, short dental implants have become an alternative to various complex bone augmentation procedures, especially those performed at the posterior region of both the maxilla and mandible. The objective of this study was to evaluate the effect of various insertion methods on the primary stability of short dental implants.
Materials and methods: Commercial dental implants were inserted into artificial mandibular bone specimens using various insertion methods (equicrestal position, subcrestal position 1.5 mm, and lateral cortical anchorage) in accordance with an implant surgical guide. Insertion torque value (ITV) curves were recorded while implant procedures were performed. Both maximum ITVs (MITVs) and final ITVs (FITVs) were evaluated. Subsequently, Periotest values (PTVs) and implant stability quotients (ISQs) were measured for all specimens. A Kruskal–Wallis test was conducted to analyze the results for four primary stability parameters, and the Dunn test was used for a post hoc pairwise comparison when a difference was identified.
Results: For all groups, their mean MITVs ranged from 33.6 to 59.4 N cm, whereas their mean FITVs ranged from 17.5 to 43.5 N cm. Insertion torque value, ISQ, and PTV decreased significantly when implants were inserted into subcrestal positions. When implants were inserted in the lateral bicortical position, the four aforementioned parameters yielded greater values.

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Conclusion: When 6-mm short implants were inserted in a lateral cortical anchorage position, high primary stability was yielded.

Introduction

The placement of dental implants is a common procedure in periodontal clinical practice. Studies have indicated that dental implants provide favorable aesthetics and strength and boast a high success rate.[1–4] Osseointegration is a key factor in the success of an implant. When an implant is assessed for its ability to achieve adequate osseointegration, its primary stability in the maxilla or mandible is a major indicator.[5–9] Various factors affect primary stability, including the design, size, and surface treatment of a dental implant; the quality and quantity of a patient's bones; and the surgical method.[5,6] The methods for assessing primary stability can be categorized into invasive methods and noninvasive methods. Invasive methods include the push-out/pull-out test and insertion/removal torque analysis. Noninvasive methods include radiographical analysis/imaging techniques, the Periotest, and resonance frequency analysis.[10] At present, the three main clinical measurements of primary stability are the implant stability quotient (ISQ), Periotest value (PTV), and maximum insertion torque value (MITV).[11,12] Measurements of ISQ and PTV involve the use of noninvasive methods that can be repeated to determine changes in postinsertion stability. MITV can be directly measured during insertion. As such, these three indicators are commonly compared against each other in clinical practice.[13,14] However, resent studies state that the torque of inserting an implant into the jawbone changes, and the maximum torque (i.e., MITV) is not always produced in the final insertion position. Therefore, final insertion torque value (FITV) should also be as an important reference.

In clinical practice, when an ideally sized implant cannot be inserted into a patient because of their anatomical limitations, bone augmentations are often performed to overcome this problem. In the maxillary sinus, a sinus lift lateral/vertical window approach can be applied. Insufficient mandibular bone width and height may require bone augmentation methods such as vertical augmentation.[15] However, the aforementioned procedures lead to more severe postoperative complications, higher costs, and a longer operation time. As such, short implants have become an alternative in clinical practice, and short-to mid-term follow-ups have indicated that long and short implants do not differ in terms of implant survival rate.[16,17] Furthermore, studies have been inconsistent with respect to the terms and definitions used to describe short implants; earlier studies defined a short implant as an implant with a length of $<$10 mm,[18,19] whereas later studies defined a short implant as an implant with a length of 6–8 mm because advancements in implant surface treatment had increased the success rate of short implants.[16,20] In 2014, Nisand proposed a rigorous classification framework for implants based not only on length but also on actual insertion depth.[21]

