Insertion Torques of Self-Drilling Mini-Implants in Simulated Mandibular Bone: Assessment of Potential for Implant Fracture

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Purpose: Fracture of orthodontic mini-implants during insertion is a limiting factor for their clinical success. The purpose of this study was to determine the fracture potential of commonly used self-drilling orthodontic mini-implants when placed into simulated thick, dense mandibular bone. 

Methods: Six mini-implant systems were assessed for the potential for fracture (Aarhus, Medicon; Dual-Top, Jeil Medical; OrthoEasy, Forestadent; tomas-pin, Dentaurum; Unitek, 3M; and VectorTAS, Ormco). First, mini-implants were inserted manually, without predrilling, into bone substitutes (Sawbones) with a 3-mm-thick, dense (1.64 g/cm²) cortical layer. A custom-made insertion device was used for placement of mini-implants. A six-axis force/torque transducer was secured at the base of the bone blocks to measure the maximum torque experienced during insertion. Measured insertion torques were compared with previously reported fracture torques, yielding a torque ratio (insertion torque as a percentage of fracture torque), which was used as an indicator of the potential for mini-implant fracture. 

Results: Significant differences in torque ratios were found among all mini-implants, except between OrthoEasy and Dual-Top, and OrthoEasy and VectorTAS. Overall, Aarhus had the highest torque ratio (91% ± 3%), with Unitek showing the lowest ratio (37% ± 3%). Aarhus and tomas-pin mini-implants displayed torque ratios ≥ 75% upon insertion and experienced fracture upon insertion. When the manufacturer’s specific predrilling recommendations were followed, no changes in torque ratio were found for Aarhus and tomas-pin. However, while Aarhus continued to fracture upon insertion, all tomas-pin mini-implants were inserted fully without fracture following predrilling.

Conclusion: These findings support the safe use of Unitek, VectorTAS, Dual-Top, and OrthoEasy self-drilling mini-implants in areas of 3-mm-thick, 1.64 g/cm² dense cortical bone without predrilling. Following predrilling, fractures did not occur with tomas-pin. For implants that continued to fracture after predrilling, other strategies may be required, such as the use of larger-diameter mini-implants in thick, dense bone conditions.

Keywords: fracture potential, insertion torque, mandibular bone, orthodontic mini-implants, predrilling, self-drilling
during insertion, and is defined as the torque required to overcome the frictional force between the mini-implant and bone. Depending on the magnitude of this force relative to the torsional strength of the mini-implant, fracture of the mini-implant can occur during insertion.

A previously published study by the present group of authors investigated the fracture resistance of commonly used manufacturer mini-implants inserted into a Plexiglas material. The study aimed to test all mini-implants to fracture, and identify their maximum insertion torques experienced just prior to fracture. The results provided information on the torque limit for each of the mini-implants, which could be used in future assessments of mini-implant fracture potential. All mini-implants in the study showed variations in their torque limits, which were dependent on the specific design of the mini-implant.

When comparing the designs of mini-implants, studies have shown that self-drilling (versus self-tapping) designs experience increased risk of mini-implant fracture. In particular, self-drilling mini-implant designs are described to cause increased contact pressure and resistance upon insertion. These increases are believed to be due to the absence of a predrilled pilot hole prior to insertion, thereby creating more intimate contact between the bone and mini-implant surface during screw advancement. While intimate contact is advantageous for improved mini-implant stability, it also increases the frictional forces experienced during insertion. Additionally, in demanding bone conditions of high density and thickness, the frictional force and stress concentration at the mini-implant surface will further increase, thereby increasing the risk of mini-implant fracture. Despite this, self-drilling insertion remains the technique of choice based on a 2008 American Association of Orthodontics (AAO) survey of 564 orthodontists, where 58% reported that they never predrilled a pilot hole prior to mini-implant placement. Although this one-step procedure is convenient, the potential for fracture of self-drilling mini-implants may limit their clinical success, and lead to increased patient morbidity during surgical retrieval of the fractured segment.

