*Original Article*

# Fracture resistance of commonly used self-drilling orthodontic mini-implants

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**ABSTRACT**
**Objective:** To investigate the fracture resistance of six commonly used self-drilling orthodontic mini-implants by comparing their respective fracture torques during insertion.
**Materials and Methods:** Ninety self-drilling mini-implants from six manufacturers (Aarhus, Dual-Top, OrthoEasy, Tomas-pin, Unitek, and VectorTAS), with diameters ranging from 1.4 to 1.8 mm, were inserted into acrylic blocks using a custom-made insertion device. Insertion torques were measured using a 6-degree-of-freedom load cell fixed to the base of the acrylic blocks, and peak torques experienced at the time of fracture for each of the mini-implants were recorded. One-way analysis of variance ($\alpha = .05$) was used to compare the fracture torques among the six different groups.
**Results:** Statistical analysis revealed significant differences ($P < .05$) in the peak fracture torques among mini-implant groups. Mean fracture torques ranked as follows: Unitek (72 Ncm) > Tomas-pin (36 Ncm) > Dual-Top (32 Ncm) ≈ VectorTAS (31 Ncm) > OrthoEasy (28 Ncm) > Aarhus (25 Ncm), with significant differences found between all manufacturers, except for Dual-Top and VectorTAS.
**Conclusions:** Mini-implants tested showed a wide range of torque at fracture depending on the manufacturer, with only a weak correlation between mini-implant diameter and fracture resistance. This torque should be considered at the time of mini-implant insertion to minimize the risk of implant fracture, especially in areas of high-density bone without predrilling. (*Angle Orthod.* 2015;85:26–32.)

**KEY WORDS:** Orthodontics; Miniscrew; Mini-implant; Temporary anchorage device; Insertion torque; Fracture torque

## INTRODUCTION

The use of mini-implants as temporary anchorage devices has become a valuable component of orthodontic treatment. They are an adjunctive device that can be inserted into specific intraoral bony structures, to provide a form of anchorage whose purpose is to prevent unwanted tooth movements. Mini-implants have expanded treatment possibilities by decreasing dependence on patient compliance, reducing unwanted tooth movements, and facilitating previously unattainable or difficult tooth movements.[1–4]

As the use of mini-implants becomes more popular, there has been a heightened focus on factors that contribute to their success. Failure rates are reported in the literature to range from 6% to as high as 30%.[5] Mini-implant fracture during placement or removal is one such reported complication associated with mini-implants. Human and animal studies have reported fracture rates of approximately 4%–5%,[6–8] but there are very few studies reporting how often mini-implants fracture in the clinical setting. However, recent surveys exploring orthodontists' experiences with mini-implant placement found that 10%–20% of clinicians reported having experienced mini-implant fracture during placement, surpassing even the rate of root damage reported at 4%–6%.[6,9,10]

It is well established that adequate primary stability, as measured by insertion torque, is required for the survival of orthodontic mini-implants.[11–13] At the same

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time, the fracture of a mini-implant is correlated with excessively high torque values generated upon insertion or removal.[6,14–17] Depending on the height at which the mini-implant fractures, removal of the screw fragment embedded in the cortical bone can be difficult. Surgical exposure of the site with a full-thickness flap must be made, and subsequent removal of bone around the implant using a trephine bur may be required to gain proper access to the fractured segment.

Currently, mini-implants are available in a variety of sophisticated head designs, body shapes, sizes (lengths and diameters), material compositions, and thread designs, all of which offer multiple options when deciding on the system best suited for a clinician or specific application but can also influence the fracture resistance of mini-implants.[15–21] Where original mini-implant designs allowed for self-tapping placement in a predrilled pilot hole, manufacturers are more recently promoting the advancement of self-drilling mini-implants, for which placement is carried out in a one-step procedure, obviating the need for predrilling. Orthodontists have shown a strong preference for the self-drilling design, as most report never drilling a pilot hole prior to mini-implant placement.[22] However, the drawback to drill-free placement is the increased placement torque generated (due to more intimate metal-to-bone contact), resulting in an increased fracture risk on insertion, particularly in areas of thick cortical bone.[14,20,23,24]

