Evaluation of Primary Stability of Cylindrical and Tapered Implants in Different Bone Types by Measuring Implant Displacement: An In vitro Study

Abstract

Aims: The purposes of this study were to investigate the primary stability of cylindrical and tapered implants in different bone types by measuring implant displacement and to examine the relationship between insertion torque value (ITV) and implant displacement. Materials and Methods: Four different polyurethane bone models consisted of low-density or low-to-medium-density cancellous bone with or without a cortical bone layer. A total of 120 cylindrical and tapered implants were placed into bone blocks (n = 15 in each group), and the ITV was measured. A lateral load of 15 N was applied to the top of the abutment, and implant displacement was recorded. Results: Implant displacement was significantly affected by cancellous bone density and to a lesser degree by cortical bone thickness. The displacement of tapered implants was significantly smaller than that of cylindrical implants in the presence of cortical bone. However, both implant groups showed similar ITV in the low-density cancellous bone model with the cortical bone layer. There was a correlation between ITV and displacement in the cylindrical and tapered implants. However, no correlation was observed between ITV and displacement within each bone type. Conclusions: Implant stability depended mainly on the bone type, whereas implant design had a limited influence on primary stability. The use of tapered implants may be advantageous for improving primary stability in patients with low-density cancellous bone only when crestal cortical bone exists. The same ITV of cylindrical and tapered implants did not necessarily represent similar primary stability in the bone type.

Keywords: Bone density, dental implants, torque

Introduction

Primary implant stability is one of the most important factors for the success of dental implants. The initial instability of an implant may result in excessive micromotion (relative displacement between the implant and bone), which may induce the formation of fibrous connective tissue, thereby preventing the osseointegration of an implant. Previous studies demonstrated that the micromotion threshold is between 50 and 150 μm. The factors influencing primary stability include implant design, host bone characteristics, the interface between the implant and surrounding bone, and the surgical technique. Poor bone quantity and density have been identified as risk factors for the immediate loading of implants. A number of studies have reported a relationship between primary stability and bone type by measuring insertion torque, removal torque, the periotest value (PTV), and the implant stability quotient (ISQ) based on a resonance frequency analysis. Finite element analysis (FEA) studies have also demonstrated that micromotion is influenced by cancellous bone density and crestal cortical bone thickness.

Various implant designs have been proposed to improve primary stability for the implant placement site with low bone density. Clinically, cylindrical and tapered implants are the most commonly used designs. Although tapered implants appear to have a higher insertion torque value (ITV) than cylindrical implants, similar primary implant stabilities for both implant designs have been reported. Furthermore, the effects of tapering on implant micromotion in different bone density sites have not yet been elucidated in detail.

The measurement of ITV, PTV, and ISQ is a widespread and valuable method for evaluating implant stability quotient (ISQ) based on a resonance frequency analysis.

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primary implant stability; however, what they measure has never been directly correlated with implant stability. Contrary to these techniques, implant displacement represents the only direct measure of initial stability.\(^\text{[18]}\) To date, several studies have measured implant displacement to evaluate the relationship between displacement and the insertion torque,\(^\text{[19]}\) bone density,\(^\text{[18,19]}\) insertion angle,\(^\text{[20]}\) and loading direction.\(^\text{[20,21]}\) However, only a few in vitro studies have investigated the effects of implant design on implant displacement.\(^\text{[17,22]}\)

The purposes of the present study were to investigate the primary stability of cylindrical and tapered implants in different bone types by measuring implant displacement and to examine the relationship between IT and implant displacement.

### Materials and Methods

#### Specimen preparation

Based on a previous study,\(^\text{[23]}\) four bone density types of artificial bone blocks were prepared: (1) low-density cancellous bone without cortical bone, (2) low-density cancellous bone with cortical bone, (3) low-to-medium-density cancellous bone without cortical bone, and (4) low-to-medium-density cancellous bone with cortical bone. Artificial bone blocks of solid rigid polyurethane (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA) with densities of 0.16 g/cm\(^3\) and 0.32 g/cm\(^3\) were used to simulate low and low-to-medium-density cancellous bone, respectively.\(^\text{[23]}\)

Since crestal cortical bone thickness was previously reported to be 0.82 mm in the anterior maxilla and 0.75 mm in the posterior maxilla,\(^\text{[24]}\) a 1-mm thick polyurethane layer with a density of 0.80 g/cm\(^3\) was used to simulate a cortical bone layer.\(^\text{[23]}\) The artificial bone was rectangular with dimensions of 58 mm × 20 mm × 40 mm [Figure 1].

