

# Does Implant Design Affect Implant Primary Stability? A Resonance Frequency Analysis–Based Randomized Split-Mouth Clinical Trial

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The purpose of this study was to assess implant stability in relation to implant design (conical vs. semiconical and wide-pitch vs narrow-pitch) using resonance frequency analysis. Twenty patients with bilateral edentulous maxillary premolar region were selected. In one hemiarch, conical implants with wide pitch (group 1) were installed; in the other hemiarch, semiconical implants with narrow pitch were installed (group 2). The implant allocation was randomized. The implant stability quotient (ISQ) was measured by resonance frequency analysis immediately following implant placement to assess primary stability (time 1) and at 90 days after placement (time 2). In group 1, the mean and standard deviation ISQ for time 1 was  $65.8 \pm 6.22$  (95% confidence interval [CI], 55 to 80), and for time 2, it was  $68.0 \pm 5.52$  (95% CI, 57 to 77). In group 2, the mean and standard deviation ISQ was  $63.6 \pm 5.95$  (95% CI, 52 to 78) for time 1 and  $67.0 \pm 5.71$  (95% CI, 58 to 78) for time 2. The statistical analysis demonstrated significant difference in the ISQ values between groups at time 1 ( $P = .007$ ) and no statistical difference at time 2 ( $P = .54$ ). The greater primary stability of conical implants with wide pitch compared with semiconical implants with narrow pitch might suggest a preference for the former in case of the adoption of immediate or early loading protocols.

**Key Words:** dental implant, geometrical design, implant stability, resonance frequency analysis.

## INTRODUCTION

Dental implants are considered predictable devices for the replacement of missing teeth, achieving success rates beyond 90% in the long term, and their use has become routine in dental practice.<sup>1,2</sup> One of the keys to successful osseointegration is the primary stability of an implant.

Implant design is one of the most fundamental elements that affects the implant primary stability and the ability to sustain loading during or after osseointegration. The design features can be divided into 2 major categories: macrodesign and microdesign. Macrodesign includes thread pitch, body shape, and thread design, while microdesign essentially regards the surface morphology.<sup>3,4</sup> In addition to implant design, the primary stability of dental implants is highly dependent on surgical technique and bone features at the implant site.<sup>4,5</sup>

Experimental findings suggest that a tolerable range of

micromotion is in the order of 50–150  $\mu\text{m}$ <sup>6</sup> and may vary according to implant design and implant surface topography.<sup>5</sup>

One of the most popular tools that have been developed to make quantitative measurements of the stability of the implant-bone interface is resonance frequency analysis (RFA).<sup>7–10</sup> This noninvasive clinical method was first described in 1996.<sup>7</sup> It consists of a small L-shaped transducer that is fastened by means of a screw to the implant or to the transmucosal abutment. This transducer has a vertical beam with 2 piezo-ceramic elements attached. One of the piezo-ceramic elements produces a vibration consisting of a small sinusoidal signal in the range of 5 to 15 kHz in steps of 25 Hz. The other piezo-ceramic element analyzes the response of the transducer to the vibration.<sup>7</sup> Resonance frequency of the transducer/implant system is estimated from the peak amplitude of the signal and is coded into a parameter called the implant stability quotient (ISQ). The latter may assume a range of values from 0 (in the case of a totally mobile implant) to 100 (a perfectly stable implant-bone complex). Resonance frequency analysis is used to measure the stability of single unsplinted implants at implant placement, at any time during healing, and after loading of the implants in case of screw-retained prostheses—it cannot be used in case the prosthesis is cemented.

The purpose of this study was to use RFA to test the stability of 2 types of implants with different design in relation to the screw shape (conical vs semiconical) and the thread pitch (wide vs narrow pitch) at 2 time periods: at implant installation and 90 days later.

