Insertion torque, pull-out strength and cortical bone thickness in contact with orthodontic mini-implants at different insertion angles

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SUMMARY This study aimed to evaluate biomechanical behaviour of inclined orthodontic mini-implants by analyzing its insertion torque (IT), axial pull-out strength (APS), and cortical bone thickness in contact with mini-implant (CBTC). A total of 102 mini-implants were inserted at 90 degree, 60 degree, and 45 degree to the surface of synthetic bone. Peak IT was measured, and the mini-implants were aligned with the mechanical testing machine to record the APS. The cortical bone thickness in contact with each mini-implant was measured after the pull-out test and the data were subjected to statistical analyses. The 45 degree group had a significantly higher IT compared with the 90 degree group (P < 0.05). There was a statistically significant increase in the average of cortical bone thickness in CBTC across the three groups (P < 0.05). A negative correlation between the angulation and the CBTC (r = −0.95, P < 0.05) and a positive correlation between the APS and the CBTC were observed (r = 0.34, P < 0.05). Mini-implants that are inserted more inclined to the surface of the bone provide greater IT and an increased contact with the cortical bone. The greater the CBTC, the greater is the APS.

Introduction

The success of any implant in promoting absolute anchorage depends on its stability (Pickard et al., 2010). The stability of the implant immediately after insertion is denoted as primary stability (Wilmes and Drescher, 2009). Some relevant factors that may affect the primary stability of orthodontic mini-implants (OMIs) are bone quality, implant design, insertion method, cortical bone thickness, and insertion angle (Motoyoshi et al., 2007; Wilmes et al., 2008; Su et al., 2009; Ono et al., 2008).

Studies have reported that mini-implants that are inclined in relation to the bone surface provide greater contact with the cortical bone, resulting in increased mechanical retention and stability of the implant (Deguchi et al., 2006; Wilmes et al., 2008; Monnerat et al., 2009).

In addition, clinical and laboratory studies have measured insertion torque (IT) as a method to evaluate the primary stability of OMIs (Wilmes et al., 2008; Motoyoshi et al., 2006). Furthermore, Wilmes et al. (2008) have examined the IT of inclined mini-implants in the iliac bones of pigs and found that mini-implants inserted between 60 degree and 70 degree from the bone surface obtained higher ITs compared with the mini-implants inserted perpendicularly to the bone. However, the mini-implants more inclined to the bone, such as 30 degree, where it would expect more contact with cortical bone, showed the least IT.

One method for evaluating the biomechanical performance of mini-implants is the axial pull-out test. Studies applying OMIs in dogs have shown a statistically significant correlation between pull-out strength and cortical bone thickness (Huja et al., 2005; Salmória et al., 2008). Even though pull-out and shear tests produce forces that substantially exceed those typically applied in orthodontics, they provide important information regarding the primary stability and material characteristics of mini-implants (Pickard et al., 2010). The pull-out tests not only exceed the clinical situation in the magnitude of force but also represent an uncommon direction of force application for the clinical loading of miniscrews.

A previous study by Petrey et al. (2010), conducted using artificial polyurethane bone and applying lateral traction loads, has demonstrated that the most effective mini-implant insertion angle to the bone surface for mechanical retention is 90 degree. On the other hand, Pickard et al. (2010) studied OMIs in different angulations to the bone surface tested to failure in pull-out (tensile) and shear tests.
but found different results. These authors pointed out that the more closely the long axis of the implant approximates the line of applied force, the greater the stability of the implant.

Considering the importance of using mini-implants in Orthodontics, more researchers are still working with inclined mini-implants (Heo et al., 2012; Holm et al., 2012), although there is no consensus in the literature, highlighting the need for further studies on the mechanical behaviour of OMIs at different angulations.

The aim of this study was to evaluate the IT, the axial pull-out strength (APS), and the cortical bone thickness in contact with OMIs at different angulations.

Materials and methods

One hundred and two self-drilling titanium mini-implants (name is omitted), of 1.6 mm diameter and 7 mm length, were inserted into synthetic bone (Sawbones, Pacific Research Laboratories, Vashon Island, Washington, USA) at three different insertion angles. Three groups were formed according to the angulation \((n = 34)\): 90 degree, 60 degree, and 45 degree (Figure 1A–C). The initial drilling was performed to a 3 mm depth (Wilmes and Drescher, 2009) with a 1.3 mm diameter drill bit (Salmória et al., 2008). This procedure was performed with a programed milling machine at 600 rpm, and angulations were set manually according to a scale of angles in this equipment. The mini-implants were manually placed with a screwdriver, and the final tapping was done with a manual digital torque wrench Lutron TQ-8800 (Lutron Electronic Enterprise Co., Ltd, Taipei, Taiwan) to register the peak IT in Newton centimeter (Ncm). The neck of the mini-implant had a short conical portion and a cylindrical part. The mini-implants were placed until the beginning of cylindrical part reached the cortical bone surface.

