Correlation Between Implant Geometry, Implant Surface, Insertion Torque, and Primary Stability: In Vitro Biomechanical Analysis

Antonello Falco, PhD, DDS1/Marco Berardini, DDS1/Paolo Trisi, PhD, DDS2

Purpose: Primary implant stability represents the first step for successful osseointegration. The knowledge of the correlation between host bone density, insertion torque, and implant macrogeometry seems to be fundamental to achieve sufficient primary implant bone fixation in each clinical situation. The purpose of this study was to measure, in vitro, the impact of dental implant macrogeometry and insertion torque values on primary stability in relation to different bone densities, representing both the human mandible and maxilla.

Materials and Methods: One hundred twenty 3.8 × 11-mm commercial dental implants were used. Forty implants had small threads with a machined neck, 40 implants had small threads with a microthreaded neck, and the last 40 implants had large threads with a reverse neck design. Fresh bovine ribs, representing a medium-dense bone density (D2-D3), and fresh ovine iliac crest, representing a soft bone density (D4), were used. Insertion torque and micromobility under lateral force data were recorded for each implant.

Results: In the medium-dense bone type, the reverse neck implant design showed less primary implant stability than the conventional straight implant neck. In soft bone, both implants with the large thread design and microthreaded neck implants showed better implant stability than the implant with a small thread design with a straight machined neck. Implants with large and self-cutting threads showed significantly (P < .05) lower micromobility values than other implants in postextractive sites in low-density bone. Conclusion: Implant geometries and bone density are the main factors involved in the degree of primary implant stability. Large-thread implant designs are highly desirable in cases of poor bone quality. Each implant geometry generates an insertion torque value, which is correlated to the stability of that specific implant in a specific bone quality, but the insertion torque is not an objective value to compare primary stability between different implant types. Int J Oral Maxillofac Implants 2018;33:824–830. doi: 10.11607/jomi.6285

Keywords: bone density, implant geometry, insertion torque, osseointegration, primary implant stability

Dental implant initial bone fixation, known as primary implant stability, is a fundamental prerequisite for successful long-term osseointegration.1 The primary implant stability could be indirectly measured by recording insertion torque data2 or by measuring the implant stability quotient (ISQ)3 using the resonance frequency analysis.4 In addition, the value of actual micromotion (VAM) in vitro value, which was recently introduced by Trisi et al,5 could directly measure the implant stability (micromobility) under lateral forces. The knowledge of a direct primary implant micromobility measurement, such as the VAM, is very important because it provides a numerical value of the effective micromobility (in loading condition) that allows comparison of different implant types to each other and to the existing threshold level of tolerated micromotion for successful osseointegration.6

There is sufficient evidence to suggest that the degree of achieved primary stability, immediately after implant placement, is dependent on several factors, including bone density,7 implant shape,8 design and surface characteristics,9,10 and surgical technique.11 Results from recent studies12,13 clearly demonstrated that host bone quality and dental implant macrogeometry are the main factors able to influence the primary
implant stability in a significant way. Some authors assessed that implant diameter has greater influence on primary stability than length, and they recommended, in the case of poor bone quality, a variation of implant geometry to improve primary stability.

The selection of a specific dental implant geometry or thread design should aim to improve the primary implant stability, especially in the case of poor bone quality or immediate postextractive implant. For this reason, it is important to compare the primary stability of different implant geometries, in different bone densities and in postextractive sites, in order to establish which implant shape or geometry should ensure high primary fixation in each clinical condition.

A previous comparison of primary implant stabilities, between five different dental implant geometries, revealed that some implant shapes were less stable than others, especially in poor bone density (D4 type). Sennerby et al focused their attention not only on the implant macrodesign and shape, but also on the drill shapes that could affect the osteotomic bone size and, consequently, the degree of primary stability.

Another in vitro study, however, measured primary stability of two different implant geometries, placed in two bone densities (D4 and D2), and the authors found no statistically significant differences in ISQ values between the implant types in either type of bone.

Data on this topic appear unclear because almost all of the studies used only surrogate parameters of implant stability, such as insertion torque or ISQ values, which allow knowledge of the primary stability of a single specific implant through time but could not compare two different implants.

The present study aimed to compare, in vitro, primary implant stability values (micromobility) of three different implant geometries in two different bone densities, representing the common human mandible and the maxilla. Another purpose was to clarify the role of implant insertion torque in the stability comparison of different implants.