Studies have suggested inserting the implant-abutment junction of a bone-level implant in a subcrestal position to prevent marginal bone loss.[22,23] However, because the outer cortical bone affects the primary stability of an implant more, inserting the implant past the range of the cortical bone may reduce its primary stability.[9,24,25] Consequently, if a short implant must be inserted, increasing the contact area between the implant and the cortical bone is essential for achieving adequate primary stability.[26,27] Clinicians have used bicortical anchorage to increase the primary stability of dental implants. Bicortical anchorage is typically applied using one of two methods; the first involves the cancellous bone between the upper and lower cortical bone layers, and it is commonly applied to the posterior maxilla.[28,29] The second involves the use of a lateral cortical anchorage, which is typically used on the posterior mandible.[25,30] Rues et al. studied bicortical anchorage by using pig bones and discovered that the primary stability of a dental implant is not determined by the overall thickness of the bone but by the density of the cancellous bone and the total thickness of the upper and lower cortical bone layers.[31] Bicortical anchorage requires precise positioning, and free-hand methods are prone to angle- and position-related errors. At the date of writing, an implant surgeon can combine cone-beam computed tomography (CBCT) with computer-aided design or computer-assisted manufacturing techniques to create a surgical guide.[32]

Past years, CBCT has become a common tool to help dentists to solve clinical problems pertaining to the diagnosis of disease and the formulation of treatment plans. Compared with conventional two-dimensional X-ray, which is affected by problems relating to magnification, distortion, and superimposition, CBCT provides a more comprehensive view of an object.[33] The use of surgical guides can help an implant surgeon to form comprehensive diagnoses and surgical plans and communicate the ideal treatment results to a patient. Moreover, a surgical guide is useful for avoiding damaging the neighboring sinus, nerves, vessels, and teeth of a patient during surgery and ensure that the maximum available alveolar bone width and height can be used to allow for the selection of a suitably sized implant and an appropriate insertion angle.[32]

In summary, the insertion of short implants with a surgical guide allows a surgeon to apply the optimal conditions based on a patient's bone conditions. However, few studies have explored the effects of various insertion techniques on the primary stability of short implants. Therefore, the objective of the present study was to leverage CBCT imaging and surgical guides to examine the effects of three insertion methods (i.e., equicrestal, 1.5-mm subcrestal, and lateral cortical anchorage methods) on four primary stability parameters (ISQ, PTV, MITV and FITV) of a 6-mm short implant.

Materials and methods

Artificial bone specimen and dental implant preparation

An edentulous composite bone comprising mandibles with cortical bone (1.64 g/cm^3) and 17 PCF solid-foam cancellous cores (0.27 g/cm^3; Model 3444, Sawbones, Vashon, WA, USA) were used in the present study (Fig. 1a). Notably, the artificial bone model in present study not only mimicked the properties of human bone but also simulated the inferior alveolar nerve. Furthermore, a commercial short dental implant dimension was selected (4.5-mm diameter with 6 BLX; Straumann, Basel, Switzerland) for the present study (Fig. 1b).

Figure 1 Specimens used in present study: (a) mandibular artificial bone; (b) dental implant component.

Grouping in accordance with various parameter settings

In the present study, three groups were formed on the basis of insertion method. Each group comprised seven samples (n = 7; Fig. 2). CBCT images were taken after an implant was inserted into an artificial mandibular bone specimen to confirm that the insertion site was correct (Fig. 3). A total of 21 implants were included in these three groups, with seven implants in each group. In each group, three and four implants were placed in the first molar position and second molar position, respectively.

Group 1: 6-mm implant inserted in an equicrestal position.
Group 2: 6-mm implant inserted in a 1.5-mm subcrestal position.
Group 3: 6-mm implant inserted with a lateral lingual cortical plate anchorage.

Surgical guide preparation

CBCT images were taken, on the basis of which the mandibular artificial bone specimens were prepared. The accuracy of the surgical guide was verified with specialized software (3 Shape Dental System 2019 Implant Max, 7.0, Denmark) by matching the position of the planned implant with the actual position on the specimen with reference to CBCT images. Several teeth positions (referred to as positions 36, 37, 46, and 47) in the posterior mandibular region were selected for the present study (Fig. 4). Orthophos SL 3D (Dentsply Sirona, Bensheim, Germany) was used to perform dental CBCT imaging, and the following scanning parameters were applied: resolution of 80 μm, voltage of 85 kV, and current of 7 mA.

