Preserving crestal bone around implants is currently a primary focus of research. Although the causative factors underlying bone loss have not been fully established, previous studies have suggested that the main factors of marginal bone loss are periimplantitis and occlusal overload.1,2 Biomechanical factors that influence the stress in the bone around an implant include the implant design, diameter, material properties, and surface configuration.3-6 Baggi et al7 demonstrated that the stress was concentrated in the cortical bone around the implant neck and was influenced primarily by the implant diameter, regardless of the implant length. Clinically, when the width of the alveolar bone is insufficient or where a concavity of the ridge is present (especially in the anterior regions of the jaws), extensive bone augmentation procedures may be necessary to allow implant placement. In these circumstances, if the patient does not accept or is not suited for additional surgeries, use of a small diameter implant may allow restoration with implant-supported restorations. Lazzara and Porter8 described some patients in whom the long-term preservation of marginal bone was better

ABSTRACT

Statement of problem. Use of a small diameter implant may increase the stress on bone around the implant neck; however, an expanded platform design may mitigate these stress concentrations. To date, no study has compared the biomechanical effect of regular platform and extended platform designs on an implant.

Purpose. The purpose of this in vitro study was to evaluate the biomechanical effects of an expanded platform-switching design for immediately loaded small diameter implants on bone strains.

Material and methods. Three groups of artificial jawbone models were prepared for small diameter (3.25-mm) and standard diameter (4.0-mm) implants with expanded or regular platform designs. Platform-switching implant design was implemented by assembling implants with a smaller connected abutment. Specimens were tested under both vertical and lateral static loads at 190 N. Peak values of the principal microstrain of bone were recorded and analyzed statistically with Kruskal-Wallis test and multiple comparisons Bonferroni test (α=.05). The initial stability of each implant was also measured for 3 types of implant.

Results. Under vertical loading, the bone strain was lowest for the regular type of immediately loaded small diameter implant. Under lateral loading, peak bone strain around the expanded platform small diameter implant with platform switched abutment was up to 74.9% lower than that of the regular type of small diameter implant. Increasing the implant diameter from 3.25 mm to 4.0 mm on the expanded platform implants reduced the bone strain by approximately 10% and 30% under lateral and vertical loading, respectively. The initial implant stability did not vary significantly among the implants tested.

Conclusions. Using the expanded platform small diameter implant with a platform-switched abutment may decrease the marginal bone strains around immediately loaded small-diameter implants under lateral loading. (J Prosthet Dent 2016;115:20-25)
Clinical Implications

Regular diameter implants are precluded from placement when there is insufficient bone or when the interradicular space is small. In some situations, small diameter implants will allow the use of implants to support restorations without ancillary procedures. This article provides information to help clinicians choose the type of implant placed and the abutment type used when deciding to use small diameter implants while immediately loading them.

with an abutment smaller than the implant platform; this approach came to be known as “platform switching.” Therefore, periimplant marginal bone preservation can be more noticeable when the implant and suprastructure have mismatched diameters.\(^9\)\(^{11}\) although the complication of platform switching has been reported recently.\(^12\) Platform switching makes it possible to use abutments with a diameter smaller than the implant platform or body width. Alternatively, an implant design can be used where the implant platform diameter is larger than the diameter of the implant body.\(^13\) In 2009, Hsu et al\(^14\) used 3-dimensional finite element analysis to investigate the behaviors of reduced-platform restorations. They found that in all such restorations, the prosthetic loading forces transmitted to the bone–implant interface in the immediately loaded implant model were reduced by 10%.

Small diameter implants are useful when the proximity of roots does not allow safe placement of larger diameter implants without involving adjunctive procedures to move the roots.\(^15\) However, using a small diameter implant may increase the stress and/or strain of bone around the implant neck. Use of an expanded platform design with small diameter implants may be an option for increasing the implant diameter at the marginal bone area. Unfortunately, few studies are available regarding the immediate loading of small diameter implants, especially those with an expanded platform. Cocchetto et al\(^10\) used both clinical and radiographic evaluations to determine the biological effects of using an expanded platform-switching restorative protocol in humans. Their results indicated that crestal bone loss may be lower in appropriately selected patients who receive expanded platform implants with platform-switched abutments than in those treated with non-platform-switching approaches.

Using smaller diameter implants may increase bone stresses and/or strains around the implant, which makes it worthwhile considering modifications to its component design. Use of an expanded platform design with small diameter implants may be an option for using the platform-switching concept and increasing the implant diameter in the marginal bone area. However, few studies have investigated the biomechanical features of these 2 kinds of implant designs. The purpose of the present study was to determine the biomechanical effects of applying an expanded implant together with a platform-switching design on immediately loaded small diameter implants, that is, those with diameters smaller than 3.4 mm that accept interchangeable abutments. The hypothesis tested in this study was that expanding the platform at the marginal bone area would reduce cervical bone strain.