Fracture testing has shown high variability among manufacturer mini-implants. Wilmes et al.[16] compared 10 manufacturer-specific mini-implants and showed that fracture torque values ranged from 10.9 Ncm to 64.1 Ncm. Similarly, Whang et al.[15] demonstrated fracture torque values ranging between 6.5 Ncm and 30.9 Ncm, depending on the manufacturer tested. Because there is such variability among manufacturers, and fracture torques can fall within the range of clinical placement torques,[12,14] it is important for clinicians to know the fracture resistance of their preferred mini-implant.

Therefore, the purpose of this in vitro investigation was to compare the peak fracture torque values of six commonly used self-drilling mini-implants using a standardized measurement system.

## MATERIALS AND METHODS

A total of 90 (n = 15 per group) self-drilling orthodontic mini-implants from six international manufacturers (Aarhus, Medicon, Tuttlingen, Germany; Dual-Top, Jeil Medical Corporation, Seoul, Korea; OrthoEasy, Forestadent, Pforzheim, Germany; Tomas-pin, Dentaurum, Turnstrasse, Ispringen, Germany; Unitek, 3M, Monrovia, Calif; and VectorTAS, Ormco, Glendora, Calif; Figure 1; Table 1) were investigated. An attempt was made to compare mini-implants of similar diameters and lengths, but because of differing manufacturer designs, diameters ranged from 1.4–1.8 mm. Final sizes were ultimately selected to represent the most commonly used mini-implant from each company.

**Figure 1.** Mini-implants used in this study. From left to right: Unitek, Aarhus, OrthoEasy, Dual-Top, VectorTAS, Tomas-pin.

To facilitate fracture testing, a custom-made device was used for manual insertion of the mini-implants, along with a sensor for measurement of insertion torques during placement (Figure 2). The heads of the mini-implants were engaged with their specific manufacturer-provided driver adaptors. The opposite end of the drivers were modified to adapt to a custom-built chuck, connected to a universal driver handle. The device incorporated a stabilizing bar, which was specifically designed to support the driver shaft and prevent oblique forces during manual screw placement. This allowed the mini-implants to be inserted vertically without introducing off-axis loading along the length of the mini-implants.

The mini-implants were inserted into an acrylic material (Plexiglas, Evonik Industries, Germany), which was chosen because of its homogeneity and appropriate stiffness that facilitated consistent fracture of all mini-implants. A total of six rectangular acrylic blocks (2 cm × 4 cm × 17 cm) were cut and prepared. Guide holes of 0.5-mm diameter and 3-mm depth were drilled along the length of the block with 10-mm hole spacing, in accordance with the requirements of the American Society for Testing and Materials standards.[25] These guide holes were used to ensure that all mini-implants were inserted past their tapered tip, and engagement of the threaded region of the cylindrical body was fully established prior to fracture. An aluminum fixture was designed to securely centralize the acrylic block onto a multi-axis load cell (AMTI 6-DOF, Advanced Mechanical Technology Inc, Watertown, Mass) for torque measurements (Figure 2). The load cell and associated software program (Instron WaveMatrix Software, Instron,

**Table 1.** Description of Mini-implants Used in This Study

| Type | Distributor | Diameter | Length | Alloy | Shape |
|---|---|---|---|---|---|
| Unitek | 3M Unitek | 1.8 mm | 8 mm | Ti-6Al-4V | Tapered (4 mm) |
| Aarhus | American Orthodontics | 1.5 mm | 8 mm | Ti-6Al-4V | Cylindrical |
| OrthoEasy | Forestadent | 1.7 mm | 8 mm | Ti-6Al-4V | Cylindrical |
| Dual-Top | Rocky Mt. Orthodontics | 1.6 mm | 8 mm | Ti-6Al-4V | Cylindrical |
| VectorTas | Ormco | 1.4 mm | 8 mm | Ti-6Al-4V | Cylindrical |
| Tomas-pin | Dentaurum | 1.6 mm | 8 mm | Ti-6Al-4V | Cylindrical |

Norwood, Mass) allowed torque measurements during mini-implant insertion.