#### Implants

Two types of implants with the same diameter and length were used (4.3 mm × 10 mm): cylindrical implants (NobelReplace Straight Groovy, Nobel Biocare AB, Göteborg, Sweden) and tapered implants (NobelReplace Tapered Groovy, Nobel Biocare AB). Both implants had an oxidized surface and parallel-walled collar with microthreads. The actual length of the cylindrical and tapered implants was 9.25 mm and 10.54 mm, respectively [Figure 2a].

#### Implant placement

A total of 120 implants (60 cylindrical and 60 tapered) for four bone types were evaluated (n = 15). Twenty artificial bone blocks were prepared and six implants were inserted into each artificial bone block: three cylindrical and three tapered implants. Since the drilling protocol influences IT, all bone holes were prepared by one operator according to the manufacturer’s recommendations for soft bone under water cooling. In cylindrical implant models, a 2.0-mm twist drill was initially used, followed by a 2.4/2.8-mm twist step drill. In the model with the cortical bone layer, a 4.3-mm counterbore drill was used. In all tapered implant models, the 2.0-mm twist drill was initially used, followed by 3.5-mm and 4.3-mm taper drills. Implants were placed with the head being level with the artificial bone surface.

#### Insertion torque measurements

The final torque required to insert each implant was measured using a digital torque meter (STC400CN, Tohnichi, Tokyo, Japan).

#### Measurement of implant displacement

About 7-mm high straight-type abutments (Snappy abutment, Nobel Biocare AB, Göteborg, Sweden) were connected to the implants and tightened to 4–15 Ncm using a manual torque wrench. The artificial bone block was placed on the table for loading on the top of the abutment, and the lateral sides of the cancellous bone layer were clamped [Figure 2b].

With reference to a previous study,\(^\text{[17]}\) lateral loads of 15 N were applied to the top of the abutment using a universal testing machine (FTN1-13A/2000, Aikoh Engineering, Tokyo, Japan) with a head speed of 5 mm/min, and the value of abutment displacement was recorded as lateral implant displacement. Each measurement was repeated five times, and the mean of these five measurements was taken as the representative value of each implant.

#### Statistical analysis

Statistical analyses were performed using the Wilcoxon single-rank test to identify differences between cylindrical and tapered implants. The Mann–Whitney test was used to investigate differences between each bone type. Pearson’s correlation coefficients were computed to evaluate the
degrees of association between insertion torque and displacement, both across and within bone types. \( P < 0.05 \) was considered to be statistically significant.

**Results**

Tapered implants showed significantly higher ITV than cylindrical implants in low-to-medium-density bone with the cortical layer. However, no significant differences were observed in ITV between both implant groups in other bone types. The implant displacement of tapered implants was significantly smaller than that of cylindrical implants in the presence of cortical bone, whereas no significant differences were noted between implant designs in the absence of cortical bone. In the low-to-medium-density bone models, the absolute value of implant displacement was similar for cylindrical and tapered implants, ranging between 58.1 and 76.5 \( \mu m \). In low-density cancellous bone with the cortical layer, displacement was significantly different between cylindrical and tapered implant groups, although both implant groups showed similar ITV [Table 1].

Insertion torque was significantly affected by cancellous bone density and cortical bone thickness in most bone types. Cancellous bone density influenced ITV more than cortical bone thickness irrespective of the implant design [Table 2]. Implant displacement was significantly influenced by cancellous bone density and cortical bone thickness for cylindrical and tapered implants. Similar to ITV, implant displacement was affected more by cancellous bone density than by cortical bone thickness [Table 3]. Cortical bone thickness strongly affected ITV and displacement in low-density cancellous bone and to a lesser degree in low-to-medium-density bone [Tables 2 and 3].