Measurement of four primary stability indices for short dental implants

Implant site osteotomy was performed using the designed surgical guide. A mandibular bone specimen was secured to a customized fixture, and an implant was inserted using a Nobel Biocare OsseoSet implant motor (OsseoSet, Nobel Biocare, Zurich, Switzerland) with a 20-rpm rotating speed (Fig. 5a). The motor could record the immediate torque (per millisecond) produced during the implant procedure. A Periotest device (Medizintechnik Gulden, Bensheim, Germany) was used to measure the primary stability of an implant after its abutment was placed (Fig. 5b). The tip of the Periotest device was positioned perpendicular to the abutment at a distance of 2 mm. Furthermore, a resonance frequency analyzer (Osstell ISQ, Osstell AB, Gothenborg, Sweden) was used to obtain ISQ values (Fig. 5c). The smart peg of the internal hex connection of an implant (Type 38, Osstell AB) was secured to the top of the implant.

Statistical analysis

All statistical analyses were performed using SPSS 19 (IBM, Armonk, NY, USA), and the significance level was set to $P < 0.05$. The statistical methods used to assess the objectives of the present study were as follows.

To assess the effects of the three insertion methods (equicrestal, 1.5-mm subcrestal, and lateral lingual cortical plate anchorage methods) on the MITV, FITV, ISQ, and PTV of the tested implants, a Kruskal—Wallis test was

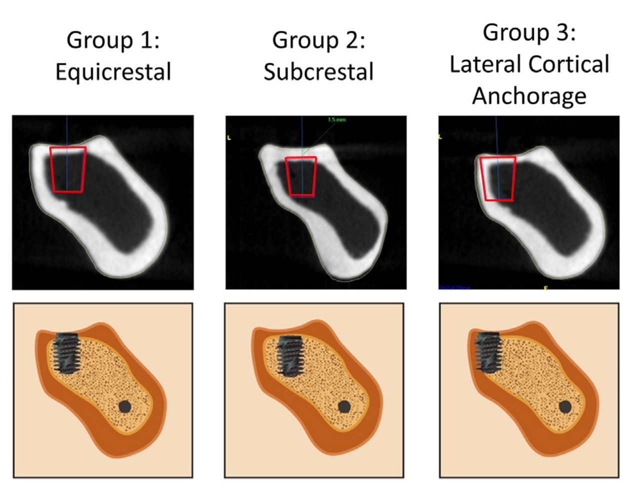

Figure 2 Parameter settings (Group 1, 6-mm implant inserted in an equicrestal position; Group 2, 6-mm implant inserted in a 1.5-mm subcrestal position; Group 3, 6-mm implant inserted with lateral lingual cortical plate anchorage).

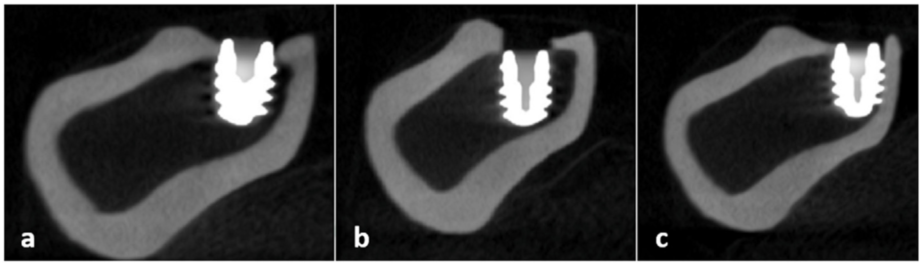

Figure 3 Cone-beam computed tomography images of three groups after insertion of implants. (a) Group 1: Equicrestal position. (b) Group 2: 1.5-mm subcrestal position. (c) Group 3: Lingual cortical plate anchorage.

performed to determine whether the three insertion methods differed in terms of their results for the four primary stability parameters, and the Dunn test was used for perform a post hoc pairwise comparison when a difference was identified.

Results

The experiment results are listed in Table 1. For the MITV, Group 3 obtained the highest mean MITV score among the three groups; its mean MITV score was 60% and 71% greater than those of Groups 1 and 2, respectively. The scores of Groups 1 and 2 did not differ significantly. Group 3 also had the highest mean FITV score among the three groups; its mean FITV score was 38% and 149% greater than those of Groups 1 and 2, respectively; Group 1's mean FITV score was also 80% greater than that of Group 2. The scores of the three groups were revealed to be significantly different. Groups 1 and 3 did not differ significantly in terms of their PTV or ISQ scores, whereas Group 2's scores were significantly different from those of Groups 1 and 3.