The synthetic bone used consists of solid rigid polyurethane foam. According to the ASTM standard F1839-08 (1997), the homogeneity and consistent properties of rigid polyurethane foam make it an ideal material for comparative testing of bone screws. The dimensions consist of a 40 mm layer with a density of 0.24 g/cm³ or 15 pcf (simulating cancellous bone) and a 1.5 mm layer with a density of 0.64 g/cm³ or 40 pcf (simulating cortical bone). The use of this material to perform mechanical tests with OMIs has been described in other studies (Petrey et al., 2010; Holm et al., 2012).

In each bone block, we demarcated an area of 10 × 10 mm for each mini-implant of the 90 degree group and an area of 15 × 10 mm for the mini-implants in the 60 degree and 45 degree groups. A larger space was designed for the inclined mini-implants to ensure full integration into the bone. Under the demarcations, 20 mm deep cuts were made to separate part of the bone blocks for subsequent mounting of the specimens. After insertion and measurement of the IT, the base of each bone block was cut with a diamond disc to individualize the segments of the bone block containing one mini-implant.

To accurately measure the final angulation of the mini-implants, each bone segment was radiographed individually with Kodak® Insight IP-21 periapical film. The radiographic images were scanned, and the angle of the mini-implants in relation to the cortical bone was measured using MB-Ruler© 4.0 software (Markus Bader—MB-Softwaresolutions, Hamburg, Deutschland; Figure 2).

A titanium claw was designed to seize the mini-implants. Its inner contour had a negative impression of the head of the mini-implant, and its upper portion was composed of a steel screw that allows coupling of the device to the mechanical testing machine. Thus, when seizing the mini-implant, the long axis remained in the same direction of tensile load application in the mechanical testing machine. The ASTM F1691-96 (1997) advocates this alignment so that only pull-out strength in the axial direction is recorded.

Figure 1 Orthodontic mini-implants: A, 90 degree group; B, 60 degree group; C, 45 degree group.
A device similar to that used by Salmoria et al. (2008) was built to prepare the specimen. The mini-implant inserted into the bone block was grasped by the claw and embedded in autopolymerizing acrylic resin inside a PVC tube that was 25 mm in length and 32 mm in diameter. Care was taken to avoid mini-implant contact with the acrylic resin. This setup was partially immersed in cold water to dissipate the exothermic reaction during polymerization. After acrylic resin setting, the mini-implant was disconnected from the claw, and the specimen was ready for the pull-out test.

The axial pull-out test was conducted in a universal testing machine Instron® 3382 (Instron Corp, Canton, Massachusetts) with a load cell of 5 kN at a constant speed of 0.5 mm/min. The maximum pull-out strength was obtained and recorded in Newtons for each mini-implant.

After pull-out tests, the specimens were sectioned through the center of the mini-implant hole (Huja et al., 2005) One half of this section was examined under a ×50 magnification with an Olympus BX-60 optical microscope, and measurements of cortical bone thickness in contact with mini-implant (CBTC) were carried out using Omnimet software (Buehler—Worldwide Headquarters, Lake Bluff, Illinois; Figure 3A–C). The two sides of the site created by the removal of the mini-implants were measured and averaged. This procedure was repeated twice, and the average obtained represented the CBTC.

Statistical analysis
All data were assessed for homogeneity of variance according to angulation by the Levene test and analyzed by one-way ANOVA, the Tukey HSD (honestly significant difference) multiple comparisons test for homogeneity of variances, the Games-Howell multiple comparisons test for heterogeneous variances, and the Pearson correlation coefficient, using the SPSS 18.0 (SPSS Inc., Chicago, Illinois) statistical package. The level of significance was set as 5 per cent.

Results
The average insertion angle in the 90 degree group, 60 degree group, and 45 degree group was 89.82 ± 0.79 degree, 64.77 ± 2.00 degree, and 48.85 ± 1.58 degree, respectively. Based on a confidence interval of 95 per cent and a Pearson’s coefficient of variation of 3 per cent, the statistical tests were performed using the average values for each group (Table 1). The means, medians, standard deviations, and confidence intervals for each variable are shown in Table 2.