The relationship between ITV and displacement was similar for cylindrical and tapered implants. Assessments of all bone types revealed a correlation between ITV and displacement in the cylindrical implant group \( (r = -0.84, P < 0.01) \) and tapered implant group \( (r = -0.76, P < 0.01) \). However, when the relationship between ITV and displacement was evaluated within each bone type, correlation coefficients ranged between \(-0.392\) and \(0.038\) with \( P > 0.149 \) in the cylindrical implant group and between \(-0.508\) and 0.093 with \( P > 0.053 \) in the tapered implant group, indicating no relationship between ITV and displacement for cylindrical and tapered implants within any bone type [Figure 3].

**Discussion**

Primary stability may be defined as the absence of implant movement immediately after insertion and is produced by the compression of bone in a lateral direction and the clamping of bone between the threads and collar in an axial direction.\(^{17,25}\) Since primary stability is influenced by implant design, host bone density, insertion torque,
Table 1: Differences in insertion torque value and implant displacement between cylindrical and tapered implants

| Cortical bone thickness (mm) | Cylindrical ITV (Ncm) | Tapered ITV (Ncm) | P      | Cylindrical Displacement (µm) | Tapered Displacement (µm) | P    |
|-----------------------------|-----------------------|-------------------|--------|-------------------------------|---------------------------|------|
| Low/0 mm                    | 4.3±0.9               | 4.6±0.7           | 0.382  | 372.6±52.9                    | 345.1±38.7                | 0.233|
| Low/1 mm                    | 10.2±2.8              | 13.4±5.9          | 0.307  | 183.3±29.1                    | 120.7±22.9                | <0.01 |
| Low to medium/0 mm          | 33.7±8.7              | 34.6±5.2          | 0.701  | 74.4±9.4                      | 76.5±12.4                 | 0.529 |
| Low to medium/1 mm          | 34.6±4.8              | 45.8±10.7         | <0.01  | 64.1±6.3                      | 58.1±9.3                  | 0.025 |

Values are presented as the mean±SD. SD: Standard deviation; ITV: Insertion torque value

Table 2: Insertion torque value in different bone types (Ncm)

| Cortical bone thickness (mm) | Cylindrical ITV (Ncm) | Tapered ITV (Ncm) | P      | LM/L |
|-----------------------------|-----------------------|-------------------|--------|------|
| 0                           | 4.6                   | 34.6              | <0.01  | 7.84 |
| 1                           | 13.4                  | 45.8              | <0.01  | 3.39 |
| P                           | <0.01                 | <0.01             |        |      |
| Tcor 1/Tcor 0               | 2.37                  | 1.03              |        |      |

L: Low-density cancellous bone; LM: Low- to medium-density cancellous bone; Tcor 0: Cortical bone thickness of 0 mm; Tcor 1: Cortical bone thickness of 1 mm

Table 3: Implant displacement in different bone types (µm)

| Cortical bone thickness (mm) | Cylindrical Displacement (µm) | Tapered Displacement (µm) | P    |
|-----------------------------|-------------------------------|---------------------------|------|
| 0                           | 372.6±52.9                    | 345.1±38.7                | 0.233|
| 1                           | 183.3±29.1                    | 120.7±22.9                | <0.01|
| P                           | <0.01                         | <0.01                      |      |
| Tcor 0/Tcor 1               | 2.03                          | 1.16                       |      |

L: Low-density cancellous bone; LM: Low- to medium-density cancellous bone; Tcor 0: Cortical bone thickness of 0 mm; Tcor 1: Cortical bone thickness of 1 mm

Surface characteristics, and surgical techniques, difficulties have been associated with evaluating primary stability and its related clinical implications.[22] A method has yet to be developed that directly measures micromotion at the bone-implant interface, and thus, there is currently no gold standard for the evaluation of primary stability. Implant displacement is the result of the deformation of bone and micromotion between bone and an implant.[21] Therefore, displacement measurements will contribute to a quantitative evaluation of primary implant stability.