Fig. 6 plots the insertion torque values of all the samples of the three groups, and it reveals that the maximum insertion torque was not produced at the final insertion position. The torque curve of the lateral cortical anchorage group was higher than that of the equicrestal group, whereas the torque curve of the subcrestal group steadily decreased to 18 N cm after peaking and was consistently maintained at that level. The subcrestal group exhibited lower torque values relative to the other two groups.

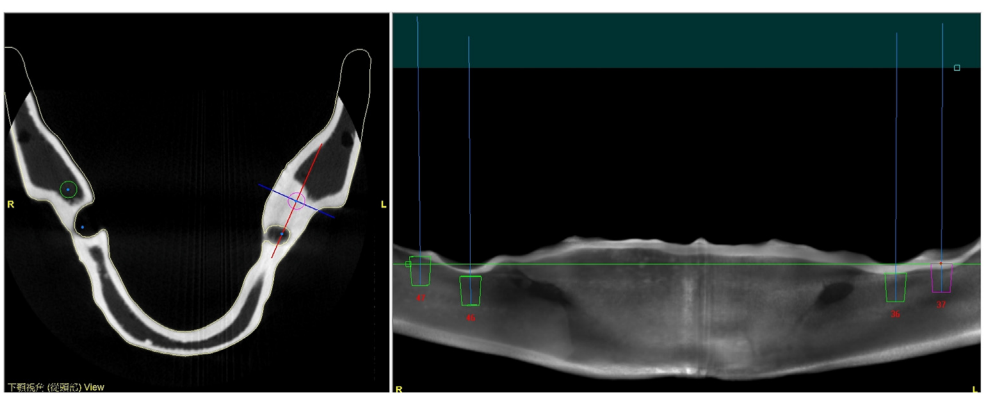

Figure 4 Surgical guide designed using specialized software.

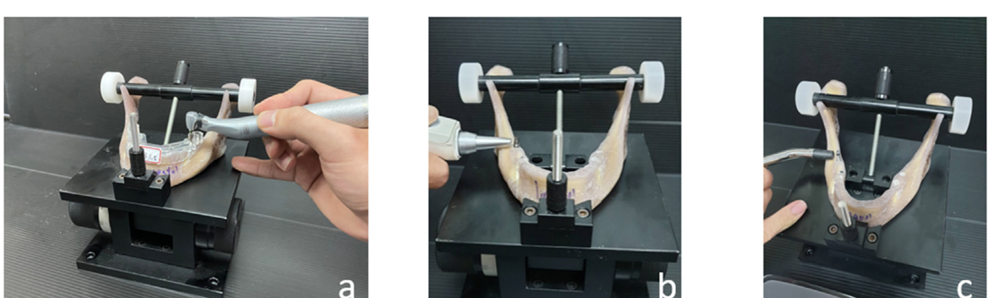

Figure 5 (a) Measurement of insertion torque value using the OsseoSet device, (b) measurement of periotest value using the Periotest device, (c) measurement of implant stability quotient (ISQ) using the Osstell ISQ device.

Table 1 MITVs, FITVs, ISQs, and PTVs of three groups.

Definition		Group 1 Equicrestal	Group 2 Subcrestal	Group 3 Lateral cortical anchorage
MITV	*Mean*	37.13[a]	33.63[a]	59.38[b]
	SD	6.66	12.15	10.95
FITV	*Mean*	31.5[a]	17.50[b]	43.50[c]
	SD	7.63	3.59	10.17
ISQ	*Mean*	70.50[a]	61.25[b]	71.75[a]
	SD	2.56	3.96	3.85
PTV	*Mean*	−1.76[a]	2.65[b]	−2.23[a]
	SD	1.20	1.77	0.96

Abbreviations: MITV, maximum insertion torque value; FITV, final insertion torque value; ISQ, implant stability quotient; PTV, Periotest value; SD, standard deviation. Noted that same letter in each row represent no significant difference.