Mini-implants were manually inserted by a single operator in a clockwise direction into the acrylic material, at a rate of approximately 20–30 RPM (one complete rotation every 2–3 seconds) with a minimum compressive load capable of inducing self-drilling and screw thread engagement. Although insertion speed has been found to have little effect on fracture torques obtained,[15] this rate was chosen to best simulate a typical clinical scenario. The corresponding peak torque value reached at time of fracture was recorded in Ncm (Figure 3). The torque measurement device was calibrated prior to each new group tested.

Descriptive statistics were calculated for the six groups using the Statistical Package for Social Sciences (SPSS version 13.0, SPSS Inc, Chicago, Ill). With the significance level predetermined at $P <$ .05, a one-way analysis of variance (ANOVA) followed by post hoc Tukey's test was used to detect significant differences between manufacturers. Spearman's correlation coefficient was used to evaluate the relationship between implant diameter and fracture torque.

## RESULTS

Peak fracture torques varied significantly among implants from different manufacturers. Descriptive statistics are summarized in Table 2. Among the six groups tested, the Unitek mini-implant had the highest mean torque value (72.07 ± 2.70 Ncm) followed by the Tomas-pin (36.12 ± 3.89 Ncm), Dual-Top (31.89 ± 2.27 Ncm), VectorTAS (30.79 ± 0.69 Ncm), OrthoEasy (27.55 ± 1.02 Ncm), and Aarhus (25.08 ± 0.51 Ncm) mini-implants (Figure 4). Statistical analysis revealed significant differences ($P <$ .05) in the peak fracture torques among all groups tested, except between Dual-Top and VectorTAS ($P =$ .744). Tomas-pin showed the greatest range in fracture torques (29.07–41.13 Ncm [SD, 3.89]), while the Aarhus and VectorTAS were the most consistent (24.2–25.71 Ncm [SD, 0.51] and 29.42–31.82 Ncm [SD, 0.69], respectively). All mini-implants fractured within the threaded portion of the cylindrical body (Figure 5), at or within 1 mm of the level of the acrylic block (Figure 6).

Spearman's correlation coefficient was used to evaluate the relationship between implant diameter and fracture torque. When all six mini-implant groups were included, a weak correlation was found to exist between mini-implant diameter and peak fracture torque ($R =$ .450; $P <$ .01). However, when only cylindrical mini-implants were analyzed (thereby removing the tapered Unitek mini-implant), no correlation was found between fracture torque and mini-implant diameter ($R =$ .035; $P >$ .05).

