Comparison of insertion torque and primary stability using a new implant macrogeometry versus conventional implant design: an in vitro experimental study

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Abstract

The objective was to evaluate the correlation between the insertion torque and primary stability of this new implant design in comparison with a conventional implant design using different synthetic bone density. Four different synthetic bone blocks were used, with three cortical thickness: Bone 1 with cortical of 1 mm, Bone 2 with cortical of 2 mm, Bone 3 with cortical of 3 mm and Bone 4 with totally cortical. Four groups were created in according to the implant macrogeometry (n = 10 per group) and surface treatment: G1 – conventional implant design without surface treatment; G2 – conventional implant design with surface treatment; G3 – new implant design without surface treatment; G4 – new implant design with surface treatment. The implants were installed using a computed torque machine and, post the installation the implant, the stability quotient (ISQ) values were measured in two directions. The data were analyzed considering 5% level of significance. All implant groups showed similar mean values of ISQ, without statistical differences (p>0.05), for the same synthetic bone block: for the Bone 1 was 57.7 ± 3.0, for the Bone 2 was 58.6 ± 2.2, for the Bone 3 was 60.6 ± 2.3 and for the Bone 4 was 68.5 ± 2.8. However, the insertion torque shows similar higher values for the conventional macrogeometry (G1 and G2 groups) in comparison with the new implant macrogeometry (G3 and G4 groups). The analysis of the results found show that primary stability does not simply depend on the insertion torque, but also on the bone quality. The new
implant macrogeometry decrease the bone compression and, consequently, reduce the insertion torque without affecting the primary stability.

Keywords: bone density; dental implants; healing chambers; initial stability; insertion torque; new implant macrogeometry.

1. Introduction

Initial implant stability is fundamental requisite to obtain the osseointegration [1]. The main parameters that involved are the bone condition (quality and quantity), the implant macrogeometry, the osteotomy design and the precise fit in the bone. Thus, to achieve adequate osseointegration of the implant, it is of fundamental importance that a good primary stability of the implant is achieved after its installation into the bed prepared in the bone tissue and is crucial for the long-term success of the implant [2,3].

The force for insertion of the implant into the bone tissue is related to the quality of the bone (density) and to the osteotomy performed (orifice size), generating compressive stresses at this contact interface between bone tissue and implant. These obtained levels of tensions determine the initial stability of the implant, being able to reach sufficiently high values resulting in local ischemia of the bone and necrosis at the implant-tissue interface [4-6]. In this sense, several studies have proposed that approaching the diameter of the drilling (during the osteotomy) with the diameter of the implant that will be inserted into the bone, can facilitate and improve osseointegration through the decrease of the bone compression [7,8]. Jimbo et al. (2014) showed in a study using a dogs animal model, where in the implants placed with high torque the samples presented a certain amount of necrotic bone inside the implants threads, whereas in the samples where a larger drilling was used, the samples presented a substantial formation of new bone [8]. The free space created inside of the implant threads, resulting from the drill-implant diameter ratio, was called healing chambers. Obviously, that procedure to create this healing chambers (over-drilling protocol) generate a sensible decrease of the final insertion torque level in the implant.

Low stability may allow micromovement of the implant during the healing period, and fibrous tissue may form at the interface between the bone and the implant and lead to failure of the implant. However, when the implants have good values of primary stability, the healing time may be shorter, as when the implants present low values of primary stability, they require longer waiting times to obtain adequate bone healing and consequent secondary stability. This acquired information about the stability of the implants can help in determining the waiting time to obtain the healing of the bone tissue around the implant for each case and in an individualized way, increasing the safety of the treatments, the effectiveness and, in some cases, decreasing the time to complete the treatment [9].

In this sense, a new macrogeometry was developed with these concepts and the idea of “no bone compression” during the implant insertion and “not lose the initial stability” after the implant installation. The healing chambers to bone decompression were created in the implant threads body, generating spaces to deposit the bone during the implant insertion.

However, the formula of higher IT torque translating into higher primary stability may not always be true because the quantity and quality of bone varies significantly among patients. Then, the purpose of the present study was to investigate the correlation between IT and primary stability of two different macrogeometry (conventional and new design) with two different surface treatment
(smooth and roughhouse) of dental implants using four different artificial bone blocks that presented variation in the cortical thickness.