MATERIAL AND METHODS

Two types of 11.5-mm-long Nanotite Certain Prevail implants with diameters of 3.25 mm and of 4.0 mm (IIOS343 and IIOS454; Biomet 3i), and internal hexagon connections and expanded platform bodies were selected for analysis and comparison with a control implant (diameter, 3.25 mm; length, 11.5 mm; NIOSM311, NanoTite Certain MicroMiniplant; Biomet 3i) with an internal hexagon connection and a standard threaded body (Fig. 1). For the IIOS343 and NIOSM311 implants, an 8-mm-long internal hexagon with a diameter of 3.4 mm, 3.8 mm in platform, and height of 2.0 mm (Certain GingiHue Post; Biomet 3i) was used as an abutment placed on the platform of the implant. For the IIOS454 implant, the same type of internal hexagon abutment with a diameter of 4.1 mm, 5.0 mm in platform, and height of 2.0 mm was applied (Fig. 2).

A Sawbones model of trabecular bone with a density of 0.4 g/cm\(^3\) and elastic modulus of 759 MPa (model 1522-05; Pacific Research Laboratories) was prepared for attachment to a 3-mm-thick commercially available synthetic cortical shell (model 3401-02; Pacific Research Laboratories) with an elastic modulus of 16.7 GPa.\(^5\)\(^6\) Density of the trabecular bone used in this study was simulated as type 2 (D2) bone,\(^16\) based on the bone density classification of Misch.\(^17\) The thickness of the cortical bone was referred to in the study by Hahn,\(^18\) which indicated that D2 bone was associated with 2.5 to 4 mm of cortical bone height. The synthetic bone had a rectangular shape with dimensions of 41×30×43.5 cm. Three specimens of artificial foam bone were prepared for each implant system.

Peak insertion torque value (ITV) was measured with a digital torque meter (TQ-8800; Lulton Electronic Enterprise) with the implant inserted into the bone block specimen.\(^7\)\(^8\) In order to simulate the interface condition of an immediately loaded implant, the interface between implant and bone was prepared for contact only. After the implant was placed, a wireless resonance frequency analyzer (Osstell ISQ; Osstell AB) was used to measure the implant stability quotient (ISQ).
the measurement was made, SmartPegs for internal hexagon connection of 3i implants (Type 1 and Type 15; Osstell AB) were placed on the top of the implants. Each peg contains a magnetic material in its upper part. When the probe of the Osstell ISQ instrument is near the SmartPeg, the peg is stimulated by magnetic pulses. The resultant vibrations are detected by the Ostell instrument, and the resonance frequency is measured and displayed as the ISQ value. For each specimen, 4 ISQ values were obtained in 4 directions (buccal, lingual, mesial, distal) of the implant. After titanium abutments were connected, the implant mobility was measured with the Periotest device (Siemens). The tip of the measurement device was positioned perpendicularly 2 mm from the abutment, and when activated, the instrument delivered calibrated impacts from a piston 4 times per second for 4 seconds. Periotest values (PTV) were also recorded 4 times for the same 4 directions in each model.

A customized device was designed to allow both a vertical load and a 30-degree lingual lateral force to be applied in the experiments. Each loading procedure involved applying a force of 190 N to the cylindrical abutment using a universal testing machine (JSV-H1000; Japan Instrumentation System) with a head speed of 1 mm/min (Fig. 3). Rectangular rosette strain gauges (KFG-1-120-D17-11L3M3S; Kyowa) were attached to the buccal and lingual sides of the crestal cortical region around the implant with cyanoacrylate cement (CC-33A; Kyowa). Signals corresponding to the 3 independent microstrains \( \varepsilon_a \), \( \varepsilon_b \), and \( \varepsilon_c \), measured by the rosette strain gauge, were sent to a data acquisition system (NI CompackDAQ; National Instruments) and analyzed by the associated software (LabVIEW SignalExpress 3.0; National Instruments). After each measurement was repeated 3 times for each specimen, the maximum (\( \varepsilon_{\text{max}} \)) and minimum (\( \varepsilon_{\text{min}} \)) principal microstrains were obtained as follows:

\[
\varepsilon_{\text{max}} = \frac{1}{2}(\varepsilon_a + \varepsilon_c) + \frac{1}{2}\sqrt{\left(\varepsilon_a - \varepsilon_c\right)^2 + \left(2\varepsilon_b - \varepsilon_a - \varepsilon_c\right)^2} \\
\varepsilon_{\text{min}} = \frac{1}{2}(\varepsilon_a + \varepsilon_c) - \frac{1}{2}\sqrt{\left(\varepsilon_a - \varepsilon_c\right)^2 + \left(2\varepsilon_b - \varepsilon_a - \varepsilon_c\right)^2}
\]

The measured primary implant stability and the peak values of the principal microstrains of bone under vertical and lateral loading conditions for the designed scenarios of 3 implant systems were summarized as medians and interquartile ranges. The Kruskal-Wallis test and multiple comparisons with the Bonferroni test were used to assess differences. All analyses were performed using commercial statistical software (SAS v9.1; SAS Institute) (\( \alpha = .05 \)).