**Materials and Methods**

A total of 120 3.8 × 11-mm tapered titanium dental implants (Geass srl, Italy) were used. The implants were not experimental, and they were present in the market. The implants had three different macrogeometries and thread designs (groups A, B, and C).

Group A implants had a small thread design, a straight neck without threads of 3 mm in length (1 mm machined and 2 mm rough), and sandblasted titanium surface (Fig 1).

Group B implants had the same thread design as group A, a machined neck of 0.25 mm in the most coronal area, and microthread collar of 3.25 mm in length. The surface was laser treated.

Group C implants had a reverse neck design with 1.8 mm in length of rough collar without threads, pronounced tapered shape with self-cutting large threads, and large pitch. The surface was laser treated.

### Table 1: Screw Pitch, Screw Height, Screw Width, Surface Roughness, and Dental Implant Tapered Angle of Each Dental Implant

<table>
<thead>
<tr>
<th></th>
<th>Group A implants</th>
<th>Group B implants</th>
<th>Group C implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screw pitch</td>
<td>0.6 mm</td>
<td>0.6 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>Screw height</td>
<td>0.35 mm</td>
<td>0.35 mm</td>
<td>0.25 mm</td>
</tr>
<tr>
<td>Screw width</td>
<td>0.45 mm</td>
<td>0.45 mm</td>
<td>0.55 mm</td>
</tr>
<tr>
<td>Surface roughness (Ra)</td>
<td>1.2 µm^a</td>
<td>0.37 µm^b</td>
<td>0.37 µm^b</td>
</tr>
<tr>
<td>Dental implant tapered angle</td>
<td>5 deg</td>
<td>5 deg</td>
<td>6.8 deg</td>
</tr>
</tbody>
</table>

*^aSanding treatment.*

*^bLaser surface characterized by a series of 20-µm-diameter holes (7–10 µm deep) every 10 µm.*
Implant features (such as thread geometry or surface) differed from each other because this study used dental implants that were present in the market (not experimental) in order to simulate real clinical conditions. The aim of this study was to evaluate the primary stability data using three different dental implant designs to better understand which geometry could be preferable in conditions of poor bone density or immediate postextractive implant.

Ten implants from each group were inserted into two different bone types, medium-dense (D2-D3) and soft (D4), both in healed sites and in bone defects with four bony walls (an immediate postextractive implant condition was simulated). The study design is schematized in Fig 4.

Tests were performed on samples of fresh humid bovine and ovine bone representative of the following quality categories: medium-dense (D2-D3) and soft (D4). This bone classification followed the preoperative evaluation of bone quality, based on computed tomography (CT)/microcomputed tomography (micro-CT), published by Rebaudi et al.22 The bone qualities were selected according to drilling resistance. The bone qualities were selected according to drilling resistance. The image shows the soft bone quality.

In the healed sites, implants were inserted following the same drill sequence (suggested by the manufacturer): 2.1-mm twist drill, 2.5-mm twist drill, and 5-degree conical drill of 3.6 mm of greater diameter.

In peri-implant defect sites, implants were inserted after creating a bone defect of 8 mm in diameter and 7 mm in length with four bony walls in order to simulate a postextractive condition. The implant site preparation was done using only the 2.1-mm twist drill in the most apical 4 mm of bone. Implants were placed 2 mm below the bone ridge.

© 2018 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
Falco et al

every 0.5 milliseconds, was customized for this study. To obtain the insertion torque peak, the signal was subsequently evaluated by the Mecodarec software (ATech s.r.l.).

After implant placement, the bone blocks were fixed on a customized loading device for evaluation of direct micromobility after application of lateral forces (VAM). Each implant was fitted with a one-piece 11-mm straight abutment. The bone blocks were fixed on a customized loading device to measure implant stability according to a previously described technique by Trisi et al.23 A digital force gauge (Akku Force Cadet, Ametek) and, on the opposite side, a digital micrometer (Mitutoyo Digimatic Micrometer) were used to measure implant micromotion during load application. Horizontal forces of 25 Ncm were applied onto the abutment of the implant perpendicularly to the major axis, and the lateral displacement was measured by the digital micrometer 10 mm above the crest.

This parameter represents the VAM, as previously published by Trisi et al (2016).23 The authors introduced this new noninvasive parameter to directly measure the secondary implant stability (ie, micromobility) that was shown to be significantly related to all of the osseointegration parameters.

