Short implants were recently introduced as a novel approach to simplify implant placement in atrophic alveolar bone and to prevent damage to vital structures. Several additional surgical procedures for bone augmentation have been proposed for patients with bone deficiency, including bone grafts, sinus floor elevation, use of onlay graft blocks, inferior alveolar nerve lateralization, and distraction osteogenesis. These surgical procedures have some limitations since they increase the patient’s discomfort, the possibility of injury to adjacent anatomical structures, and the time for beginning prosthetic procedures. Short implants have been proposed as a less traumatic alternative for atrophic alveolar ridges, and may provide surgical advantages, including reduced morbidity, treatment time, and treatment costs.

The success of implants is highly dependent on obtaining primary stability, and factors such as implant design, size, bone density, and insertion torque influence this parameter. Primary stability, defined as biomechanical stability immediately after implant placement, is a critical factor in determining the long-term success of dental implants. Poor primary stability is considered a major cause of implant failure. As primary stability increases, micromotions become smaller between the surface of the implant and the surrounding bone that enables healing and osseointegration. Considering biomechanical factors, the importance of primary stability in implant success is expected to be more critical for short implants. However, no study has reported an ideal surgical technique to improve the primary stability and success of these implants.

Different methods have been suggested for evaluating implant stability. A scientifically determined method is the measurement of insertion torque as an invasive, single-use technique. Resonance frequency analysis is another easily applicable method for measuring quantitative stability. The scale used ranges from 1 to 100, with the correlation to the resonance

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**Purpose:** This study was designed to evaluate the effects of four different surgical techniques on the primary stability of short implants in two sizes (4-mm and 6-mm length) through resonance frequency analysis and insertion torque measurement in vitro. **Materials and Methods:** Forty implant site preparations and implant insertions were performed in pig ribs. Guided surgery, bone condensing, conventional drilling, and undersized preparation surgical techniques were used five times in each bone block to prepare 4-mm/6-mm-length implant beds. The maximum insertion torque and implant stability quotient (ISQ) values were recorded for each implant. **Results:** Both the ISQ and torque differed significantly for various surgical techniques ($P = .009$ and $P < .001$). The conventional technique had higher ISQ (79.00), whereas the condenser technique had higher torque (48.00 Ncm) than did the other techniques. The mean torque was significantly higher in all surgical techniques other than the guided surgery group regardless of implant length ($P < .01$ for all). Implant lengths were not significantly different in terms of ISQ and torque in all surgical techniques. **Conclusion:** There are significant correlations between the implant bed preparation technique and primary implant stability when using short implants. Conventional surgery and the bone condensing technique are favorable alternatives with higher primary stability and torque values in short implants. Int J Oral Maxillofac Implants 2020;35:700–706. doi: 10.11607/jomi.8081

**Keywords:** dental implants, oral surgery, osseointegration, resonance frequency analysis

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frequency value being almost linear. The higher the implant stability quotient (ISQ), the more securely the implant is presumed to be connected to the bone. ISQ values less than 50 are considered to be critical. Studies have also shown that the measurement of implant stability with resonance frequency analysis is reliable and noninvasive, and can be used at any time after implant insertion.

Various techniques to prepare the implant site are available, and these are believed to improve primary stability, particularly in low-density bones. These techniques include undersized drilling (ie, using a drill with a smaller diameter than that of the implant) to optimize bone density and stability; bone condensing using condensers after a pilot drill to displace the bone at the periphery of the cavity; and the fully guided technique with sleeves based on a virtually planned implant osteotomy, which is believed to lead to smaller micro-motions between the implant and the bone, as well as to better primary stability.

Although studies have compared the different surgical techniques for the primary stability of normal-sized dental implants, to the authors’ knowledge, no studies have compared four different techniques (namely, guided, condensing, conventional, and undersized) for short implants. Therefore, the objective of this study was to evaluate the effects of different surgical techniques on the primary stability of short dental implants in two sizes (4-mm and 6-mm length) through resonance frequency analysis and insertion torque measurement in poor bone quality in vitro.