The displacement of tapered implants was significantly smaller than that of cylindrical implants in the presence of cortical bone. Previous studies reported higher ITV for tapered implants than cylindrical implants.[11-13,23] In contrast, similar primary implant stability for two implant designs have also been reported by measuring ITV[15,16] and ISO.[14] This may be explained by differences in implant design and the related drilling protocol as well as the type of bone tested (cancellous bone with a cortical layer or cancellous bone only).[26] Tapered implants offer more lateral compression and stiffness.[11] and thus induce a greater degree of compression of cortical bone at a poor bone implant site. Therefore, the greater the effect of clamping crestal cortical bone, the greater the differences in primary stability between cylindrical and tapered implants. The effects of clamping crestal cortical bone will be enhanced by the degree of tapering of implants, smaller drilled holes, and increasing the thickness of crestal cortical bone.

At present, there is limited evidence to support the effectiveness of tapered implants in obtaining higher primary stability compared with cylindrical implants.[27] A previous study reported that cylindrical and tapered implants had similar biological behavior during the healing process when installed in the posterior mandible[15] and showed similar clinical and histological outcomes in an animal mandible model.[28] In the present study, both implant groups showed similar displacement values in low-to-medium-density bone. This result is consistent with the influence of the implant design decreasing with higher bone densities. Our results indicate that the use of tapered implants is advantageous for improving primary stability.
in patients with low-density cancellous bone only when crestal cortical bone exists. Clinically, the effectiveness of tapered implants compared with cylindrical implants might be observed when the implant is inserted in the posterior maxilla.

Implant displacement depended mainly on the bone type rather than implant design. The importance of bone quantity and density for primary stability has been extensively examined. However, controversy remains regarding the relative importance of these bone parameters. In the present study, implant displacement was influenced more by cancellous bone density than by cortical bone thickness regardless of implant designs, which is in agreement with previous studies that showed the importance of cancellous bone for primary stability by measuring ITV and calculating micromotion using FEA. The results obtained suggest that cortical bone thickness plays a major role in low-density cancellous bone, which is also consistent with the findings of previous biomechanical studies.

Trisi et al. demonstrated that increasing ITV reduced the level of displacement and micromotion in an implant design. However, this relationship may not be applicable to all implant designs and their related drilling protocols. In this context, researchers have been interested in whether the same ITV of different implant designs represents similar primary stability. In the present study, the overall relationship between ITV and displacement was similar for cylindrical and tapered implants. However, we found that the same ITV of cylindrical and tapered implants does not necessarily represent similar primary stability in the bone type (low-density cancellous bone with cortical bone). Smaller micromotion between bone and an implant as well as lower bone stress (a lower insertion torque) may be desirable to achieve osseointegration. Additional research is needed to clarify the effects of implant design on the relationship between insertion torque and primary stability.

A correlation was observed between ITV and displacement for cylindrical and tapered implants when comparing across all bone types. However, no correlation was noted between ITV and displacement within each bone type. This result is partially consistent with the findings obtained by Freitas et al. but not with those by Trisi et al. This may be explained by two reasons. In the present study, insertion torque was not assessed in a wide range as an independent parameter but was measured when implants were placed with the head being level with the artificial bone surface, leading to small variations in ITV. Furthermore, bone deformation may contribute more to implant displacement than micromotion, as shown in an in vitro experimental and FEA study. Accordingly, implant micromotion may not markedly change with variations in ITV in a small range, even though micromotion was influenced by ITV.

There were several limitations in the present in vitro study. Implants were placed with recommended socket preparations. However, an undersized preparation technique may enhance primary stability. Since the experiment focused on biomechanical aspects, biological behavior was not investigated. Further studies are needed to identify which implant design effectively reduces implant displacement in clinical settings.

Conclusions

Within the limitations of this in vitro study, the following conclusions were reached:

1. Implant stability depended mainly on the bone type, whereas implant design had a limited influence on primary stability. The use of tapered implants may be advantageous for improving primary stability in patients with low-density cancellous bone only when crestal cortical bone exists.
2. The overall relationship between ITV and implant displacement was generally similar for both implant designs. However, the same ITV of cylindrical and tapered implants did not necessarily represent similar primary stability in the bone type.

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Conflicts of interest

There are no conflicts of interest.

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