2. Materials and Methods

**Synthetic bone characteristics:** Synthetic bone blocks of polyurethane (Nacional Ossos, São Paulo, Brazil) with cortical and medullar portion. The cortical portion was fabricated in a density of 40 pounds per cubic foot (PCF) or 0.64 g/cm³ and, the cancellous bone portion of all blocks presented a density of 15 PCF or 0.24 g/cm³ (Figure 1). The blocks configurations used presented 2 cm of height, 2 cm wide, 13 cm length and four different cortical thicknesses at 1, 2, 3 mm and totally cortical (Figure 2). Polyurethane blocks were used at different densities to simulate bone in an in vitro setting. The American Society for Testing Materials has shown that polyurethane blocks have mechanical properties simulating human bone [10]. Polyurethane is considered as the standard material used for performing mechanical tests on orthopedic implants [11-14].

![Cortical bone and Cancellous bone](image1.png)

**Figure 1:** Representative image of the synthetic bone blocks show the cortical portion (black arrow line) and cancellous bone portion (yellow arrow line).

![Synthetic bone blocks](image2.png)

**Figure 2:** Image of the synthetic bone blocks with three cortical thickness variation (1, 2 and 3 mm) and totally cortical, respectively.

**Implants characteristics and groups distribution:** The conical conventional design shows progressive trapezoidal threads, cervical portion with 1 mm of plane configuration in the final cervical area and Morse taper connection; whereas, the conical new implant design shows progressive trapezoidal threads, cervical portion with 1 mm of plane configuration in the final cervical area, healing chambers in the threads and Morse taper connection. The Figure 3 show a schematic image of the both implant design.
Both models were tested with surface treated by blasting process plus acid conditioning and, not treated (machined surface). The Figure 4 show a representative image of the implant designs analyzed in the present study. Then, four groups (n = 10 per group) were formed of according to the implant design (Fig. 2): group 1 (G1) – conventional conical design without surface treatment; group 2 (G2) – conventional conical design with surface treatment; group 3 (G3) – new conical design without surface treatment; and, group 4 (G4) – new conical design with surface treatment. The dimension of all implants used were of 4 mm in diameter and 10 mm in length, manufactured by Implacil De Bortoli (São Paulo, Brazil).

**Implants management and biomechanical analysis:** The drilling was made in accordance with the manufacture designation for each implant model. All osteotomies were prepared using a bench drill with a 2 Kg of pressure using a surgical drill at a rotational speed of 1200 rpm under intense external irrigation with saline solution, using a predeterminate drilling sequence of the implant system (Figure 5).
The implants installation was made using a computed torquimeter machine (Torque BioPDI, São Paulo, Brazil), shown in the image of the Figure 6.

All implants were installed at the bone level. The maximus insertion torque value was recorded for each sample and, then, the implants were removed and the maximus removal torque was recorded. Using these data (insertion and removal torque values), the torque reduction (TR) was calculated:

\[
\text{Torque reduction} = \frac{\text{insertion} - \text{removal}}{\text{removal}} \times 100
\]

Following each installation, the implant stability quotient (ISQ) was measured using the Osstell Mentor device (Osstell, Göteborg, Sweden). The smart peg was screwed in the implant and a torque of 10 Ncm was applied [15]. The ISQ values were represented on a scale from 1 to 100. The measurement was performed in 2 directions for each sample (Figure 7) and an average was performed for each implant.

The insertion of both implant models and the threads behavior was evaluated and described using the fully cortical bone model, as shown in Figure 8.
Statistical analysis: The IT and ISQ values were summarized using means and standard deviations. One-way analysis of variance was used to compare the mean IT and ISQ values. The Pearson's correlation coefficient was used to evaluate the correlation between the IT and the ISQ at implant placement. All analyzes were made using GraphPad Prism version 5.01 for Windows (GraphPad Software, San Diego, California, USA). When p-value was <0.05 the differences were considered significant.

3. Results

The ISQ values showed similar values for both implant macrogeometry with the same treatment. However, the G2 and G4 groups, which the implants presented surface treatment (roughhouse surface), show values slightly higher to the G1 and G2 groups (without treatment on the implant surface) in all bone models. The data values (mean and standard deviation) and statistical comparison are summarized in the Table 1 and demonstrate in the graph line of the Figure 9.