Self-drilling mini-implants inserted into areas of dense bone, such as the mandibular posterior region and midpalate of an adult, have been shown to experience insertion torques that approach their torques at fracture. As such, authors have suggested that there may be a benefit to predrilling in these regions, to decrease the frictional forces and the chance of fracture of the self-drilling mini-implant. However, when manufacturers’ pamphlets and product guides were examined for guidance on the placement of self-drilling mini-implants into regions of thick, dense cortical bone, there was ambiguity and variability in recommendations for predrilling.

Considering the influence of screw design and bone properties on the potential for mini-implant fracture, it is important to fully understand the risks associated with placement of various self-drilling mini-implants into regions of thick, dense cortical bone. There remains uncertainty with regard to drilling prior to placement of self-drilling mini-implants into these clinically challenging bone regions. Such information would help clinicians avoid complications associated with mini-implant fracture, such as surgical removal of the embedded screw portion or recurrent evaluation of the fractured stump if left in situ. Therefore, the purpose of this study was to determine the fracture potential of commonly used self-drilling orthodontic mini-implants when inserted into simulated bone with a thick, dense cortical layer. In addition, for mini-implants with high fracture potential, this study aimed to verify individual manufacturers’ predrilling recommendation for safe insertion into these regions.

**MATERIALS AND METHODS**

A total of 60 (n = 10 per group) self-drilling orthodontic mini-implants from six manufacturers (Aarhus, Medicon; Dual-Top, Jeil Medical; OrthoEasy, Forestadent; tomas-pin, Dentaurum; Unitek, 3M; and VectorTAS, Ormco) were investigated (Fig 1). The characteristics of each group are summarized in Table 1.

For assessment of insertion torques, all mini-implants were manually inserted into artificial bone blocks (2 × 4 × 17 cm; Sawbones, Division of Pac ific Research Laboratories), chosen to ensure standardized, reproducible testing (Fig 2). The bone blocks were custom-made by Sawbones to simulate the cortical and cancellous layers found in the posterior interradicular sites and retromolar regions of the mandible. The cortical layer consisted of a 3-mm sheet of short fiber-filled epoxy (density: 1.64 g/cm³; Sawbones product number 3401-02), which was laminated onto the simulated cancellous layer of cellular rigid polyurethane foam (density: 0.32 g/cm³; Sawbones product number 1522-12). Mini-implants were inserted at 10-mm intervals along the length of the bone block, in accordance with the standards of the American Society for Testing and Materials (ASTM).

A custom-designed device was used for insertion of all mini-implants (Fig 3). The insertion device consisted of a universal screwdriver supported by a stabilizing arm. The screwdriver was modified to adapt to a drill chuck, which secured the mini-implant specific driver adaptors. The stabilizing arm was specifically designed to support the screwdriver shaft and prevent oblique forces during manual screw insertion. This allowed the mini-implants to be inserted vertically, without introducing off-axis loading along the length of the mini-implants.
Fig 1  Mini-implants used for insertion torque assessments. All mini-implants were 8 mm in length. (a) Unitek, (b) Aarhus, (c) OrthoEasy, (d) Dual-Top, (e) VectorTAS, and (f) tomas-pin.

Fig 2  (above)  Mini-implants inserted into simulated bone with a thick, dense cortical layer. Five OrthoEasy mini-implants inserted into the synthetic bone block with 3-mm-thick, 1.64 g/cm² dense cortical layer. All mini-implants were inserted up to the level of full screw thread engagement within the bone.

Fig 3  (right) Custom insertion device. (a) Testing apparatus used for mini-implant insertion. (b) VectorTAS mini-implant during manual insertion, engaged by its manufacturer-supplied driver adaptor secured within the drill chuck.