Table 1 Sample for the adhesive resistance test.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Coefficient of variation (%)</th>
<th>Lower limit</th>
<th>Upper limit</th>
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<td>34</td>
<td>89.82°</td>
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<td>3.08</td>
<td>64.08°</td>
<td>65.47°</td>
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<tr>
<td>45°</td>
<td>34</td>
<td>48.85°</td>
<td>1.58°</td>
<td>46.48°</td>
<td>52.79°</td>
<td>3.24</td>
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</table>
The ANOVA revealed significant difference between the mean values for IT, APS, and CBTC (*P* < 0.05).

According to Tukey’s HSD test (Table 3), there was a statistically significant difference between the mean IT values of the 90 degree group and the 45 degree group (*P* < 0.05). The same was not observed when comparing the 90 and 60 degree groups or the 60 and 45 degree groups (*P* > 0.05). The 45 degree group had the highest mean for IT (2.96 ± 0.71 Ncm) followed by the 60 degree (2.60 ± 0.97 Ncm) and 90 degree (2.36 ± 0.86 Ncm) groups (Table 2).

For the mean values of APS, the Tukey HSD (Table 3) revealed a statistically significant difference between the 90 and 45 degree groups (*P* < 0.05). The same was not observed when comparing the 90 and 60 degree groups or the 60 and 45 degree groups (*P* > 0.05). The 45 degree group had the highest mean of APS (175.01 ± 45.22 N) followed by the 60 degree (153.57 ± 43.63 N) and 90 degree (133.55 ± 41.29 N) groups (Table 2).

The Games-Howell test showed a statistically significant difference in the mean values of CBTC among the three groups (*P* < 0.05). In the 45 degree group, the mean of CBTC was higher (2.09 ± 0.05 mm) followed by the 60 degree (1.72 ± 0.04 mm) and 90 degree (1.51 ± 0.02 mm) groups (Table 2).

There was a statistically significant and very strong negative correlation between the angulation and the CBTC (*r* = −0.95, *P* < 0.05) and a weak negative correlation between angulation and IT (*r* = −0.30, *P* < 0.05; Table 4).

There was a significant regular positive correlation between APS and the CBTC (*r* = 0.34, *P* < 0.05). There was a significant positive, but weak, correlation between IT and CBTC (*r* = 0.29, *P* < 0.05; Table 4).

### Discussion

Considering that the inclination of OMI's can influence their primary stability, studies involving this approach are of paramount importance in the clinical application of these anchorage devices.

Studies on this topic are current and involve different aspects (Heo et al., 2012; Holm et al., 2012). Petrey et al. (2010), using artificial polyurethane bone, have analyzed mechanical retention by varying the angulation of mini-implants at the bone surface, but with samples subjected to lateral loads of traction. Pickard et al. (2010) also performed an *in vitro* study applying lateral loads but obtained contrary results.

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### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean IT (Ncm)</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
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<th>Upper limit</th>
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*Significant at *P* < 0.05.

### Table 3

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<td>0.000*</td>
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<td></td>
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*Significant at *P* < 0.05.

### Table 4

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<td>APS and CBTC</td>
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<td>0.001*</td>
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*Significant at *P* < 0.05.
results. In the present study, we analyzed the mechanical behaviour of OMIs inserted at different angulation but subjected to parallel loads along the long axis.

Of course, both lateral and axial pull-out tests are static tests and do not simulate the dynamic nature in which these devices are loaded in clinical practice. In this study, the axial pull-out test does not simulate the magnitude of force or the direction of force application for the clinical loading; however, our intention was to evaluate the stability of OMIs based on their contact with cortical bone since this application has been described in previous studies (Huja et al., 2005; Salmória et al., 2008).

In artificial bone, the present study showed that the mini-implant ITs in the 45 degree group were significantly higher compared with those of the 90 degree group ($P < 0.05$). Although the average IT increased in the 60 degree group, there was no statistically significant difference compared with the 90 degree group ($P > 0.05$). In a study using pig iliac, Wilmes et al. (2008) have also asserted that the IT can be increased by tilting the mini-implant at 60 degree and 70 degree from the bone surface to achieve greater IT. However, the authors also observed that the most inclined mini-implants (with a 30 degree angle to the bone) had the lowest ITs. The latter statement is not in agreement with the results of this study, because we observed a progressive increase in IT as the degree of inclination with respect to the bone surface increased.