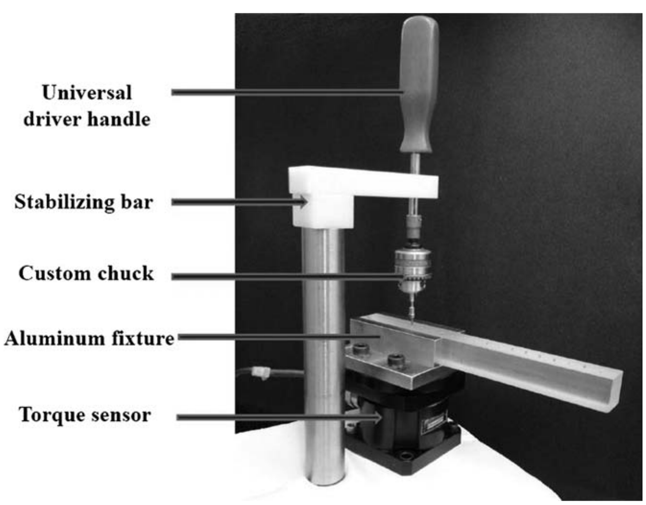


**Figure 2.** Experimental apparatus used for fracture testing.

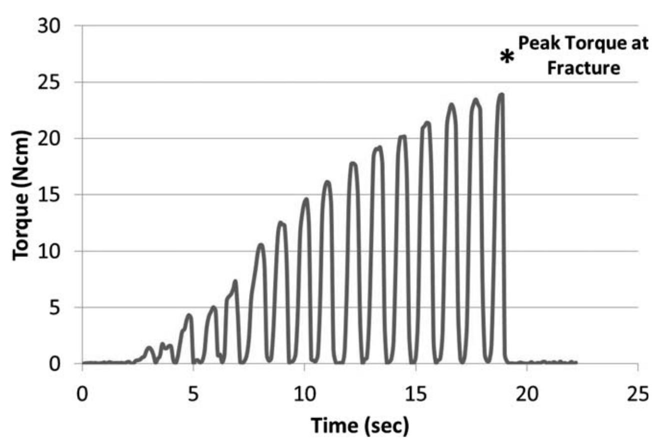


**Figure 3.** A representative graph of insertion torque against time for the Aarhus mini-implant. The asterisk (*) represents the maximum insertion torque just prior to mini-implant fracture.

**Table 2.** Peak Torque Values at Fracture (Ncm) on Insertion Into Acrylic Blocks

| | Unitek | Aarhus | OrthoEasy | Dual-Top[a] | VectorTAS[a] | Tomas-pin |
|---|---|---|---|---|---|---|
| n | 15 | 15 | 15 | 15 | 15 | 15 |
| Mean | 72.07 | 25.08 | 27.55 | 31.89 | 30.79 | 36.12 |
| SD | 2.70 | 0.51 | 1.02 | 2.27 | 0.69 | 3.89 |
| Range | 68.75–78.07 | 24.2–25.71 | 26.45–29.60 | 29.39–37.06 | 29.42–31.82 | 29.07–41.13 |

[a] Represents nonsignificance; found only between Dual-Top and VectorTAS ($P = .744$).

## DISCUSSION

Since commercially available mini-implants present in such varied designs and dimensions, knowledge of their mechanical performance can improve clinical guidelines and increase their success rates. Self-drilling mini-implants are associated with increased torque during placement.[20,23,24] This is beneficial for primary stability but could increase the risk of mini-implant fracture upon insertion, especially in high-density bone.[13,14,17] Identification of the fracture torques of commonly used self-drilling mini-implants could provide a basis for determining the risk of this undesirable complication prior to insertion. As such, this in vitro study investigated fracture torques of commonly used self-drilling mini-implants.

The present study showed that resistance to fracture varied significantly among implants from different manufacturers. The mean values obtained ranged from 25.08 Ncm (Aarhus) to 72.07 Ncm (Unitek). Comparison of the six manufacturers tested revealed significant differences in peak fracture torques among all groups tested, except between Dual-Top (31.89 Ncm) and VectorTAS (30.79 Ncm). Among the mini-implants studied previously for fracture torques, results reported were similar to those found within this study.[15,16,19] The exception was the fracture torque observed for Tomas-pin (36.12 Ncm), which was higher than that reported by Whang et al.[15] This may be due to increased variability in the manufacturing process inherent to this specific mini-implant or batch.[26] This may further offer an explanation for the large variation in fracture torques observed within this mini-implant group in this (SD, 3.89 Ncm) and previous studies.[15]

While some studies have shown a strong relationship between implant diameter and peak fracture torque,[16,17,19,21] others were unable to demonstrate a correlation.[15,27] When mini-implants of identical shape and alloy were compared, screw diameter showed a strong influence on peak torque reached at fracture, with both insertion torque and fracture resistance increasing as diameter increased.[16,21,28] However, when evaluating mini-implants from different manufacturers, factors such as material composition, implant shape, thread design, heat treatment, and machining process have the potential to contribute to fracture resistance as well.[15,19,26] In the present study, no relationship was observed between fracture torque and diameter of the cylindrical-shaped Aarhus, Tomas-pin, VectorTAS, Dual-Top, and OrthoEasy mini-implants ($R = .035$). This was in accordance with correlation results reported by Whang et al.[15] As such, mini-implant diameter alone should not be used to assess the resistance to fracture of cylindrical-shaped mini-implants from different manufacturers.

