Insertion torque, resonance frequency, and removal torque analysis of microimplants

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Received 6 April 2016; accepted 19 July 2016
Available online 24 August 2016

Abstract This study aimed to compare the insertion torque (IT), resonance frequency (RF), and removal torque (RT) among three microimplant brands. Thirty microimplants of the three brands were used as follows: Type A (titanium alloy, 1.5-mm x 8-mm), Type B (stainless steel, 1.5-mm x 8-mm), and Type C (titanium alloy, 1.5-mm x 9-mm). A synthetic bone with a 2-mm cortical bone and bone marrow was used. Each microimplant was inserted into the synthetic bone, without predrilling, to a 7 mm depth. The IT, RF, and RT were measured in both vertical and horizontal directions. One-way analysis of variance and Spearman’s rank correlation coefficient tests were used for intergroup and intragroup comparisons, respectively. In the vertical test, the ITs of Type C (7.8 Ncm) and Type B (7.5 Ncm) were significantly higher than that of Type A (4.4 Ncm). The RFs of Type C (11.5 kHz) and Type A (10.2 kHz) were significantly higher than that of Type B (7.5 kHz). Type C (7.4 Ncm) and Type B (7.3 Ncm) had significantly higher RTs than did Type A (4.1 Ncm). In the horizontal test, both the ITs and RTs were significantly higher for Type C, compared with Type A. No significant differences were found among the
groups, and the study hypothesis was accepted. Type A had the lowest inner/outer diameter ratio and widest apical facing angle, engendering the lowest IT and highest RF values. However, no significant correlations in the IT, RF, and RT were observed among the three groups.

Introduction

Favorable anchorage design is a critical factor for successful orthodontic treatment. Orthodontic microimplants have been verified as highly stable anchorage devices exhibiting diverse applications for effectively overcoming the difficulties encountered in orthodontic treatment. The stability and reliability of microimplants enable the successfully controlling orthodontic forces, limiting undesired tooth movements and correcting severe malocclusion. Orthodontic microimplants have a success rate of 60–90% [1–3]; therefore, they can be used as an effective tool for orthodontic treatment.

The stability of orthodontic microimplants that are inserted into bones can be categorized into two types; primary and secondary. Primary stability is the initial strength of the mechanical interlock between a microimplant and bone, whereas secondary stability is a biological osseointegration between an orthodontic microimplant and bone during healing. However, orthodontic microimplants are typically loaded with the orthodontic force immediately or after a period of 2–3 weeks, unlike dental implants that require at least 4 months for bone integration (secondary stability). Therefore, primary stability is the most critical concern in the application of orthodontic implants.

Different technologies have been employed to evaluate the stability of orthodontic microimplants, and such technologies include insertion torque (IT) [4,5], removal torque (RT) [6,7], and resonance frequency (RF) analysis [8–10]. RF analysis is a noninvasive, harmless, repeatable, and reliable method that has been successfully and widely used to measure the stability of dental implants. However, this method has seldom been used to study the stability of orthodontic implants. Therefore, the objective of the current study was to use the IT, RF, and RT analyses to investigate and compare the mechanical forces among three different brands of orthodontic microimplants.

Methods

As illustrated in Figure 1, 30 commercial orthodontic microimplants exhibiting three distinct features and belonging to three different brands were used in this study, and they can be categorized as follows: Type A (titanium alloy, 1.5-mm × 8-mm), Type B (stainless steel, 1.5-mm × 8-mm), and Type C (titanium alloy, 1.5-mm × 9-mm). From each of the three brands, five microimplants were used for vertical tests (90°) and five for horizontal tests (0°). Both the vertical and horizontal tests could include and interpret the degree of insertion of the clinical condition. Each test included IT, RF, and RT analyses.

Scanning electron microscope analysis (Hitachi SU8010, Tokyo, Japan) was applied to evaluate the surface feature of a thread (Figure 2). Under a clinical condition, a microimplant is placed in the interdental alveolar bone, which possesses a 2-mm thick cortical plate. A synthetic bone (Sawbone, Pacific Research Laboratories Inc., Vashon Island, WA, USA) with a 2-mm thick cortical plate (40 pcf) was developed from rigid polyurethane foam. The density of the cortical plate represented the relative densities of the maxillary and mandibular cortices, whereas the density of the cancellous bone (20 pcf) represented that of the bone marrow.