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**Figure 1.** Standard diameter (left) and small diameter (center) implants with expanded platform design compared with small diameter (right) implant with regular platform design.

**Figure 2.** Smaller internal hexagon abutment attached to expanded platform of implant to implement concept of platform switching.

**Figure 3.** Thirty-degree lingual lateral force of 190 N applied to top of abutment by universal testing machine. Microstrains in bone near implant were measured by data acquisition system and analyzed by LabVIEW SignalExpress software.
RESULTS

ITV and ISQ values did not differ significantly among the NIOSM311, IIOS343, and IIOS454 implants. However, PTV varied significantly (P<.05) among the implants, and was lowest for IIOS343 (Table 1).

Under vertical loading, the peak values of the principal microstrains of bone (simply referred to as peak bone strains) around the immediately loaded small diameter implants differed significantly among the NIOSM311, IIOS343, and IIOS454 implants in results of both the Kruskal-Wallis and multiple comparisons Bonferroni tests (Table 2; Fig. 4). Bone strain was highest for the IIOS343 implant, at least 31.2% higher on the buccal side and 29.8% higher on the lingual side than with the other implants.

Under lateral loading conditions, peak bone strains around the implants differed significantly among the NIOSM311, IIOS343, and IIOS454 implants in the Kruskal-Wallis test results (P<.05) (Table 2; Fig. 5). Bone strains were 9.8% lower on the buccal side and 74.9% lower on the lingual side for the IIOS343 implant than for the NIOSM311 implant. Bone strain was lowest for the IIOS454 implant, 10.7% lower on the buccal side than that for the IIOS343 implant (Table 2; Fig. 5).

DISCUSSION

A systematic review of platform-switching implants found that the survival rate did not differ between platform-switching and conventional implants; however, there was less marginal bone loss over time for the former implants. The reason for this phenomenon is not fully understood, but various biological and mechanical theories have been proposed. The design of platform switching might increase the distance between the inflammatory-cell infiltrate in the microgap and the crestal bone, thereby minimizing the effect of inflammation on marginal bone remodeling. In addition, based on the results of finite-element analyses, some researchers have suggested that this design reduces the stress at the bone–implant interface and in the crestal region of cortical bone by shifting the stress to cancellous bone during loading. If the biologic and mechanical advantages of platform switching are proven true, extrapolating the platform-switching design to small-diameter implants could improve the outcomes in clinical applications. However, few studies have investigated small diameter implants with a platform-switching design. One study did investigate implants incorporating the expanded platform-switching concept with a provisional restoration immediately after implant placement, and found limited mean implant crestal bone loss of 0.97 ±0.39 mm after a 5-year follow-up period; however, that study did not include any small diameter implants.

In the present study, the bone strain value differed significantly among the 3 groups of implants under lateral loading. Both the IIOS343 and NIOSM311 implants have a small diameter (3.25 mm), but the surrounding bone strain decreased more for the IIOS343 implant that for the NIOSM311 implant, which could be attributed to the expanded platform design together with the platform-switched abutment design of the former. Because platform switching changes the traditional design of the abutment–implant connection, the stress/strain distributions from the abutment to the implant and from the implant to the bone might be influenced when occlusal loading occurs. The present results indicate that use of an expanded platform small-diameter implant in combination with a platform switched abutment for an immediately loaded small-diameter implant can reduce strain around the implants, especially under lateral loading conditions.

In general, an increase in implant diameter can markedly reduce bone stress and/or strain values. With immediate loading, increasing the implant diameter also decreases bone strain around the implants. The IIOS454 and IIOS343 implants used in the present study have the same degree of 0.7-mm–expanded platform-switching design but different implant diameters. The IIOS454 implant, which has a larger diameter, produced

| Table 1. ITV, PTV, and ISQ values for immediately loaded NIOSM311, IIOS343, and IIOS454 implants |
| Evaluation Parameters<sup>b</sup> |
| Implant | ITV (Ncm) | PTV | ISQ |
| NIOSM311 | 62.00<sup>a</sup> (2.00) | -6.00<sup>a</sup> (1.00) | 82.00<sup>a</sup> (1.00) |
| IIOS343 | 65.00<sup>a</sup> (0.00) | -3.00<sup>a</sup> (1.00) | 81.00<sup>a</sup> (0.50) |
| IIOS454 | 65.00<sup>b</sup> (6.00) | -5.00<sup>b</sup> (1.00) | 84.00<sup>b</sup> (5.00) |
| P<sup>c</sup> | <.001 | <.001 | .137 |

<sup>a</sup>Kruskal-Wallis test.
<sup>b</sup>Data are median (interquartile range) values.