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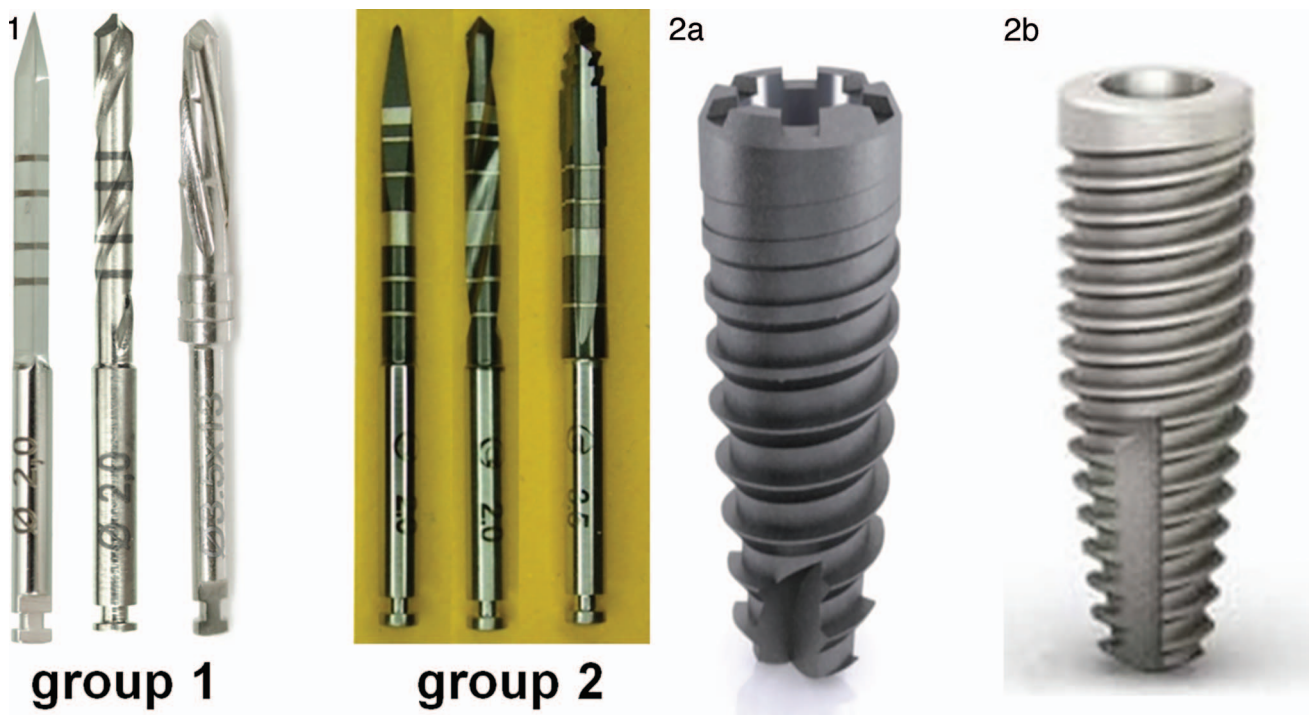
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DOI: 10.1563/aaid-joi-D-13-00294



**FIGURES 1–2. FIGURE 1.** Image of the bur sequence used to prepare the implant sites. **FIGURE 2.** Image of implants used in the study: conical implant with wide pitch (a) and semiconical implant with narrow pitch (b).

#### MATERIALS AND METHODS

Twenty patients (14 women and 6 men) were selected for this study. The patients were between 21 and 54 years of age. The study was approved by the Ethics and Research Committee of São Leopoldo Mandic University (Campinas, Brazil). All patients were informed regarding the nature of the study and their participation, and written consent was granted by every participant according to the Helsinki Declaration of 1994.