**MATERIALS AND METHODS**

Due to the nature of this study, it was granted an exemption from requiring ethics approval by the Institutional Review Board.

**Bone Models**

Ten samples of fresh pig ribs were prepared. Pig bone was chosen because of its anatomical and physiologic similarities to the human bone regarding bone structure. The rib was chosen because of its histologic similarities to the human jaw bone (quality 3 or 4, according to the classification of Lekholm and Zarb).

**Surgical Techniques**

In total, 40 implant site preparations and implant insertions were performed for each group. Detailed descriptions of the surgical techniques are as follows:

1. **Guided surgery**: The Straumann planning software complementing the Straumann guided instruments (coDiagnostiX, Straumann) was used for preparing the surgical template. Four ribs were selected for this group and numbered 1 to 4. Grooves were prepared on the ribs and scanned using an intraoral scanner. A computed tomography (CT) image was acquired for each rib, and Digital Imaging and Communications in Medicine CT images were superimposed on the scanned image by using the grooves as a guide. Implants were placed after virtual planning, and a surgical template was designed for implant positions. After the software-based planning was completed, the surgical template was produced by the manufacturer. The surgical procedure began with the stabilization of the surgical template using the adjacent bone surfaces as a support. After fixing the surgical templates to the ribs, the implant beds for the implant lines were prepared by using a milling cutter (3.5 mm), pilot drill (2.2 mm), and guided drill (2.8 mm, 3.5 mm), respectively. The implants were then placed via insertion drills indicated by the manufacturer (Straumann Guided Surgery Cassette).

2. **Bone condensing**: Implant sites were prepared by pilot drill with 2.2-mm diameter, followed by condenser diameters of 2.2, 2.8, and 3.5 mm, respectively. Each bone condenser was mildly hammered to the proper depth with a surgical mallet according to the manufacturer’s instructions.

3. **Conventional drilling**: Implant areas were determined with a 1.4-mm-diameter round bur, and then all implant beds were prepared by using a pilot drill of 2.2-mm diameter. Surgical twist drills with diameters of 2.8 and 3.5 mm were used to prepare implant sites of 4 and 6 mm in length. Drilling was performed using a surgical handpiece connected to a surgical motor unit (Straumann Surgical Motor Pro, Surgery System) along with constant irrigation. The drilling speed for drill diameters of 2.8 and 3.5 mm was at 600 rpm. Finally, implants with various lengths were inserted via insertion drill as indicated by the manufacturer.

4. **Undersized preparation**: This protocol was implemented as in the aforementioned conventional protocol. With the difference of the former protocol, the final drill used was one size narrower than that recommended by the manufacturer (ie, a 2.8-mm final drill for a 4.1-mm-diameter implant).
Insertion Torque Measurement
During machine implant insertion, the maximum torque values were recorded for each implant. The maximum insertion torque value during implant placement was recorded using the same electronic surgical device (Straumann Surgical Motor Pro, Surgery System) used for implant placement. Starting at 20 Ncm, the insertion torque was increased in 5-Ncm steps until machine insertion concluded and the implant reached its final position. This method enabled the measurement to be conducted in a controlled manner.

Resonance Frequency Analysis
Resonance frequency analysis was performed using Osstell (Integration Diagnostics) following the manufacturer’s instructions for all implants. A transducer was screwed by the specific hand screw driver to the implants, and the measurements were performed immediately after implant placement in five directions: anterior, posterior, superior, left, and right.20,21 The measurements were repeated three times. The mean ISQ value of all measurements was calculated and recorded for each implant.

Statistical Analysis
Descriptive statistics were represented as the mean and standard deviation. The dependent variables were Osstell ISQ and torque values. The independent variables were surgical techniques (guided surgery, condenser, conventional, and undersized groups) and implant lengths (6 mm and 4 mm). Two-way analysis of variance (ANOVA) was used to examine the main effects of the groups and the interaction effects between them in terms of the Osstell ISQ and torque values.