Discussion

In the past, the problem of insufficient bone mass in the edentulous area due to long-term tooth loss or other factors prevented clinicians from inserting ideally sized dental implants. This problem is particularly pronounced in the molar region because of the anatomical limitations imposed by the maxillary sinus and inferior alveolar nerve; clinicians often had to perform bone augmentation procedures to insert a dental implant of sufficient length. Nowadays, advancements in dental implant designs and surface treatments have led to massive improvements in implant success rates and the development of short implants, which are increasingly being used on patients with anatomical limitations to avoid having to perform complex procedures. However, few studies have examined the primary stability of short implants, and even fewer have explored the effects of insertion depth on primary stability. This study is the first to use four indicators of primary stability. In addition to the commonly used ISQ, PTV, and MITV, the present study incorporated the less common but equally important FITV for comparisons. The results indicate that during the insertion of a dental implant, torque increases initially and decreases subsequently, and the maximum insertion torque and final insertion torque are not necessarily achieved at the same insertion depth. Thus, the FITV may be more

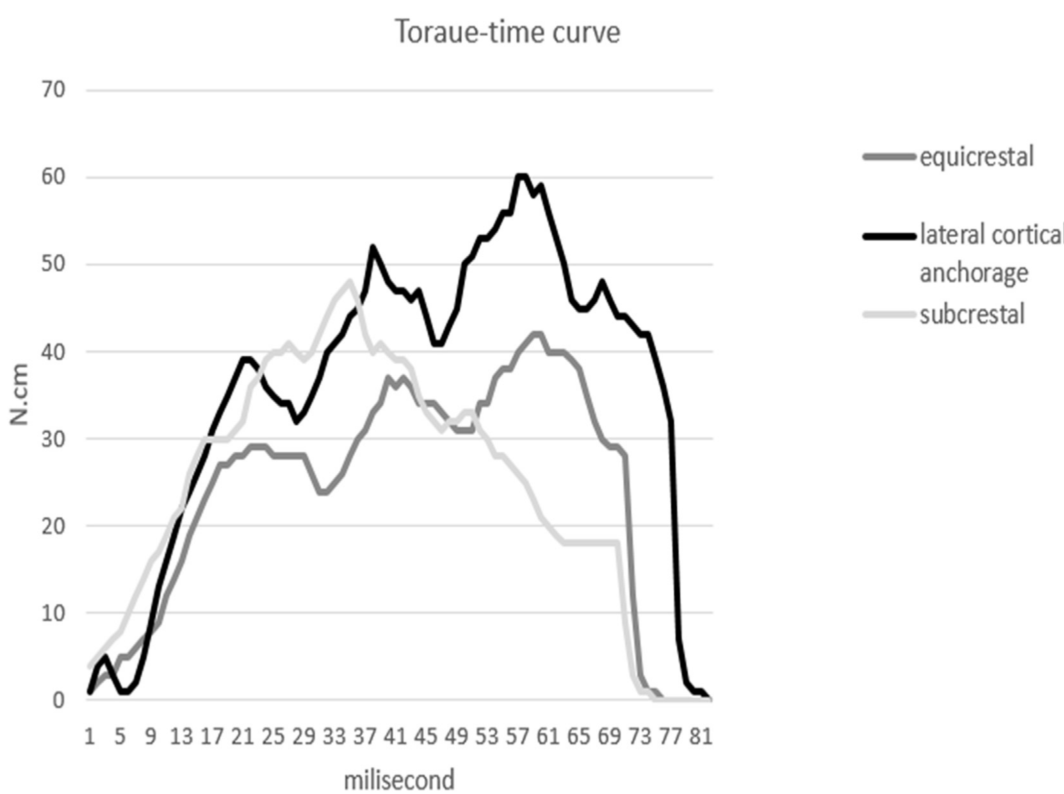

Figure 6 Torque over time of a randomly selected sample from each group.

appropriate for assessing the primary stability of an inserted dental implant. Furthermore, the present study demonstrated that when we insert a dental implant past the cortical bone layer, the loss of cortical engagement causes the ISQ, PTV, and FITV of the implant to decrease considerably. The cortical bone is crucial to the primary stability of a dental implant.