When the lone tapered Unitek mini-implant was included in the analysis, a weak positive correlation

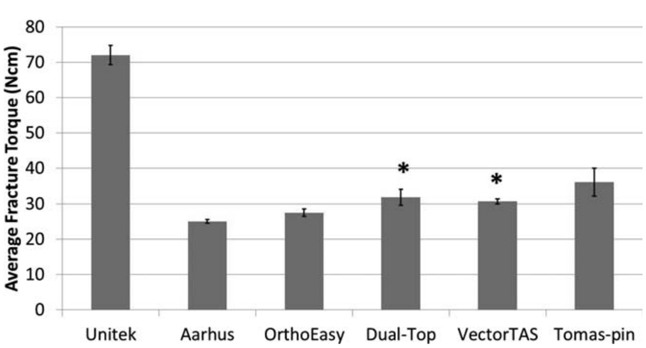


**Figure 4.** Bar graph showing the mean fracture torques for various mini-implant manufacturers (mean ± SD; n = 15). All differences were significant ($P < .05$), except the difference between Dual-Top and VectorTAS ($P = .744$), indicated by the asterisk (*).

**Figure 5.** Fracture position of the mini-implants tested. Upper row from left to right: Unitek, Aarhus, OrthoEasy. Lower row, from left to right: Dual-Top, VectorTAS, Tomas-pin. All fractured within the threaded portion of the mini-implant body.

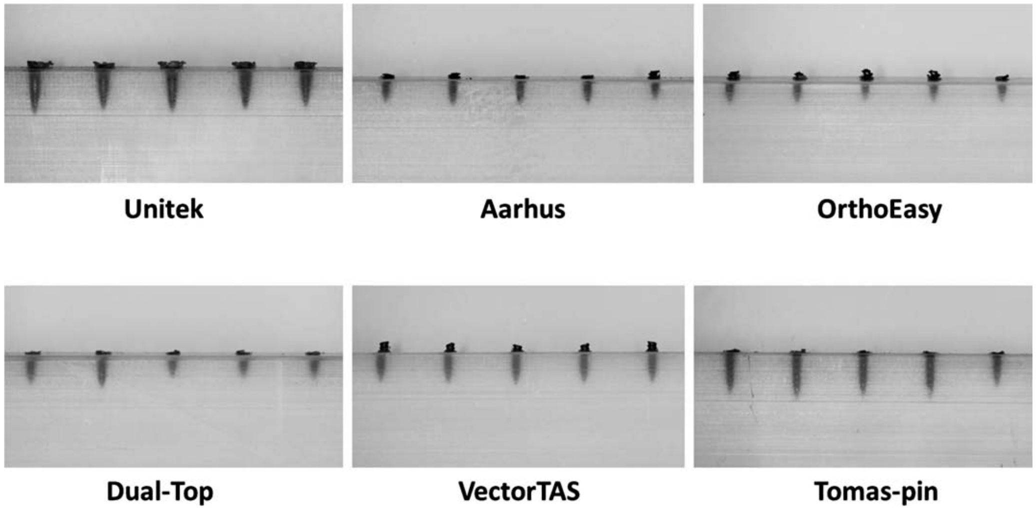


**Figure 6.** Photographs showing the level of mini-implant fracture. All mini-implants failed at the level of the acrylic block, leaving up to 1 mm of mini-implant exposed.

between diameter and fracture torque was observed ($R = .450$). Unitek was the largest diameter mini-implant tested, and this likely contributed to the increased torque at fracture. However, the higher fracture torque value may also be partly explained by its tapered body shape. Previous studies have shown that tapered screws reach significantly higher mean insertion and fracture torques than cylindrical screws.[17,19,28,29] Since both the diameter and shape of mini-implants have been shown to greatly influence fracture resistance, it cannot be determined from this study which plays a greater role with regard to fracture torque. However, it does appear that the largest diameter, tapered mini-implant (Unitek), after full-thread engagement, had the highest fracture resistance of all the commercial mini-implants tested in this study.