The patient inclusion criteria were a healthy medical condition (ASA 1 and ASA 2 according to the American Society of Anesthesiologists classification), the ability to withstand the stress of dental implant surgery, and the need for bilateral implant-supported rehabilitation in the maxillary premolar area. In case of tooth extraction, patients were required to have had at least 6 months of healing without any grafting procedure performed at the time of or after the extractions. Patients with unstable systemic conditions (such as diabetes, hypertension, or osteoporosis), patients with oral pathologies in their soft or hard tissues, and patients with harmful oral habits (such as bruxism, clenching, and smoking) were not included. Further exclusion criteria included the presence of uncontrolled or untreated periodontal disease, insufficient bone volume to insert implants without augmentation procedures at the intended implant site (a crest of less than 13 mm in height and 5 mm in width), and insufficient mesiodistal space (an estimated implant-to-adjacent tooth distance of less than 2 mm).

#### Surgical procedure

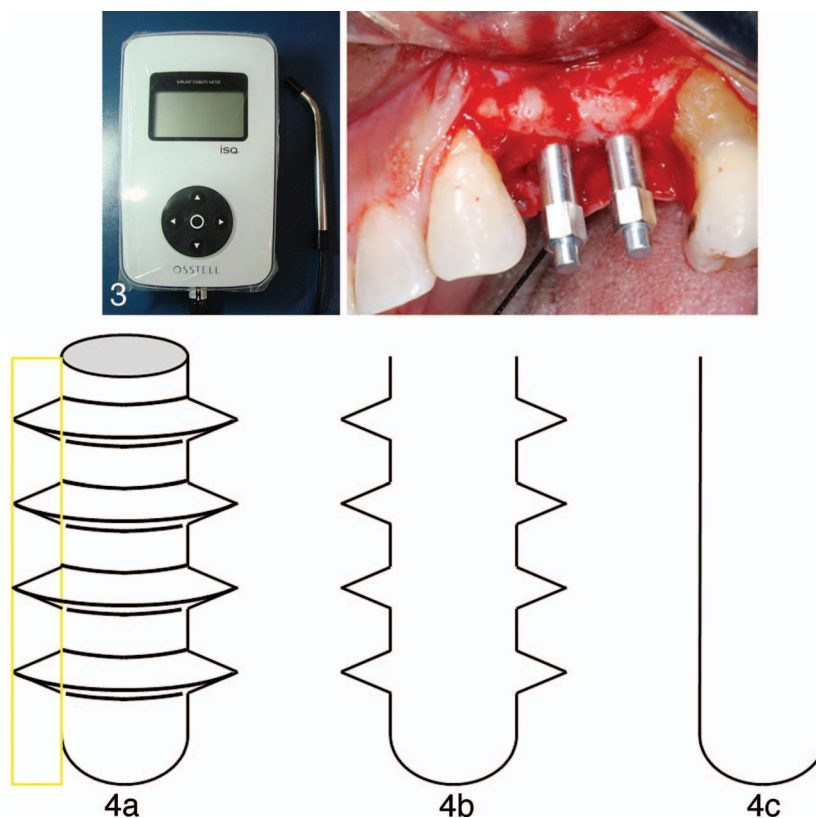
Patients were prescribed amoxicillin (875 mg orally, twice per day) for 5 days prior to surgery, and an additional dose (2 g)

was administered 2 h before surgery. All surgical procedures were performed under local anesthesia with articaine 2% (Dfl Ltda, Rio de Janeiro, Brazil) in an outpatient setting by the same surgeon, who was familiar with both traditional and piezoelectric surgical techniques.

In the present study, both patients requiring 2 contralateral single implants and 4 implants (2 on each contralateral side) in the premolar region were included. In case of patients scheduled to receive 1 implant per site, the implant type was randomly allocated. In case of patients to be treated with 4 implants, implant type was randomly assigned so that on the same side there could be 2 implants belonging either to the same group or to 2 different groups. Randomization was determined by coin toss.

After a full-thickness mucoperiosteal flap was elevated, the underlying alveolar bone was exposed for osteotomy preparation. Both the contralateral and the adjacent implant sites were prepared in each patient during the same surgery. The osteotomies were made using the conventional drilling method with a sequence of burs (Figure 1) in accordance with each manufacturer's instructions.