Numerous scholars have used artificial bones[24,34,35] or fresh animal bones[36] as materials for testing the biomechanics of implants. However, these two testing materials each have their own limitations. Artificial bones that are more common in the market are artificial bone blocks and mandibular artificial bone models. Artificial bone blocks can stimulate the mechanics of human bone but not the appearance of human jawbones. Mandibular artificial bone models, which simulate the appearance of the mandible, are composed of a homogeneous material and cannot simulate the difference between cortical bone and cancellous bone. Furthermore, when animal bone specimens are used, each bone specimen exhibits slightly different material properties, and they do not resemble the human mandible in appearance. The density and elastic modulus of the cortical and cancellous bones of the artificial mandibular bones used in the present study are similar to that of the human jawbone.[24,34,35] Miyamoto et al.[37] demonstrated that the cortical bones in the human mandible have a mean thickness of 2.22 ± 0.47 mm. The cortical bone thickness of our artificial bone was 2.0–2.5 mm, which falls within the typical range of cortical bone thickness in human mandibles.[37,38] Furthermore, the artificial bone samples used in the present study had an inferior alveolar nerve passing through the bone structure, which is consistent with actual clinical conditions.

Numerous studies have asserted that the cortical bone layer is essential to the primary stability of a dental implant. Bicortical anchorage can increase the primary stability of a dental implant. In a laboratory study conducted in 2016, Han et al.[39] experimented on artificial bone blocks and used the primary stability parameters, namely the ISQ, PTV, MITV, and removal torque value, to compare a bicortical group (i.e., cancellous bone blocks with varying thickness are each sandwiched between two pieces of 1-mm-thick cortical bone layers) and a monocortical group. Their results indicated that the bicortical group scored higher than the monocortical group for the four primary stability parameters; this finding is consistent with those of the present study. In 2012, Xiao et al.[30] inserted 4.3 mm $\times$ 13 mm dental implants into bovine ribs and compared two experiment groups, namely a monocortical group in which the implant was only inserted into the upper cortical bone and a bicortical group in which the implant was inserted into the upper cortical bone and lateral cortical bone. In their experiment, they compared the ISQs of the two aforementioned groups under 50 N in various cycles. The results did not reveal any difference between the two groups in terms of ISQ before a load was applied; however, the bicortical group exhibited higher ISQ values than did the monocortical group. This finding is consistent with those of the present study. However, after 1800 cyclic loadings, the bicortical group exhibited a significantly higher ISQ than that of the monocortical group. In 2016, Hsu et al.[29] conducted a clinical randomized control study of patients with an average distance from the maxillary sinus of 7–11 mm to determine the effects of bicortical fixation and unicortical fixation on implant stability. Their ISQ results indicated that bicortical fixation allowed for higher ISQ scores to be achieved relative to unicortical fixation. In another clinical study, de Oliveira Nicolau Mantovani et al. sorted patients into three groups, namely G1 (monocortical implants with only apical cortical bone contact), G2 (bicortical implants with both apical and cervical cortical bone contact), and G3 (monocortical implants with only cervical cortical bone contact). Their results revealed that G2 had a significantly greater MITV than the other two groups; this finding is consistent with the results of the present study.

Numerous studies have advocated the insertion of a bone-level implant in a subcrestal position to prevent subsequent marginal bone loss. Cristina Valles et al.[40] compared the subcrestal and equicrestal positions and reported that subcrestal implants cause less marginal bone loss relative to equicrestal implants. In 2020, Linkevicius et al.[41] conducted a meta-analysis of studies that compared 1.5-mm subcrestally placed implants and equicrestally placed implants. They discovered that after 2 years of observations, subcrestal implants exhibited 0.18 ± 0.32 mm of bone loss, whereas equicrestal implants exhibited 0.51 ± 0.4 mm of bone loss. Accordingly, they suggested submerging the implant platform of a bone-level implant under the bone to reduce crestal bone loss. However, the studies that they analyzed did not explore the possibility that inserting a dental implant in a subcrestal position affects the primary stability of the implant. In 2021, Ferraro-Bezerra et al.[42] inserted dental implants of different brands in a 2-mm subcrestal position and equicrestal position; their results revealed a significant decrease in torque across all implant brands when the implants were inserted subcrestally—a finding consistent with those of the present study. They suggested that the reduced torque was caused by the loss of contact between the implant and the upper cortical bone. In 2016, Al-Hashedi et al.[43] compared implants made by Bicon (implants with lengths of 6 and 8 mm) and Ankylos (implants with a length of 8 mm) on the basis of their PTVs after they were inserted into the posterior mandible. Al-Hashedi et al.[43] highlighted that the implant manufacturers Bicon and Ankylos suggested inserting their implants to a depth of 1.5 mm and to a depth of 0.5–1 mm, respectively. The PTVs of the Ankylos and Bicon implants were -1.61 (2.02) and 2.15 (2.52), respectively, indicating that the Ankylos implants exhibited a greater level of primary stability. Al-Hashedi et al. argued that their results could be attributed to the differences in the two manufacturers' implant designs. However, our results indicate that in addition to implant design, deeper insertions may reduce primary stability of an implant because of the lack of contact with the cortical bone.