For measurement of insertion torques, a multiaxis load cell (6DOF, Advanced Mechanical Technology) was attached to the base of the bone blocks using an aluminum fixture (Fig 3). The fixture was designed to secure the bone blocks directly above the load cell, ensuring that the mini-implant insertion site was always positioned at the center of the load cell. The load cell measured the torque generated during screw insertion, and the associated software program (Instron WaveMatrix Software, Instron) recorded the real-time insertion torque generated during screw advancement. All mini-implants were inserted in a clockwise direction at a rate of approximately 20 revolutions per minute (RPM), replicating the typical clinical technique, and the maximum torque values reached during mini-implant insertion were identified.

To assess the fracture potential of the mini-implants inserted into thick, dense cortical bone, individual maximum insertion torques were directly compared with predetermined fracture torque values for all mini-implants, and a resultant torque ratio was calculated (Equation 1). This torque ratio described the tendency for the insertion torque of the mini-implants to approach the predetermined fracture torque values. Higher torque ratios were indicative of higher potential for implant fracture. The predetermined fracture torques of the various mini-implants were acquired from a study previously published by the present group of authors, where identical mini-implants were tested to fracture using a similar testing apparatus and Plexiglas as the insertion medium.

Table 1  Description of Self-Drilling Mini-Implants Used in This Study

<table>
<thead>
<tr>
<th>Type</th>
<th>Distributor</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unitek</td>
<td>3M Unitek</td>
<td>1.8</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>Aarhus</td>
<td>American Orthodontics</td>
<td>1.5</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>OrthoEasy</td>
<td>Forestadent</td>
<td>1.7</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>Dual-Top</td>
<td>Rocky Mt. Orthodontics</td>
<td>1.6</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>VectorTAS</td>
<td>Ormco</td>
<td>1.4</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>tomas-pin</td>
<td>Dentaurum</td>
<td>1.6</td>
<td>8</td>
<td>Ti-6Al-4V</td>
</tr>
</tbody>
</table>
RESULTS

The fracture potential, based on torque ratios associated with mini-implant insertion into simulated thick, dense cortical bone, varied among manufacturers’ self-drilling designs (Table 2; Fig 4). Among the mini-implants tested, Aarhus and tomas-pin showed torque ratios greater than 75%. In addition to falling above the predefined criteria for further testing, five of the 10 tomas-pin mini-implants, and all 10 Aarhus mini-implants, fractured prior to full insertion into the synthetic bone blocks without predrilling. Aarhus mini-implants consistently fractured approximately 3 to 4 mm into the threaded portion of their implant body, while tomas-pin mini-implants fractured at varying levels (Fig 5).

Significant differences in torque ratios among all mini-implants were found, with the exception of OrthoEasy and Dual-Top (P > .05), and OrthoEasy and VectorTAS (P > .05). Overall, Unitek mini-implants showed the lowest torque ratio (37% ± 3%) when inserted into 3-mm-thick, 1.64 g/cm³ dense cortical bone blocks, whereas Aarhus had the highest torque ratio (91% ± 3%) among the group (Fig 4).

When manufacturer recommendations were followed for tomas-pin mini-implants, no significant change was found in the torque ratio with or without predrilling (P > .05; with predrilling: 77% ± 5%; without predrilling: 76% ± 8%; Table 3). Despite this result, all tomas-pin mini-implants experienced complete insertion into the predrilled pilot holes, and torque ratios found (prerdmed: 93% ± 5%) were similar to those observed without predrilling (91% ± 3%; P > .05; Table 3).

Table 2  Calculated Torque Ratio (Mean ± SD) for Each Mini-Implant Inserted into Simulated Thick, Dense Cortical Bone, Based on Measures of Maximum Insertion Torque During Placement (Mean ± SD) and Predetermined Fracture Torque Values