A total of 60 implants were inserted and distributed into 2 groups ( $n = 30$  for each group): group 1, conical implants with a Morse taper connection with wide pitch, which have 1 mm of distance between threads (Implacil De Bortoli, São Paulo, Brazil), and group 2, semiconical implants with a Morse taper connection with narrow pitch, which have 0.5 mm of distance between threads (Neodent, Curitiba, Brazil). The implants are shown in Figure 2. All implants were 3.5 mm in diameter and 13 mm in length. The torque of the implants was limited to 50 Ncm using a motor control.



**FIGURES 3–4.** **FIGURE 3.** Image of the Osstell and the Smartpeg installed in the implants used to measure the stability, respectively. **FIGURE 4.** Scheme of the measurements: (a) area of the implant that is inserted in the bone, (b) linear measurement of the implant profile, (c) linear measurement of the implant body.

For implant placement, a motor Kavo Concept (KaVo Dental GmbH, Biberach, Germany) and counterangle Kavo with a 27:1 reduction and an external irrigation with 0.9% saline solution were used. All implants were installed with the use of surgical guides. The flaps were sutured using nylon 5-0 (Ethicon, Inc, Somerville, Mass). Ketoprofen (200 mg/d) and paracetamol (750 mg, 3 times per day) were given for pain relief for 3 days after surgery.

Resonance frequency analysis was performed to analyze the implant stability soon after installation in both hemiarches using the Osstell Mentor and a Smartpeg (Integration Diagnostics AB, Göteborg, Sweden), demonstrated in the Figure 3. The Smartpeg was screwed into each implant and tightened to approximately 5 Ncm. The transducer probe was aimed at the small magnet at the top of the Smartpeg at a distance of 2 or 3 mm and held stable during the pulsing until the instrument beeped and displayed the ISQ value. The ISQ values were measured during the surgical procedure (time 1) and at 90 days (time 2) after surgery. The measurements were taken twice in the buccolingual direction and twice in the mesiodistal direction.<sup>11</sup> The mean of the 2 highest measurements from each direction was regarded as the representative ISQ of that implant. In addition, each implant was clinically evaluated at all visits for mobility, pain, and signs of infection.

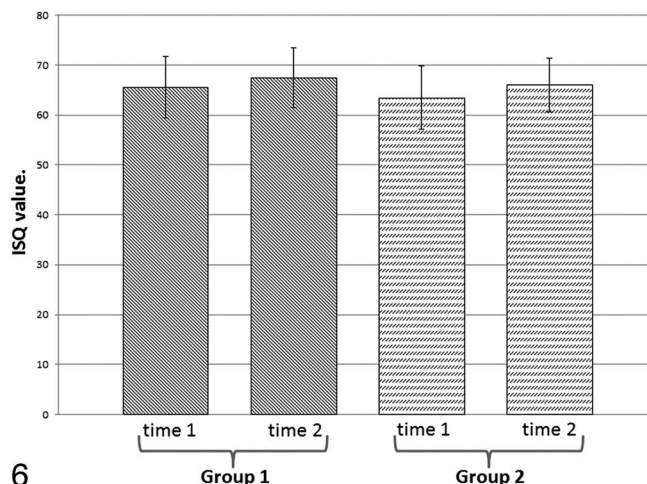
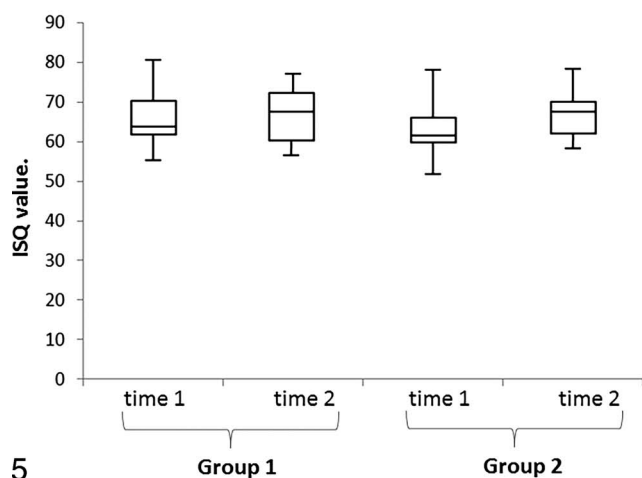
For patients receiving 2 implants per side, the ISQ values of the 2 implants of each group were averaged, so as to provide a

single value for each implant type for each patient. In this way, the final analysis of this split-mouth study was based on 20 bilateral patients and 20 ISQ values for each group of implants.