Assumptions about homogeneity of variance-covariance matrices were tested using Box’s M test and Levene’s univariate tests, and the proximity to zero of the residual correlations was checked using Bartlett’s test. According to Bartlett’s and Levene’s tests, Pillai’s trace multivariate test result was reported because the group variances were not homogenous for the torque-dependent variable. When a significant difference was observed among the means, the Bonferroni test was implemented for post hoc multiple comparisons. For the multiple comparisons, Tukey’s honestly significant difference test was applied for Osstell ISQ when the assumption of homogenous variance was met among the groups, and the Games-Howell test was used for torque values when the homogenous variance assumption was not met.

Implementing the power analysis to the independent factors, ie, the four surgical techniques and two implant lengths, for Osstell ISQ, the necessary sample size was determined in each block. All statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 20.0 (IBM), and the power analysis was performed using statistical analysis software STATISTICA version 10.0 (StatSoft Inc. 2010).

RESULTS
All the mean values, standard deviations, and minimum and maximum values of Osstell ISQ and torque, as functions of implant length and surgical technique, are shown in Table 1, and the related changes are plotted in Figs 1 and 2. Comparisons of the average values for the different surgical techniques (guided surgery group–surg. tech. 1; condenser–surg. tech. 2; conventional–surg. tech. 3; and undersized group–surg. tech. 4) depending on the two implant lengths are provided in Table 2. Osstell ISQ showed significantly different means between the surgical techniques at an implant length of 6 mm. According to this result, the mean Osstell ISQ of the guided surgery group was significantly lower than that of the conventional group alone (66.84 ± 10.53 and 79.36 ± 2.92, respectively). However, when comparing the surgical techniques according to the torque value based on the implant lengths separately, significant differences were detected among the surgical techniques, irrespective of the implant length (all P < .01). The mean torque value of the guided surgery group was significantly lower than that of the other three groups at both implant lengths (32.00 ± 2.74 Ncm for 6 mm and 36.00 ± 2.24 Ncm for 4 mm; P < .001 for both).

Both Osstell ISQ and torque were significantly different in the various surgical techniques (P = .009 and P < .001, Fig 1). The conventional technique had higher Osstell ISQ (79.00), whereas the condenser technique had higher torque (48.00 Ncm) than did the other techniques. When the interaction plots were evaluated, the mean Osstell ISQ was significantly higher only in the conventional surgery group than in the guided surgery group at an implant length of 6 mm (P = .019, Fig 2a). In contrast, the mean torque was significantly higher in all surgical techniques other than guided surgery regardless of implant length (P < .01 for all, Fig 2b).

DISCUSSION
The primary stability of implants, which plays a crucial role during the osseointegration period, is a significant driver in achieving implant treatment.6,22 Although the preference for short implants has increased recently, clinicians often hesitate to use them as another alternative to conventional implants. This may be linked to the lower rates of success with the insertion of short implants reported in the literature.23,24 The outcomes of the present study may be helpful in enhancing the
The present study aimed to evaluate the effect of various surgical techniques on the primary stability of short implants. The main and interaction effects of four different surgical techniques and length of implants (6 mm and 4 mm) on ISQ and insertion torque measurements were investigated. For this purpose, at the beginning of the study, a power analysis was implemented for the data structure in the two-way ANOVA arrangement of $4 \times 2$, and implant measurements repeated five times for each subgroup were taken into account. At the 5% significance level, the obtained power values to determine the differences between the means were 85.8% for the surgical technique effects, 1.000 for implant size, and 91.2% for the interaction effect.