Table 1. Mean, standard deviation and statistical analysis of the measured values of ISQ for each group in the different synthetic bone blocks.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>group G1</th>
<th>group G2</th>
<th>group G3</th>
<th>group G4</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone 1</td>
<td>56.2 ± 3.71</td>
<td>58.5 ± 2.17</td>
<td>57.0 ± 3.79</td>
<td>59.2 ± 2.32</td>
<td>0.4093</td>
</tr>
<tr>
<td>Bone 2</td>
<td>57.2 ± 1.60</td>
<td>59.5 ± 1.87</td>
<td>58.0 ± 2.28</td>
<td>59.5 ± 2.88</td>
<td>0.4842</td>
</tr>
<tr>
<td>Bone 3</td>
<td>59.3 ± 2.34</td>
<td>60.7 ± 2.17</td>
<td>60.2 ± 2.48</td>
<td>62.0 ± 2.10</td>
<td>0.2105</td>
</tr>
<tr>
<td>Bone 4</td>
<td>66.8 ± 3.25</td>
<td>69.2 ± 2.79</td>
<td>68.7 ± 2.42</td>
<td>69.3 ± 2.66</td>
<td>0.2551</td>
</tr>
</tbody>
</table>

Figure 9: Bar graph of the ISQ values distribution for each model of synthetic bone blocks in each group proposed.

The torque of insertion and remove of the implants presented different values between the two macrogeometry, where the conventional macrogeometry show superior values for both groups (G1 and G2 group) in comparison with G3 and G4 groups, independent of the bone density. The data values (mean and standard deviation) and statistical comparison are summarized in the Table 2 and demonstrate in the graph line of the Figure 10.
Table 2. Mean, standard deviation and statistical analysis of the measured values of ISQ for each group in the different synthetic bone blocks.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>group G1</th>
<th>group G2</th>
<th>group G3</th>
<th>group G4</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone 1</td>
<td>13.4 ± 2.04</td>
<td>13.8 ± 2.55</td>
<td>11.0 ± 2.06</td>
<td>11.2 ± 2.19</td>
<td>0.1117</td>
</tr>
<tr>
<td>Bone 2</td>
<td>16.0 ± 1.93</td>
<td>16.4 ± 1.98</td>
<td>13.1 ± 2.58</td>
<td>13.8 ± 2.03</td>
<td>0.0711</td>
</tr>
<tr>
<td>Bone 3</td>
<td>19.5 ± 2.39</td>
<td>20.2 ± 2.89</td>
<td>15.7 ± 3.99</td>
<td>16.2 ± 3.36</td>
<td>0.0968</td>
</tr>
<tr>
<td>Bone 4</td>
<td>29.6 ± 2.33</td>
<td>30.4 ± 2.85</td>
<td>25.8 ± 3.89</td>
<td>26.2 ± 3.32</td>
<td>0.0968</td>
</tr>
</tbody>
</table>

Figure 10: Bar graph of the removal torque values distribution for each model of synthetic bone blocks in each group proposed.

No correlation was detected between the insertion torque and stability (ISQ) values for the groups.

Analyzing the behavior of both implant models during their insertion into the bone tissue, it was possible to observe that the samples with the conventional macrogeometry (groups G1 and G2) promote a compression of the bone during the passage of the threads, while in the model with the new macrogeometry, we can observe that the bone tissue is cut and carried by the threads, as shown in the images of Figure 11.
Figure 11: Representative image of the behavior of the two implants macrogeometry used. (a) the conventional macrogeometry that promote the compression of the bone (black arrows); (b) the new macrogeometry that make the cut of the bone (black arrows) during the implant insertion.

4. Discussion

The primary stability of the implants during installation is determined by bone quality, bone quantity, implant geometry and installation technique. Several authors have demonstrated the importance of primary stability in obtaining osseointegration of dental implants [16-18] and failure to obtain an efficient primary stability can lead to early implant loss [19]. In addition to these factors, it has been demonstrated in other studies that treatment of the implant surface can influence the results of primary stability [16-18]. In this sense, the present study evaluated the insertion and removal torque of two implants with different macrogeometry (conventional and a new design), with and without surface treatment, also measuring the primary stability through resonance frequency analysis in different bone densities.

The implants of the groups G3 and G4 with a new macrogeometry was development to improve and accelerate the osseointegration based in the hypothesis that the no bone compression during the installation [20]. This concept was demonstrated in several recent studies [8,20], which tested the undersized osteotomy to decrease the bone compression during the implant insertion. The histological results showed that maneuver improve and accelerate the osseointegration of the implants. However, the authors related that technique can promote a decrease of the initial stability of the implants. In this sense, the idea of a new macrogeometry with healing chambers incorporated in the implant body does not alter the size of the osteotomy but generate spaces to make the bone decompression. Then, we proposed to compare this new macrogeometry with a conventional macrogeometry to evaluate the relation of the less bone compression during the implant installation with the obtention of the insertion torque and the initial stability. The results showed that the insertion torque of the new macrogeometry is less in 16% (overall of the mean) in comparison with the conventional macrogeometry, while the initial stability was not affected.