Each microimplant was inserted into the synthetic bone, without predrilling, to a depth of 7 mm, leaving at least 1-mm gingival thickness for IT and RT measurements using a digital torque meter (Lutron, Taipei, Taiwan). The analyzer (Implomates, BioTech One, Inc., Taipei, Taiwan) was based on the impulse force method and was used to measure resonance frequencies (Figure 3).
Statistical analyses in this study were conducted using SPSS (IBM SPSS 20, New York, USA). One-way analysis of variance with Tukey Honestly Significant Difference (HSD) post comparison was applied to test the significant differences among the three mechanical forces (IT, RF, and RT). Spearman’s rank correlation coefficient test was used to investigate correlations among the three experimental values (IT, RF, and RT) during intragroup comparisons. Absence of correlations among the mechanical forces among the three brands used was considered as the null hypothesis. Statistical significance was tested at $p < 0.05$.

## Results

The dimensions of the three microimplants are presented in Table 1 and Figure 4. The inner diameter of Type B (1.08-mm) was greater than those of Type C (1.01-mm) and Type A (0.92-mm). Similarly, the inner/outer diameter ratio of Type B (0.71) was higher than those of Type C (0.66) and Type A (0.61). Type A (0.29-mm) had the highest thread depth, compared with Type C (0.25-mm) and Type B (0.22-mm). Moreover, Type A demonstrated the greatest apical facing angle ($35^\circ$) and coronal facing angle ($17^\circ$), compared with the other two types.

![Figure 2. Scanning electron microscope analysis (15 kV x 30, Hitachi SU8010, Japan): diameters and thread depths of the three types of mini-implants (from left to right: Type A, Type B, and Type C).](image1)

![Figure 3. Resonance frequency analysis (Implomate; BioTech One, Inc., Taipei, Taiwan).](image2)

![Table 1 The parameters (mm) of microimplants.](image3)

<table>
<thead>
<tr>
<th>Microimplants</th>
<th>Type A</th>
<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner diameter</td>
<td>0.92</td>
<td>1.08</td>
<td>1.01</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>1.50</td>
<td>1.52</td>
<td>1.52</td>
</tr>
<tr>
<td>Inner diameter/outer diameter</td>
<td>0.61</td>
<td>0.71</td>
<td>0.66</td>
</tr>
<tr>
<td>Thread depth</td>
<td>0.29</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>Thread pitch</td>
<td>0.61</td>
<td>0.67</td>
<td>0.66</td>
</tr>
<tr>
<td>Apical facing angle (degree)</td>
<td>35.00</td>
<td>34.00</td>
<td>32.00</td>
</tr>
<tr>
<td>Coronal facing angle (degree)</td>
<td>17.00</td>
<td>15.00</td>
<td>14.00</td>
</tr>
</tbody>
</table>

![Figure 4. The dimensions of microimplant.](image4)
Table 2 shows a summary of the IT, RF, and RT values, and Table 3 presents the results of the Tukey HSD post comparison tests for the intergroup comparison. In the vertical test (Figure 5), the ITs of Type C (7.8 Ncm) and Type B (7.5 Ncm) were significantly higher ($p < 0.0001$) than that of Type A (4.4 Ncm). Moreover, the RFs of Type C (11.5 kHz) and Type A (10.2 kHz) were significantly higher ($p = 0.005$) than that of Type B (7.5 kHz). In addition, the RTs of Type C (7.4 Ncm) and Type B (7.3 Ncm) were significantly higher ($p < 0.0001$) than that of Type A (4.1 Ncm).

In the horizontal test (Figure 6), the IT of Type C (6.4 Ncm) was significantly higher ($p = 0.028$) than that of Type A (5.0 Ncm). The RFs of the three types were as follows: Type A, 9.8 kHz; Type C, 8.4 kHz; and Type B, 7.5 kHz. No significant differences in RF were observed in the intergroup comparison ($p = 0.160$). The RT of Type C (6.6 Ncm) was significantly higher ($p = 0.036$) than that of Type A (4.7 Ncm).