<table>
<thead>
<tr>
<th>Implant type</th>
<th>No. of implants tested</th>
<th>No. of implants fractured</th>
<th>Maximum insertion torque (Ncm)</th>
<th>Fracture torque (Ncm)</th>
<th>Torque ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unitek</td>
<td>10</td>
<td>0</td>
<td>26.9 ± 2.4</td>
<td>72.1</td>
<td>37 ± 3</td>
</tr>
<tr>
<td>Aarhus</td>
<td>10</td>
<td>10</td>
<td>22.8 ± 0.7</td>
<td>58.1</td>
<td>91 ± 3</td>
</tr>
<tr>
<td>OrthoEasy</td>
<td>10</td>
<td>0</td>
<td>16.2 ± 2.1</td>
<td>27.6</td>
<td>59 ± 8</td>
</tr>
<tr>
<td>Dual-Top</td>
<td>10</td>
<td>0</td>
<td>17.2 ± 1.9</td>
<td>31.6</td>
<td>54 ± 6</td>
</tr>
<tr>
<td>VectorTAS</td>
<td>10</td>
<td>0</td>
<td>19.0 ± 1.0</td>
<td>30.8</td>
<td>62 ± 3</td>
</tr>
<tr>
<td>tomas-pin</td>
<td>10</td>
<td>5</td>
<td>27.6 ± 3.0</td>
<td>41.6</td>
<td>77 ± 8</td>
</tr>
</tbody>
</table>

Fracture torque values for the manufacturer-specific mini-implants were obtained from a previously published study by Smith et al.8

Torque ratio was calculated from the maximum insertion torque as a percentage of fracture torque for each of the mini-implants. Higher torque ratios were indicative of higher potential for mini-implant fracture.

Fracture potential of the mini-implants tested. Differences in fracture potential, as identified from individual torque ratios, were found among all mini-implants (P ≤ .05), except between OrthoEasy and Dual-Top (P > .05), and OrthoEasy and VectorTAS (P > .05). Unitek showed the least fracture potential (P ≤ .001), while Aarhus showed the greatest fracture potential (P ≤ .001). Both Aarhus and tomas-pin showed torque ratios greater than 75%, which coincided with observations of screw fracture (F) upon insertion into the simulated bone blocks.
DISCUSSION

Self-drilling mini-implants have become well accepted in orthodontic practice, due to their minimal invasiveness, straightforward surgical procedure, and ease of chairside placement for both the patient and clinician during routine orthodontic appointments.1 While predrilled pilot holes are not a requirement, there may be some advantage to predriiling in areas of thick, dense cortical bone. Previous research has found that insertion torques of self-drilling mini-implants inserted into these regions gradually approach their respective torque values at fracture.9,11,13 However, since fracture torques vary among manufacturers,8,10,16,29 any assessment of fracture potential must be specific to mini-implant type. An understanding of these risks is important for clinicians when placing mini-implants into regions with unyielding conditions, such as the posterior mandible or midpalatal region of the maxilla.8,16,30 These regions are concerning since there are limited options available if mini-implant fracture occurs.24 The compromised mini-implant can be retrieved surgically, but this option is dependent on the fracture site and patient consent, and involves risking trauma to surrounding vital structures such as tooth roots and periodontal ligament.5,24 Conversely, the fractured stump can be left in situ, but regular clinical evaluation is required for monitoring further possible complications.24 Considering these clinical difficulties associated with mini-implant fracture, it is necessary to determine the probability of its occurrence in regions of thick, dense bone. As such, this in vitro study aimed to investigate the fracture potential of self-drilling mini-implants inserted into thick, dense cortical bone, and to determine whether manufacturers’ recommendations for predrilling in these areas reduce the possibility for fracture.

Fracture potential of mini-implants can be assessed by comparing their insertion torques to their fracture torques.31 The proximity of these two measures reflects the potential for mini-implant fracture. In the present study, a custom-defined torque ratio was used to quantify the fracture potential of the various mini-implants tested. This torque ratio was calculated as the percentage of the mini-implant’s insertion torque relative to its predetermined fracture torque. Implant-specific fracture torques were determined in a study previously published by the present group of authors, where the same types of mini-implants were inserted into a Plexiglas material and tested to fracture.8 Whereas the previous study identified baseline fracture torques for each mini-implant design, the current study used those fracture torques and directly compared them with the insertion torques measured during placement into simulated thick, dense bone. The ratio of insertion torque to fracture torque was used as a predictor of mini-implant fracture, where higher torque ratios were indicative of a higher probability of fracture.