Generally, the implant inserted with a lateral lingual cortical plate anchorage; however, the approach of group 3 used in this study, is not a common surgical approach. However, there remain some clinical situations that require inserting implants near the lingual cortical plate. Froum et al.[44] reported that to avoid implant invasion of the inferior alveolar nerve, some clinicians may insert the dental implant close to the lingual lateral cortical plate.

Additionally, Chu et al.[45] showed that even if the bone grafting surgery is performed, considering the position of the crown and wish to insert the implant in the mature bone as much as possible, it may still be necessary to anchor the implant along the lingual lateral cortical bone. Furthermore, Hindi et al.[46] indicated that anchoring the implant close to the lingual lateral cortical bone may increase the initial stability. Nevertheless, for this approach, the implant inserted with a lateral lingual cortical plate anchorage, the correct implant three-dimensional position is crucial for preventing damage to major anatomical structures and subsequent prosthesis; this was particularly applicable in the present study, in which implants were inserted into the mandibular lingual plate. In clinical practice, this method may lead to an increased risk of lingual plate perforation. In 2011, Chan et al.[47] classified edentulous ridges in the posterior mandibular region into C, P, and U types. The U type is similar to the artificial bones used in the present study; it has a pronounced depression at its base and is prone to developing lingual plate perforations warranting special attention. The use of implant surgical guides to predict the position of posterior dentures and prevent damage to major anatomical structures has led to favorable outcomes. Numerous studies have verified that using a surgical guide is a safer and more precise method relative to free-hand methods.[48,49] In 2020, Henprasert et al.[50] reported that when a surgical guide made through either additive or subtractive techniques was used, the deviation of an inserted implant from its ideal position was <0.5 mm in the buccal and lingual directions. In the present study, surgical guides were used to insert implants into their ideal insertion site, and in the lingual cortical anchorage group, the threads of implants were verified to have adhered to the lingual cortical bone (Fig. 5).

The present study has several limitations. First, because of the difficulty of procuring and storing fresh human mandibles, the present study was conducted using mandibular artificial bone models. However, the ASTM F-1839 standard states that artificial foam bone is "an ideal material for the comparative testing of bones screws and other medical devices and instruments".[51] Thus, the results may differ from those obtained under actual physiological conditions. However, in contrast to other studies, the experiment materials used in the present study optimally simulated both the appearance and biomechanics of the mandible. Second, because of the differences between implant manufacturers in terms of implant appearance, thread, and surface treatment, only a single type of fixture with a standard size was used in the present study. Consequently, not all scenarios were fully represented. Third, only four indicators of primary stability were measured; notably, stress and strain distribution on the marginal bone and other clinical factors that may influence implant success rate were not considered in the present study.

Based on the results of the experiment, the following three conclusions are drawn: (1) Implant insertion torque increases initially and decreases subsequently during the insertion procedure, and the MITV and FITV are not necessarily achieved at the same insertion depth. Therefore, the present study suggests using the FITV as the clinical indicator for implant primary stability. (2) The cortical bone has a major influence on primary stability. When we insert an implant through the cortical bone layer, the loss of cortical engagement leads to a considerable drop in primary stability, as evident in results for the ISQ, PTV, and FITV. Therefore, when an implant is clinically inserted in a subcrestal position, the contact between the implant and the cortical bone layer should be maintained to ensure sufficient primary stability. (3) Primary stability can be improved by inserting a short implant with a lateral cortical anchorage.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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