The results of ISQ and insertion torque measurements performed on 40 implants were determined.
be statistically different among the four different site preparation procedures. According to the present results, it was clear that the ISQ values are not affected by implant length (4 mm or 6 mm) but rather by the surgical techniques. Experimentally, the highest ISQ values were obtained in the conventional technique. In contrast to the present outcomes, Rastelli et al investigated a possible correlation between primary implant stability and five different preparation techniques by using resonance frequency analysis in pig ribs, and the results revealed no statistical differences among those in vitro procedures. Moreover, other studies comparing piezosurgery and standard techniques showed no differences in terms of the primary stability of implants. In accordance with the aforementioned studies, Stacchi et al reported no difference in primary stability between piezoelectric surgery and the conventional drilling technique in one group. Additionally, the most well-known drawback of piezoelectric devices is the prolonged operative time compared with that of conventional preparation. In an attempt to contribute to the literature, the guided surgery technique was opted for rather than piezosurgery. In addition, when clinicians encounter poor cancellous bone quality, modified surgical protocols might be beneficial in improving the primary stability of implants; in such cases, a final drill size narrower than that recommended might be used.

Table 2

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Implant length</th>
<th>Surg. tech. 1-2</th>
<th>Surg. tech. 1-3</th>
<th>Surg. tech. 1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osstell-ISQ</td>
<td></td>
<td>Mean difference</td>
<td>SE P value</td>
<td>Mean difference</td>
</tr>
<tr>
<td>6 mm</td>
<td></td>
<td>–10.60</td>
<td>3.74 .053</td>
<td>–12.52</td>
</tr>
<tr>
<td>4 mm</td>
<td></td>
<td>1.48</td>
<td>4.27 .985</td>
<td>–8.20</td>
</tr>
<tr>
<td>Torque value</td>
<td></td>
<td>–17.00</td>
<td>2.23 **.001</td>
<td>–13.00</td>
</tr>
<tr>
<td>(Ncm)</td>
<td></td>
<td>–11.00</td>
<td>1.58 **.001</td>
<td>–6.00</td>
</tr>
</tbody>
</table>

*P < .05; **P < .01.

SE = standard error.

Fig 2a Changes in the implant stability quotient (Osstell ISQ) values according to implant length and surgical techniques.

Fig 2b Changes in the torque values according to implant length and surgical techniques.
The present analysis revealed that the mean ISQ value was statistically higher in the conventional drilling technique group than in the guided surgery group when using the 6-mm-length implants. Although the literature\textsuperscript{37,38} shows that guided implant surgery has promising consequences with high success rates when the bone quality is poor, the present study showed that the insertion of short implants through surgical templates does not produce beneficial outcomes in favor of implant stability. According to the present authors’ interpretation, the reason for the lowest ISQ and torque values in the guided surgery group is that software-based drill planning must be strictly implemented on the surgical cassette, in accordance with the manufacturer’s instructions. Some surgical modifications may be necessary, such as in the undersized implant bed preparation technique, especially in areas with poor bone density. Apart from that, in light of the findings of this experimental study, the manipulation of short implants seems harder in the guided surgery group than in the other treatment groups.

Some authors have suggested osseocompaction via bone condensers to enhance implant stability.\textsuperscript{39} This recommendation is in line with the present results showing that a significantly higher insertion torque value was obtained in the condenser group than in the other treatment groups. Furthermore, the study conducted by Krafft et al. reported a notable increase in stability and insertion torque with the expander technique rather than the conventional techniques.\textsuperscript{40}

In the present study, primary implant stability was evaluated using resonance frequency analysis immediately after implant placement. Both resonance frequency analysis and insertion torque measurement provide reliable and valuable information about primary implant stability.\textsuperscript{33,41} Moreover, pig bone, which is usually utilized in dental implantology or in maxillofacial surgery courses and for investigations, was preferred because of its structural similarities to the human bone.\textsuperscript{18}

Some limitations of this study need to be mentioned. Bone quality, microgeometry, diameter, and surface features of the implants also play crucial roles in obtaining primary stability.\textsuperscript{42,43} These parameters were maintained constant, while the surgical techniques and implant lengths were varied in the present study. Further in vivo studies are required to determine if these findings are valid in humans.

**CONCLUSIONS**

Within the limitations of this in vitro study, the following conclusions can be made: conventional osteotomy preparation is associated with the highest level of implant stability quotient, and implant insertion torque is the highest when the condenser technique is used.

**ACKNOWLEDGMENTS**

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