The results of this study found that Unitek, OrthoEasy, Dual-Top, and VectorTAS all had torque ratios that were less than 65%, and experienced no fractures, when placed into the simulated thick, dense cortical bone. Within this group, Unitek experienced the lowest torque ratio among all the mini-implants tested. In comparison, Aarhus and tomas-pin mini-implants both experienced fracture and

Table 3 Fracture Results and Torque Ratios (Mean ± SD) for Aarhus and tomas-pin Mini-implants with and without Manufacturer Predrilling Recommendations

<table>
<thead>
<tr>
<th></th>
<th>Aarhus</th>
<th></th>
<th></th>
<th>tomas-pin</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Implants tested</td>
<td>No. of implants fractured</td>
<td>Torque ratio (%)</td>
<td>No. of implants fractured</td>
<td>Torque ratio (%)</td>
</tr>
<tr>
<td>Without predrilling</td>
<td>10</td>
<td>10</td>
<td>91 ± 3</td>
<td>5</td>
<td>76 ± 8</td>
</tr>
<tr>
<td>With predrilling</td>
<td>10</td>
<td>9</td>
<td>93 ± 5</td>
<td>0</td>
<td>77 ± 5</td>
</tr>
</tbody>
</table>

No changes in torque ratios (P > .05) were observed when manufacturer recommendations were followed for both Aarhus and tomas-pin mini-implants. However, while nine of the 10 Aarhus mini-implants continued to fracture following manufacturer recommendations, all tomas-pin mini-implants were fully inserted without fracture.

Fig 5 Fracture of Aarhus and tomas-pin mini-implants without predrilling. (a) Aarhus consistently fractured approximately 3 to 4 mm into the threaded portion of its implant body, while (b) tomas-pin fractured at varying levels.
torque ratios greater than 75%, falling into the study criteria for further testing with manufacturer-specific predrilling recommendations. The difference in these torque ratios among mini-implants is believed to be dependent on the design specifications of their respective screw bodies, since all mini-implants were reported to be manufactured with similar titanium alloy material.

Visual inspection of the fractured Aarhus and tomas-pin mini-implants found that Aarhus consistently fractured within the thickest portion of its threaded cylindrical body, while tomas-pin experienced fractures at various levels, including the tapered tip. Although fracture potential is influenced by the properties of the bone that the mini-implant is being inserted into (ie, quantity and quality), which affects the insertion torques experienced, the response of the mini-implant to those values is reliant on the distribution of those forces (stresses) along the screw’s body.33 Depending on the design and specific geometry of the screw body, the distribution of the forces can vary. As such, observation of region-specific fractures with Aarhus and tomas-pin mini-implants is likely explained by their difference in screw geometries, where initiation of fractures is specific to the mini-implant body design.

The effect of the screw-bone interface mechanics on mini-implant fracture potential may also explain the results observed during follow-up testing with predrilling manufacturer recommendations. Results found no influence of predrilling on the torque ratios for Aarhus and tomas-pin mini-implants inserted into thick, dense cortical bone. While predrilling is expected to reduce the contact between the bone and screw surface during insertion, the diameter of the predrilled pilot hole is still expected to fully engage the screw threads upon insertion. As such, the rotational frictional forces at the screw-bone interface may not be reduced by creating a clearance path for screw insertion. With no change in frictional force (insertion torque), torque ratios remain unaltered.

When comparing the guidelines provided by each of the manufacturers, Unitek, Dual-Top, and VectorTAS did not recommend predrilling of pilot holes.21–23 However, VectorTAS suggested the use of its 2-mm-diameter mini-implant in areas of thick cortical bone.22 Although OrthoEasy recommended that the cortical bone be perforated “if the thickness of the corticalis is greater than 1.5 mm,”19 its torque ratio during insertion into 3-mm-thick cortical bone (58.8%) was below the predefined threshold (≥ 75%), and no fracture was observed for further testing.