Insertion torque and micromotion data (VAM) of different groups were analyzed and compared for statistical significance by paired t test using the statistical software Graphpad Prism 6 (www.graphpad.com).

The mean stability values of all implants inserted in soft bone were compared with those of all implants inserted in medium-dense bone in order to evaluate the influence of bone density in the degree of implant stability.

**RESULTS**

**Healed Sites**

In soft bone, implants belonging to group A had a mean insertion torque value of 32.68 ± 8.10 Ncm and VAM of 85.75 ± 16.57 µm. Group B implants had a mean insertion torque of 35.78 ± 9.74 Ncm and VAM of 71.33 ± 24.18 µm. Self-cutting thread implants (Group C) had a mean insertion torque of 37.96 ± 11.78 Ncm and VAM of 73.75 ± 11.47 µm (Fig 9). The statistical comparison revealed that significant differences existed (P < .05) between implants with large threads (group C) and implants with small threads and unthreaded neck (group A) in VAM data. No statistical differences were found between groups in insertion torque values.

In medium-dense bone (D2), group A implants had a mean insertion torque value of 45.31 ± 23.59 Ncm and VAM of 36.20 ± 8.20 µm. Group B implants had a mean insertion torque of 58.87 ± 27.84 Ncm and mean VAM of 27.6 ± 3.30 µm. Group C implants had a mean insertion torque of 112.39 ± 41.25 Ncm and mean VAM of 46.6 ± 10.58 µm (Fig 10). The statistical analysis showed that group C implants had significantly (P < .05) higher insertion torque values than other groups. As for the micromobility (VAM), implants belonging to group B showed significantly (P < .05) lower micromotion than the other two groups.

**Simulated Postextractive Sites**

In simulated postextractive sites (peri-implant bone defect with four bony walls) in soft bone, group A implants had a low mean insertion torque value (17.97 ± 5.95 Ncm), and they did not reach any stability under lateral force application (VAM). Group B implants had mean insertion torque values of 25.60 ± 11.76 Ncm but low stability mean values (204.5 ± 127.81 µm).

© 2018 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.
Implants belonging to group C showed the highest insertion torque (32.24 ± 17.86 Ncm) and lowest micromotion data (132.3 ± 67.80 µm) among the groups (Fig 11). No statistically significant differences were found in insertion torque mean values among the groups. Implant micromobility values (VAM) were significantly (P < .05) different between the groups.

In medium-dense bone, implants belonging to group A had low values of primary stability with a mean insertion torque of 24.84 ± 10.32 Ncm and a mean micromotion value of 135.7 ± 77.73 µm. Group B implants had a mean insertion torque value of 32.43 ± 11.56 Ncm and VAM of 114.6 ± 64.58 µm. Group C implants, with large and self-cutting threads, showed the best primary implant stability with a mean insertion torque of 46.19 ± 18.64 Ncm and mean VAM of 105.2 ± 61.75 µm (Fig 12). The insertion torque peak differences were statistically significant (P < .05). No statistically significant differences in VAM were detected.

**DISCUSSION**

Data from the present study confirmed that bone density\(^{12}\) and implant macrogeometry\(^{24,25}\) are the factors mainly involved in primary implant stability development. Implants inserted in medium-dense bone showed significantly lower actual micromotion data than implants used in poor-quality bone, both in healed sites and in peri-implant bone defects.

The VAM, instead, measured the actual implant micromovements in µm under lateral forces (simulating the occlusal forces), and it represents an objective measurement of implant stability. This parameter is important to measure and compare, in vitro, the mechanical stability of different implant types or implants placed in different host bone densities.

Trisi et al\(^{26}\) demonstrated a relationship between implant micromotion and bone density, and they found consistently high implant micromobility (under lateral forces) when implants were placed in soft bone.

Other authors (Lachmann et al\(^{29}\)) confirmed that the outcome of implant stability assessment depends on environmental factors such as bone quality and implant geometry.

The poor bone density type (D4) is mainly composed of weak bone trabeculae surrounded by a thin layer of lamellar bone. These trabeculae are broken during implant drilling procedures, and the implant fixation is achieved by trapping fractured bone chips between the threads. Larger implant threads with greater pitch could contact more bone trabeculae.
and better compact this “bone dust” around the implant body than small-thread geometry. Data from the present study demonstrated that large and self-cutting implant threads had higher primary stability than implants with a small-thread design in cases of soft bone or peri-implant defect in poor-density bone. If a few millimeters of apical bone are available for implant stabilization (such as in case of immediate postextractive implant), the implant macrogeometry may be fundamental to achieve a sufficient primary stability, especially in poor bone density. A wrong implant geometry selection, in cases of poor bone density and peri-implant defect situations, could result in insufficient stability for an immediate or early loading protocol (group A).