Although the results of this study demonstrated an increase of IT values in the 45 degree group, the general mean of these values was 2.96±0.71 Ncm. In the clinical study by Motoyoshi et al. (2006) a higher rate of success observed among mini-implants was related to ITs between 5 and 10 Ncm. This discrepancy in success rates may be because this study was conducted in the laboratory and involved the insertion of mini-implants into synthetic bone. The method and standard for the measurement of IT may also have influenced the difference in results.

From a clinical standpoint, it would be interesting to increase the IT to achieve a mini-implant with improved primary stability. However, very high IT, above 10 Ncm, may affect the stability of the mini-implant, leading to a higher failure rate (Motoyoshi et al., 2006). Motoyoshi et al. (2010), who studied the long-term stability of OMIs, have found that a 4 Ncm torque may be sufficient for orthodontic anchorage.

The synthetic bone model used in this study had been chosen only for mechanical testing and, more specifically, to simulate fresh or live bone. Rigid polyurethane foam is a test material that has been used for the evaluation of OMIs (Petrey et al., 2010; Holm et al., 2012). The advantages of this material compared with other materials used for testing, such as bones from cadavers, are its batch-to-batch consistency, increased homogeneity, and decreased anisotropia when simulating cortical and medullary bone (Calvert et al., 2010).

Our results revealed a statistically significant correlation ($P < 0.05$) between IT and the CBTC. In a study using CT scans, Motoyoshi et al. (2010) also found a relationship between the IT of OMIs and the thickness of cortical bone in the posterior maxilla. According to Motoyoshi et al. (2007) the stability of OMIs is facilitated in areas with cortical bone thickness of 1.0 mm or more.

Monnerat et al. (2009) have used CT to study the sites and ideal angulations for the placement of mini-implants and have reported that there is increased contact between the mini-implant and cortical bone with a lower insertion angle, resulting in greater mechanical retention for the implant. In our study, we found a statistically significant increase in the mean values of CBTC in each of the three angle groups evaluated (90, 60 and 45 degree) and a very strong correlation between angulation and CBTC ($r = −0.95$, $P < 0.05$). On a geometrical standpoint, it was possible to understand that the greater the degree of mini-implant inclination to the bone surface, the greater its contact with the cortical bone. Furthermore, other authors stated that mini-implant angulation can reduce the risk of root damage (Kim et al., 2009). However, very oblique insertion angle may create slippage of the mini-implant at its first contact with bone and leads to the need for predrilling even with self-drilling mini-implants (Wilmes et al., 2008). Very inclined mini-implants may also make it difficult to apply traction materials and might increase the danger of maxillary sinus perforation (Kim et al., 2009).

With respect to the axial pull-out test, the average values of the 45 degree group were significantly higher compared with those of the 90 degree group ($P < 0.05$). As for implementation of the pull-out test, the mini-implants were aligned with the axis of the mechanical testing machine; the angulation itself was eliminated and only the contact of mini-implants with cortical bone provided by the different angles was taken into account. The 45 degree group showed higher CBTC values as compared with the 90 degree group ($P < 0.05$). There was also a regular positive correlation between APS and CBTC ($r = 0.34$, $P < 0.05$). In this case, we can infer that the greater the contact of the mini-implant with cortical bone, the greater its APS. Other authors have also found a positive correlation between cortical bone thickness in CBTC and APS (Huja et al., 2005; Salmória et al., 2008). In clinical practice it seems that OMIs success or failure cannot be predicted easily. Thus primary stability is one of the many factors that may aid in success, and some aspects can be explored on biomechanical approaches. Results from this study suggest that mini-implants that are inclined relative to the bone surface, from the biomechanical point of view, may offer greater primary stability in comparison to mini-implants inserted perpendicularly to the bone surface. Considering areas where the thickness of cortical bone is reduced, this advantage could optimize the clinical performance of these devices and provide better anchorage. Finally the screw angulation can reduce the risk.
of root contact and is therefore advisable beyond biomechanical considerations.

Conclusions

1. The angulation of the mini-implant to the bone surface influences the IT, the APS, and the cortical bone thickness in CBTCs.
2. The IT increases as the mini-implant is inclined on the surface of the bone.
3. The more inclined the mini-implant is to the bone surface, the greater its contact with cortical bone.
4. The IT increases as the cortical bone thickness in CBTCs increases.
5. The larger is the cortical bone thickness in contact with the mini-implants, the greater is the APS.

Acknowledgement

We thank Neodent® for donations of the implants used for this study.

References

American Society for Testing and Materials 1997 Standard specification for rigid polyurethane foam for use as a standard material for testing orthopaedic devices and instruments (F1839-08). ASTM Standards medical devices and services, West Conshohocken