<p>| Table 2. Peak values of principal microstrains of bone around immediately loaded NIOSM311, IIOS343, and IIOS454 implants |</p>
<table>
<thead>
<tr>
<th>Location</th>
<th>Model</th>
<th>Vertical Loading</th>
<th>Lateral Loading</th>
</tr>
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<tbody>
<tr>
<td>Buccal side</td>
<td>NIOSM311</td>
<td>-401.84&lt;sup&gt;a&lt;/sup&gt; (49.38)</td>
<td>-1064.28&lt;sup&gt;a&lt;/sup&gt; (217.04)</td>
</tr>
<tr>
<td>IIOS343</td>
<td>-583.87&lt;sup&gt;b&lt;/sup&gt; (82.06)</td>
<td>-959.77&lt;sup&gt;b&lt;/sup&gt; (63.09)</td>
<td></td>
</tr>
<tr>
<td>IIOS454</td>
<td>-481.57&lt;sup&gt;c&lt;/sup&gt; (19.75)</td>
<td>-856.81&lt;sup&gt;c&lt;/sup&gt; (28.57)</td>
<td></td>
</tr>
<tr>
<td>P&lt;sup&gt;c&lt;/sup&gt;</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>Lingual side</td>
<td>NIOSM311</td>
<td>-357.67&lt;sup&gt;a&lt;/sup&gt; (18.07)</td>
<td>656.36&lt;sup&gt;a&lt;/sup&gt; (162.37)</td>
</tr>
<tr>
<td>IIOS343</td>
<td>-627.92&lt;sup&gt;b&lt;/sup&gt; (65.93)</td>
<td>164.60&lt;sup&gt;b&lt;/sup&gt; (76.15)</td>
<td></td>
</tr>
<tr>
<td>IIOS454</td>
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<td>111.73&lt;sup&gt;c&lt;/sup&gt; (26.66)</td>
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<tr>
<td>P&lt;sup&gt;c&lt;/sup&gt;</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
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</table>

<sup>a</sup>Kruskal-Wallis test.
<sup>b</sup>Data are median (interquartile range) values.
significantly less bone strain than the IIOS343 implant under lateral loading. These results indicate that, under the same platform-switching degree of 0.7 mm, bone strain around immediately loaded implants may also be affected by the implant diameter, with bone strain being lower around wider implants.

However, under vertical loading, bone strain was lowest for the NIOSM311 implant and highest for the IIOS343 implant. Therefore, the designs of platform switching and widening implant diameter may not always be advantageous for decreasing bone strain, especially under vertical loading. Because the underlying biomechanical mechanism remains unclear, further investigations are needed of the effects of small diameter implants with an expanded platform-switching design on the surrounding bone strain under vertical loading.

In terms of the data related to implant stability, the ITV and ISQ did not differ among the 3 implant models. However, the PTV was lower for the IIOS343 implant than for the 2 other groups. This might have been due to the measurements being made at the abutment level or the test peg level of the equipment; this requires further investigation.

Limitations of the study were in the simulation of bone with artificial substrate, the morphology of the

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**Figure 4.** Medians and interquartile ranges of peak values of principal microstrains on buccal (left) and lingual (right) sides of bone in 3 implant groups under vertical loading.

**Figure 5.** Medians and interquartile ranges of peak values of principal microstrains on buccal (left) and lingual (right) sides of bone in 3 implant groups under lateral loading.
substrate, and the homogeneity of the substrate; in addition, the strains measured were obtained only where strain gauges were placed.5,6 Unlike actual bone, the test specimens were ASTM F-1839 certified, with simplified geometry, so muscle attachments and viscoelasticity could not be duplicated. This study compared only the strains of small diameter implants with differing platform configurations with respect to primary stability under these test conditions. Future studies using differing configurations of strain gauges or having more representative artificial bone developed or different methodology (such as 3-dimensional finite element analysis) can be used to compare these results. Nevertheless, the conclusions of this study can be regarded as general principles which constitute useful information for clinicians. That is, under lateral loading, the strain values vary significantly with the widths of the implant and abutment (platform switching) and with the implant diameter.

CONCLUSIONS

Within the limitations of the in vitro experiments performed in this study, it can be concluded that using an expanded platform-switching design with an immediately loaded small diameter implant can reduce the strain around the implant neck under lateral loading. Moreover, for the same degrees of expanded platform switching, the bone strain around an immediately loaded small diameter implant may also be affected by the implant diameter.

REFERENCES


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