For regions of thick cortical bone such as in the posterior mandible, tomas-pin recommended using its supplied pilot drill to perforate the cortical bone for placement of self-drilling mini-implants.18 Although there was no change in torque ratio of tomas-pin mini-implants following the manufacturer’s predrilling recommendations (non-perforated: 76%; perforated: 77%), all 10 mini-implants were able to be inserted without fracture, in contrast to their placement without perforation. Perforation created a clearance path for mini-implant advancement through the thick, dense cortical bone, thereby reducing the compressive forces at the screw tip. Since tomas-pin was found to fracture at various levels, including the screw tip, the authors believe these compressive forces play a significant role in compromising the fracture safety of the tomas-pin mini-implants. However, future studies will be needed to confirm the influence of compressive forces on the fracture potential of mini-implants.

When Aarhus’ manufacturer recommendations for predrilling in cases of thick cortical bone20 were followed, no change in torque ratio was found, and nine of the 10 mini-implants continued to fracture within the screw body region. This may be due to Aarhus’ specific screw body design/geometry, which is unable to resist the torsional forces generated at the screw-bone interface upon insertion into thick, dense cortical bone. Predrilling would have created a clearance for insertion, but the frictional force (ie, insertion torque) resulting from engagement of the screw threads would remain unaltered. Since the screw body geometry influences the stress distribution within the implant, it seems valid that the mini-implant would continue to fracture at a consistent level within the screw body. One such important geometrical factor that dictates the fracture risk of mini-implants is screw diameter. Barros et al31 found that incremental increases of 0.1 mm in screw diameter were associated with significant reductions in fracture risk of mini-implants. Taking this into consideration, it is advised that clinicians utilize the 2.0-mm-diameter Aarhus mini-implants, in lieu of the 1.5-mm-diameter, in areas of thick (ie, 2 mm or more), dense cortical bone.

The simulated bone used in this study was chosen to replicate the demanding bone conditions of the posterior mandible.26,28,34–36 Previous studies have reported mandibular cortical bone thickness ranging between 1.6 and 3.0 mm26,28,35,36 and cortical bone densities falling within the range of 1.7 to 2.0 g/cm3.28 As such, simulated bone with a 3-mm-thick, 1.64 g/cm3 dense cortical bone layer was used to represent the extreme end of the range of bony conditions found in the mandible. The material and mechanical properties of artificial bone blocks have been reported in the literature37–39 and have been found to closely match those of real bone.37 These blocks were useful for replicating the compact bone characteristics of the interradicular and retromolar regions of the posterior mandible, but it is necessary to reiterate that they were not representative of the average properties of all bone encountered in the oral cavity. As such, results found in this study were specific to the morphology and material properties of the simulated bone used, and are not an indication of the overall clinical success of the respective self-drilling mini-implants.
CONCLUSIONS

The findings from this study suggest that Unitek, VectorTAS, Dual-Top, and OrthoEasy self-drilling mini-implants can be safely inserted into simulated bone with a 3-mm-thick, 1.64 g/cm³ dense cortical layer, and experience torque ratios of less than 65%. Incorporating manufacturers’ recommendations for predrilling of Aarhus and tomas-pin mini-implants did not alter their torque ratio values, but all tomas-pin mini-implants were able to be successfully inserted without fracture. While predrilling may create a clearance path for the insertion of self-drilling mini-implants, it does not affect the insertion torque generated. Therefore, other factors such as screw design may be more influential in reducing implant fracture associated with the placement of self-drilling mini-implants into thick, dense bony regions, such as that found in the mandible. Considering this, it may be beneficial to use the 2-mm-diameter (versus 1.5-mm-diameter) Aarhus mini-implant in these extreme bone conditions to reduce the risk of mini-implant fracture.

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