In healed sites, in soft bone, although the large-thread implants (group C) had higher insertion torque values than those recorded in other groups, the implant micromotion was similar to that of small-thread implants with a straight and microthreaded neck (group B), and both of them had lower values than the conventional implant design with a machined collar (group A).

In medium-dense bone, in which strong bone trabeculae are surrounded by a thick cortical layer of 2 to 3 mm, implant thread size and pitch were less effective in influencing the primary implant stability. In fact, large-thread implants showed a higher insertion torque value than the other two groups but a higher value of actual micromotion as well. This result is probably due to the reverse neck design of group C implants that did not allow contact with the coronal bone in this area. The dental implant neck design plays a significant role in primary implant stabilization because the resulting vectors of horizontal and vertical forces are concentrated in this area. Lack of bone contacts in the dental implant neck area, such as in the case of reverse neck design, results in reduction of primary implant stability that could become relevant in cases of immediate loading.

Some authors (Bilhan et al\textsuperscript{17}), who compared different implant geometries by measuring the primary stability using ISQ, failed to individuate any differences in implant stability because the indirect measurements of implant stability do not allow comparison of different implants. It was reported, in fact, that resonance frequency analysis could be useful to monitor the changes of stability of the same implant over time, but not to provide an absolute value of it, and it does not allow comparison of the stability of different implants. The findings from the present study clearly showed that the insertion torque peak value also represents a kind of “intrinsic implant stability”, i.e., the stability of the same implant (macro- and microgeometry) inserted into the same bone type. Any changes in insertion torque values implicate an increase or decrease of implant primary stability of the analyzed implant, but the stabilities of two different implants cannot be compared by using only insertion torque data.

The insertion torque value could not be used to compare the stability of different implants (micro- or macrogeometry) in different bone sites.

In fact, implants with large threads (group C) had an insertion torque value more than two times higher than small-thread implants (groups A and B) in healed sites in medium-dense bone, but the implant micromobility was lower in these second groups (the macrogeometry of the implant was different, especially at the neck area).

For this reason, some authors recommended reaching high torque values in order to achieve implant stability with some specific dental implant geometry, while others\textsuperscript{31,32} demonstrated achievement of sufficient primary implant stability with other implant designs and lower insertion torque peaks. No bone resorption was, however, demonstrated to be associated with high insertion torque values\textsuperscript{33,34} It is important to underline that implants used in the present study were present in the market (they were not experimental dental implants specifically created for the study) and, for this reason, they showed different geometric features (such as collar length, thread design, etc). The authors’ aim was, in fact, to simulate real critical conditions (poor-density bone or immediate postextractive implants) in which the knowledge of dental implant features, useful in potential increase of primary stability, may help the oral surgeon for the surgery planning.

**CONCLUSIONS**

Results from this study clearly demonstrated that bone density and dental implant geometry are the main factors able to significantly influence the primary implant stability achievement.

In cases of poor bone density, aggressive implant thread designs are strongly suggested, while, on the other hand, in cases of medium-dense bone, even a small-thread design could reach significant primary fixation.

Large- and self-cutting–thread implant designs appeared more suitable in cases of poor bone density or inadequate bone amount (i.e., immediate postextractive implant) in order to reach high mechanical bone anchorage. The length of implant collar is important for the cortical engagement, while the reverse neck design appears not to be very suitable in cases of healed bone (lack of cortical engagement). Standard small-thread implant designs are indicated in medium-dense bone because they could reach high primary stability with adequate insertion torque peaks.
(huge insertion torque value could cause mechanical failure of dental implant connection).

Another important conclusion is the concept of insertion torque as a subjective value of primary stability of a specific implant in a specific bone. The insertion torque value could not be used to compare the stability of different implants in different bone sites, but it represents an indirect stability measurement of particular dental implant geometry and surface inserted in a specific bone density.

ACKNOWLEDGMENTS

The authors wish to thank Geass S.r.l (Pozzuolo del Friuli, Udine, Italy) for providing dental implants and abutments used in the present study. The authors declare that they have not received any grant of financial support for the present study. The authors reported no conflicts of interest related to this study.

REFERENCES