In the intragroup comparison, Spearman’s rank correlation test (Table 4) revealed no significant correlations among the IT, RF, and RT values in both the vertical and horizontal tests. Therefore, the proposed null hypothesis was accepted.

### Table 2
Resonance frequency (kHz), insertion torque (Ncm), and pullout strength (Ncm) analysis of microimplants.

<table>
<thead>
<tr>
<th>Microimplant</th>
<th>IT Mean</th>
<th>IT SD</th>
<th>RF Mean</th>
<th>RF SD</th>
<th>RT Mean</th>
<th>RT SD</th>
</tr>
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<tbody>
<tr>
<td>Vertical</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Type A</td>
<td>4.4</td>
<td>0.56</td>
<td>10.2</td>
<td>1.65</td>
<td>4.1</td>
<td>0.43</td>
</tr>
<tr>
<td>Type B</td>
<td>7.5</td>
<td>0.79</td>
<td>7.5</td>
<td>0.49</td>
<td>7.3</td>
<td>1.17</td>
</tr>
<tr>
<td>Type C</td>
<td>7.8</td>
<td>0.80</td>
<td>11.5</td>
<td>2.05</td>
<td>7.4</td>
<td>0.80</td>
</tr>
<tr>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>5.0</td>
<td>0.27</td>
<td>9.8</td>
<td>2.66</td>
<td>4.7</td>
<td>1.40</td>
</tr>
<tr>
<td>Type B</td>
<td>6.1</td>
<td>1.17</td>
<td>7.5</td>
<td>0.91</td>
<td>6.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Type C</td>
<td>6.4</td>
<td>0.55</td>
<td>8.4</td>
<td>1.11</td>
<td>6.6</td>
<td>0.55</td>
</tr>
</tbody>
</table>

IT = insertion torque; RF = resonance frequency; RT = removal torque; SD = standard deviation.

### Table 3
Statistical significance ($p < 0.05$) of intergroup in the Tukey HSD post comparison.

<table>
<thead>
<tr>
<th></th>
<th>Vertical</th>
<th></th>
<th>Horizontal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td></td>
<td>$p &lt; 0.0001$; C &gt; A, B &gt; A</td>
<td>$p = 0.028$; C &gt; A</td>
<td></td>
</tr>
<tr>
<td>RF</td>
<td></td>
<td>$p = 0.005$; C &gt; B, A &gt; B</td>
<td>$p = 0.160$</td>
<td></td>
</tr>
<tr>
<td>RT</td>
<td></td>
<td>$p &lt; 0.0001$; C &gt; A, B &gt; A</td>
<td>$p = 0.036$; C &gt; A</td>
<td></td>
</tr>
</tbody>
</table>

A = Type A; B = Type B; C = Type C; IT = insertion torque; RF = resonance frequency; RT = removal torque.
and demonstrated a tendency to increase from the cemento¬
toenamel junction to the apex in both jaws. To prevent or-
thodontic microimplants from contacting the teeth or
damaging periodontal membrane tissue, each microimplant
was inserted at least 0.5-mm away from the adjacent roots.
Therefore, in the present study, we selected 1.5-mm diam-
eter microimplants.

When a screw is inserted into the bone, the continuous
resistance force created between the bone and the screw is
referred to as the IT. Brown et al. [13] found that stainless
steel miniscrews had significantly higher IT levels,
compared with those made of titanium alloy. In the present
study, the IT of Type B was significantly higher than that of
Type A, but not significantly different from that of Type C.
Yoo et al. [14] studied the shape of minimplants and
determined that the IT of tapered minimplants was
significantly higher than that of cylindrical miniimplants.
However, they reported that success rates of these two
types of miniimplants were similar. Similarly, in the present
study, the IT of Type B (tapered shape) was significantly
higher than that of Type A (cylindrical shape), but not
significantly different from that of Type C (cylindrical shape).