#### **Implant features**

As part of the present investigation, some features of the 2 types of implants, such as the total surface area available for contact with bone tissue and linear measurements of the implant profile, were evaluated through a computerized analysis using the software Image Tool 5.02 for Microsoft Windows, with high-resolution pictures of the implants. The hypothetical profile of the implant body without threads was also calculated to estimate the surface area increase due to the threads. The surface area of the threads alone (from the implant body to the tip of the threads), measured along the implant from the first thread to the apical part in one side, which theoretically corresponds to the area of the implant, which is inserted in the bone after implant placement, was 2.85 mm<sup>2</sup> for the conical implant and 2.15 mm<sup>2</sup> for the semiconical implants. Therefore, the latter had 25% less area available for bone contact. The linear measurement of the implant profile was 24.0 mm and 30.1 mm for the conical and semiconical implants, respectively. Finally, the linear measurement of the implant body without threads was 16.7 mm and 17.2 mm for the conical and semiconical implant, respectively. See Figure 4.





**FIGURES 5–6.** **FIGURE 5.** Box plot of the stability values measured in each time for the 2 groups. **FIGURE 6.** Graph of the implant stability quotient values and standard deviation of each group.

### Statistical analysis

The comparison between the 2 groups at each time and within each group at different times was performed using the *t* test for paired samples (R Software version 2.6.2, R Foundation for Statistical Computing, Wien, Austria). The level of significance was set at  $\alpha = .05$ .

### RESULTS

Ten patients presented with an absence of the 4 upper maxillary premolars, and 10 patients presented with an absence of 2 upper premolars, 1 per side. No patients dropped out of the study during the observation period. All implants survived and were osseointegrated after 90 days.

The graph in Figure 5 shows a box plot of the degree of stability (ISQ) at each evaluation time for each group. Implants belonging to Group 1 displayed a significantly higher average ISQ value than implants in group 2 at time 1 ( $P = .007$ ); however, such difference was not significant at time 2 ( $P = .54$ ). In the within-group comparison between time 1 and 2, both groups presented an increase in the ISQ values, even though only group 2's increase achieved statistical significance ( $P = .002$ ; while  $P = .07$  for group 1). The mean values and standard deviations of ISQ values are shown graphically in Figure 6.

### DISCUSSION

Primary implant stability has long been considered a fundamental predictor for successful osseointegration.<sup>5,11,12</sup> Previous studies have reported a high rate of implant failure (32%) for implants that showed inadequate initial stability.<sup>13</sup> Thus, it appears that high primary stability reduces the risk of micromotion and adverse tissue responses, such as fibrous tissue formation at the bone-implant interface during healing and loading.<sup>11</sup> Initial implant stability was suggested to be influenced by the bone quality and quantity, implant design, and surgical technique used.<sup>4,5,11,14,15</sup> The present study

compared the primary stability of 2 models of implants that differ in macrodesign and thread pitch during the initial phase of osseointegration. These types of implants are widely used because their macrodesign facilitates implant insertion in situations with scarce residual bone quantity and quality.