A study by Wilmes et al.[16] demonstrated that while most mini-implants failed at the level of the acrylic block, Tomas-pin and Dual-Top screws experienced fractures in the region of the neck and driver interface, respectively. They concluded that mini-implant and driver shaft design may play a role in the various fracture patterns found. The present study ascertained findings similar to those of Whang et al.,[15] in which all mini-implants consistently fractured within the threaded portion of the cylindrical body (Figure 5) at or within 1 mm from the level of the acrylic block (Figure 6). This region may have experienced higher concentrations of internal stress during mini-implant insertion, but future studies will be needed to verify this finding.

When comparing clinical placement torques of mini-implants, a study by Motoyoshi et al.[12] found that self-tapping mini-implants (requiring predrilling) experienced mean placement torques between 7.2 and 13.5 Ncm, depending on mini-implant location. A clinical study by Suzuki and Suzuki[14] showed that self-drilling mini-implants experienced higher insertion torques than mini-implants requiring predrilling, with means ranging between 12 and 21 Ncm, when inserted into the midpalatal suture and dentoalveolar bone. These clinical insertion torque values are close to approaching the fracture torques observed in the present study, and they are likely to increase when placed into locations of thick cortical bone.[17,23,24]

It has been reported that there is likely an optimal insertion torque for enhancing the success of any mini-implant, a value that is not too high nor too low, likely in the range of 5–10 Ncm.[12] Although low insertion torque values may lead to a lack of mechanical retention and primary stability,[11] larger insertion torque values may generate excessively high stress levels, thereby increasing the level of micro damage in the surrounding bone.[30] This might provoke local necrosis and remodeling of bone at the implant-tissue interface, leading to a decrease in secondary stability over time, with potential for eventual loosening of the mini-implant.[31] Since self-drilling mini-implants tend to generate higher insertion torques than predrilling mini-implants,[13,14] both fracture on insertion and poor secondary stability might be complications that could be more frequently associated with their use.

Mini-implants that describe themselves as self-drilling bring about the assumption that pilot holes are never required prior to placement. Even though the self-drilling insertion technique has many advantages (simple surgical procedure, reduced risks of root damage, enhanced tactile feedback, decreased bony damage, and superior primary stability),[13,14,32,33] some authors and manufacturers claim that there might be a benefit to predrilling under certain circumstances.[17,31] Since insertion torque is proportional to the area of contact between the mini-implant and the bone, various characteristics such as the density and quality of bone, thickness of the cortical bone, design of the implant used, and the insertion technique employed can influence its magnitude.[14,28,33,34] Excessively high insertion torques can be reached upon placement into areas of high density and/or thick cortical bone such as the mandibular posterior region or maxillary palate, particularly in adults.[14,17] Therefore, when using self-drilling mini-implant designs in these areas, the use of torque-limiting drivers and gauges,[31] as well as predrilling pilot holes,[11,17] may be beneficial in controlling insertion torques and decreasing the risk of fracture.

## CONCLUSIONS

- Significant differences exist in fracture torques among manufacturer-specific mini-implants.
- Among the six groups tested, the Unitek mini-implant had the highest mean torque value (72.07 $\pm$ 2.70 Ncm), followed by the Tomas-pin (36.12 $\pm$ 3.89 Ncm), Dual-Top (31.89 $\pm$ 2.27 Ncm), VectorTAS (30.79 $\pm$ 0.69 Ncm), Orthoeasy (27.55 $\pm$ 1.02 Ncm), and Aarhus (25.08 $\pm$ 0.51 Ncm) mini-implants.
- Only a weak correlation ($R = .450$) between implant diameter and fracture torque was detected in the mini-implants from different manufacturers, indicating that other design variables inherent to each mini-implant type may also play a role in influencing fracture resistance.

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