In the present study, the inner/outer diameter ratios of
the microimplants are outlined as follows: Type B, 0.71;
Type C, 0.66; and Type A, 0.61. We observed that a higher
inner/outer diameter ratio could lead to a higher IT.
Regarding the application of both vertical and horizontal
forces, the IT of Type A was significantly lower than those of
Type B and Type C. In terms of thread design, Type A
demonstrated the highest thread depth, lowest thread
inner diameter, and lowest inner/outer diameter ratio,
compared with the other two types used in this study. The
apical facing angle of the Type A screw was the widest
among the three types, implying that the resistance expe¬
rienced during implant insertion was relatively low. The
thread depth and thread pitch diameter of the Type B and
Type C screws were similar, whereas the apical facing angle
of the Type C screw was narrower than that of Type B. Hence,
Type C exhibited a higher IT than did Type B. To summa¬
ize the preceding results, the IT is correlated with the
thread inner diameter, inner/outer diameter ratio, and
apical face angle.

Since 1998, several reports have revealed that RF
analysis is a reliable and noninvasive method of detecting
the stability of dental implants [8–10]. Therefore, RF
analysis is also an efficient and safe method of assessing
the primary stability of orthodontic microimplants. Inter¬
group comparisons reveal that the RFs of Type C (11.5 kHz)
and Type A (10.2 kHz) were significantly higher than that
of Type B (7.5 kHz) in the vertical test. In the horizontal
test, despite the lack of significant differences, the RFs of
Type A (9.8 kHz) and Type C (8.7 kHz) were higher than
that of Type B (7.5 kHz). Furthermore, our results suggest
that the inner/diameter ratio could affect the RF level. Type
B had the highest inner/outer diameter ratio and lowest thread depth. Hence, Type B demonstrated the least anchorage on the artificial bone, thereby affecting its RF level.

Regarding the RT in both the vertical and horizontal di¬
rections, all the microimplants demonstrated a perfor¬
ance level similar to that observed for the IT. In other
words, the RT of Type A was lower than those of Type B and
Type C in both the vertical and horizontal directions. A
lower thread inner diameter and inner/outer diameter
ratio may imply lower resistance during RT. Notably, the
conical facing angle of Type A was also wider than those of
Type B and Type C. Because the RT involves anticlockwise
rotation, a wider coronal facing angle necessitates a lower
strength for RT. In our study, the Type B microimplants
were made of stainless steel and were tapered in shape,
whereas the Type A and Type C microimplants were made
of titanium alloy and had a cylindrical shape. Therefore,
there is still controversy that mechanical forces (IT, RF, and
RT) depend upon the material composition and shape of
orthodontic microimplants. Nienkemper et al. [15] reported
that no significant correlation existed between the IT and
RF. In the correlation analysis of the present study, the IT,
RF, and RT were not significantly correlated in both the
vertical and horizontal directions; therefore, our results
are consistent with those of Nienkemper et al. [15]. This
implies that the IT cannot be used to infer the RF (primary
stability), and similarly, the RF cannot be used to infer the
RT. The lack of a significant correlation between the IT and
RT indicates that the application of a higher force during
insertion does not necessitate a larger force during micro¬
implant removal. The findings of our study reveal that a
lower inner/outer diameter ratio accompanied by a wider
apical facing angle may reduce the IT and serve an energy¬
saving method for the placement of microimplants.
Furthermore, a lower inner/outer diameter ratio accompa¬
nied by a wider coronal facing angle may reduce the RT
and serve as an energy-saving method for the removal of
microimplants. However, the RF was still unaffected by the
design of threads.

In conclusion, Type A exhibited the lowest inner/outer
diameter ratio and the widest apical facing angle, leading
to the lowest IT and a higher RF values, compared with the

<table>
<thead>
<tr>
<th>Microimplants</th>
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<th>Type B</th>
<th>Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT vs. RF</td>
<td>0.300</td>
<td>0.000</td>
<td>−0.205</td>
</tr>
<tr>
<td>RF vs. RT</td>
<td>0.821</td>
<td>0.460</td>
<td>−0.300</td>
</tr>
<tr>
<td>IT vs. RT</td>
<td>0.051</td>
<td>−0.410</td>
<td>−0.564</td>
</tr>
</tbody>
</table>

IT = insertion torque; RF = resonance frequency; RT = removal torque.
two other microimplants used in this study. The detailed dimensions of microimplants, including the inner diameter, inner/outer diameter ratio, thread pitch, thread depth, and apical as well as coronal face angles, are critical factors affecting their mechanical strength.

Acknowledgments

This work was partially supported by a grant (KMUH99-9M30) from Kaohsiung Medical University Hospital, Taiwan.

References