Regards to the synthetic bone blocks used for in vitro analysis, the rigid polyurethane foam with homogenous and good characteristics, is considered an ideal material and, is in accordance to the ASTM standard F1839-08 (1997) [21]. In this way, we used a polyurethane foam density of 0.48 g/cm³ in the cortical portion, considering that the mean of cortical bone density in human maxilla is 0.31 g/cm³ for posterior area and 0.45 g/cm³ for anterior area [21]. The cancellous bone is more efficient to receive and dissipate the forces generated by mastication after the implant osseointegration; however, to obtain the initial stability, the cortical bone is more important because present high density and resistance (~40% mayor) in comparison to the medullary bone [22].

Resonance frequency analysis (RFA) measurement using Osstell Mentor is frequently method used to evaluate the implant stability in preclinical and clinical studies [23-25]. This technique has been widely used because it is not invasive and does not require extra procedures to obtain the data. However, this method revealed the absence of mobility of the installed implant, and not the bone quantity at the implant-bone interface [26,27]. The determination of a good osseointegration is directly related to the absence of movement at the bone-implant interface, in the different types of bone density. Therefore, the lack of micromovement determined by rigid primary stability and healing period free from external stimuli is originally a prerequisite for obtaining a satisfactory clinical result [28]. However, for implants placed in low density bone, the stability indices (RFA) at the end of the osseointegration process will be similar to those of medium- and high-density bone implants. Differently from this result, we did not find a correlation between the values of the RFA at the moment of the implant installation and the torque in the fixation of the implants, which was also
reported in another study [29]. By means of these results, we must determine greater caution when conferring the analysis of frequency of dental implants, because the limit of height and width of the implants, as well as factors of bone density can influence its result.

The results showed that the insertion torque increased in accordance to the bone density increase, whereas the implant stability (ISQ) showed no variation in Bone 1-3 models. The results found in our study showed that there is no correlation between the two parameters tested. Therefore, the only factors that showed a positive correlation between the IT and the ISQ value were the bone density and thickness of the cortical bone. This result is in accordance to other publications [30,31]. Moreover, Lages et al. report that the clinician should choose only one of the methods to determine the primary stability of implants, as these are independent and incomparable methods [31].

The interaction between the implant and the adjacent bone immediately after its insertion depends mainly on the macrogeometry of the implant and the topography of its surface [32,33]. However, some studies in the literature still question the influence of surface treatment on primary stability [34-37], corroborated by the results obtained in the present study, where the two implant designs did not present statistical difference between the treated and non-treated surfaces to the insertion torque values.

Several authors evaluate the strength and the stiffness of the shear bone-implant interface, through frequency of resonance analysis, in search of information about the degree of contact in this interface [38,39]. In the present study, when evaluating the initial stability of the implants inserted in the synthetic cortical bone (40 PCF), it was verified that all implants obtained the highest values. However, the implants with the conventional macrogeometry showed superior values, due to the greater contact and friction surface between the screw and the material [34,40].

In the resonance frequency analysis, larger values were observed in implants with surface treatment (G2 and G3 groups) compared to machined ones (G1 and G3 groups), corroborating findings described by other authors [41]. Despite these data, the presence of surface treatment did not present a significant difference between implants machined and treated on all substrates. These results corroborate with studies in the literature [34,42] and suggest as hypothesis the fact that RFA is not sensitive enough to detect minor alterations, such as the surface treatment of the implants.

Some studies have shown that, due to lateral cortical compression of bone sites with low quality, conical implants have a higher IT than cylindrical [43-46]. This statement is consistent with the results found in the present study, in which the conical implants presented higher IT, compared to cylindrical ones, when inserted in swine bone and artificial polyurethane bones of 15 PCF, suggesting the use of this type of screw in low bone density [44]. Then, the conical implant design was selected and used in the present study because they presented higher insertion torque when compared to cylindrical implant design [44-48].

Among the limitations of the present study we can report that only mechanical aspects of the effect of surface format and treatment were evaluated, that is, biological factors such as bone response, individual characteristics, local variations of human bone and the surgical technique, which also influence primary stability in a clinical situation. However, it has been demonstrated that surface treatment, shape and difference in implant threads depends on the correlation between shape and bone density, in order to promote an optimal biomechanical condition for osseointegration.

5. Conclusions

Within the limitations of the present in vitro study, the results demonstrated that implant macrogeometry influences the insertion torque values; however, they do not influence the initial
stability values measured by resonance frequency analysis. In addition, the insertion torque and initial stability values did not differ in relation to the surface treatment of the tested implants. The new implant macrogeometry decrease the bone compression and, consequently, reduce the insertion torque without affecting the primary stability. Finally, no correlation was found between insertion torque and initial values of primary stability.

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