The methods commonly used to clinically assess implant stability and osseointegration include percussion, mobility tests, and clinical radiographs. All of these methods are limited by their lack of standardization, poor sensitivity, and susceptibility to operator variables.<sup>8,9,16</sup> To better standardize the results of this study, only RFA was used. This technique is rapid, straightforward, and easy to accomplish as part of a routine clinical procedure, and there is no risk of patient discomfort. Resonance frequency is determined by both the rigidity (stability) of the implant-bone interface and the distance from the transducer to the first bone-implant contact. In fact, it has been demonstrated that a linear relationship exists between the abutment height and ISQ values.<sup>10</sup> The numerical output is also interpreted as a value that is linearly related to the degree of micromotion at the implant-bone interface. This device may be able to detect changes in micromotion that could be associated with an increase or decrease in the degree of osseointegration.<sup>17</sup> Furthermore, such values are moderately correlated with the insertion torque and are dependent on a number of variables, among which are implant length and width, as well as bone density.<sup>18–20</sup> Conversely, there was no correlation between ISQ and bone-implant contact, which is a histologic parameter used to assess the amount of newly formed bone making contact with the implant surface during the osseointegration process.<sup>21</sup> The normal range of ISQ values that has been generally reported for implants achieving primary stability is between 60 and 80, although a consensus on the ISQ threshold below which an implant should not be considered stable has not been established.<sup>18–20</sup> However, some studies suggested that ISQ values of at least 55 at the time of implant placement might be considered as representing clinically relevant stability and possible predictors of successful osseointegration.<sup>19,20</sup> Under conditions of moderate bone density, the ISQ values showed a significant difference in

primary stability between the implants tested in this study, with higher values recorded for the conical implants group. This might be because the conical implants had a larger surface area available for bone contact as compared with the semiconical ones. This was mainly due to the thread pitch that was especially prominent in the apical part of the conical implants as compared with the semiconical ones. The latter, conversely, have smaller and more packed threads that account for a greater linear profile.

Biomechanical and finite element analysis studies showed that maximum effective stress decreased as screw pitch decreased and implant length increased.<sup>22,23</sup> Moreover, it was already demonstrated how the thread width and thickness assume a relevant role in the mechanical behavior of titanium dental implants in the osseointegration process.<sup>23</sup> In this study, the implants with wide thread pitch demonstrated higher values of ISQ. This would confirm that wider thread pitch is related to better implant primary stability, providing a higher mechanical interlocking with bone tissue.

Albrektsson et al<sup>24</sup> reported that factors such as surgical technique, host bed, implant design, implant surface, material biocompatibility, and loading conditions have been shown to affect implant osseointegration. Studies to comprehend these factors and how they influence each other have been the focus of recent research. Understanding these factors and applying them appropriately in the science of dental implants can lead us to achieve predictable osseointegration, thus minimizing potential implant failures. With this knowledge, implant therapy could be easily applied, even in less favorable situations (eg, early or immediate loading, smokers, diabetic patients, or unfavorable bone quality). In fact, previous studies have demonstrated that for the early and immediate implant loading protocols, achievement of adequate implant stability is mandatory to achieve proper osseointegration leading to successful treatment.<sup>25</sup> Previous evidence suggests that an ISQ measure of 60–65 at the time of implant installation is a predictor of a good prognosis for immediate implant loading.<sup>10</sup>

The hypothesis of this study was that differences of the implant macrodesign could lead to different levels of initial implant stability as well as affect the process of osseointegration. The results of the present study seem to support such a hypothesis, although it is necessary to confirm the present outcomes in bone substrates with different density as well as in different categories of patients and prosthetic rehabilitations. Furthermore, a periodical assessment of implant stability using RFA during the healing period could be a helpful, noninvasive, and objective tool for the estimation of implant osseointegration, as also recommended in previous studies.<sup>19,20</sup>

#### CONCLUSION

Within the limitations of this study, it was observed that when placed in conditions of moderate bone density, conical implants with wide pitch achieved a small initial advantage as compared with semiconical implants with narrow pitch, and after 90 days, both implant designs showed a similar primary stability as measured by RFA. It can be concluded that the characteristics of macrodesign may improve the primary stability of dental implants.

#### ABBREVIATIONS

ISQ: implant stability quotient  
RFA: resonance frequency analysis

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