Thread shape factor: evaluation of three different orthodontic miniscrews stability

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SUMMARY The thread shape factor (TSF) to evaluate the relationships between geometrical characteristics and mechanical properties of the temporary anchorage devices (TADs) has recently been introduced. This in vitro experimental study evaluated in 30 different tests with three TADs: ORTHOImplant (1.8 mm diameter and 10 mm length; 3M Unitek), Tomas (1.6 mm diameter and 10 mm length; Dentaurum), and Orthoeasy (1.7 mm diameter and 10 mm length; Forestadent). Scanning electron microscopy images were acquired for each TAD to measure the TSF; afterwards, the maximum insertion torque (MIT) was evaluated and thereafter pull-out tests on two differently designed organic bone analogs were carried out using a testing machine with a crosshead speed of 2 mm/minute being applied. One-way analysis of variance with group as factor was performed. Post hoc multiple comparisons Bonferroni test was used. Rank-transformed data were used when asymmetry of data was shown. To assess correlation between characteristics, load, and MIT, Spearman’s rank correlation coefficient was used. A P-value of 0.05 was considered statistically significant. Significant direct correlations were found between TSF and depth and both load and MIT. Particularly, a correlation of 0.90 (P < 0.001) was found between depth and MIT for 2.2 mm cortical thickness. The authors conclude that MIT and maximum load values of pull-out test are statistically related to depth of the thread of the screw and to TSF.

Introduction

Skeletal anchorage obtained with temporary anchorage devices (TADs) has become an acceptable and reliable method for providing additional anchorage during orthodontic treatment (Kanomi, 1997; Costa et al., 1998; Melsen and Costa, 2000; Kyung et al., 2003).

Because these miniscrews use the bone as anchorage, they have become widely accepted as viable alternatives to extraoral devices in patients who either have insufficient dental support suitable for anchorage or are not compliant in wearing extraoral devices (Melsen and Verna, 2005).

The primary stability of miniscrew implants has been frequently associated with the increased success rates of miniscrews (Motoyoshi et al., 2006, 2007). The thickness of the cortical bone has the greatest effect on the load transfer mechanism. A recent study stated that primary stability depends on insertion site and clinician experience (Lim et al., 2011).

Thread shape factor (TSF), a geometrical TAD relationship to describe the mechanical properties of miniscrews, has recently been added (Migliorati et al., 2011). TSF is calculated as the relationship between the mean thread depth and the pitch (D/P); it is expressed as per cent. It was first introduced by Chapman et al. (1996) who described the influence of TSF in resistance to extraction of cancellous bone screws.

In order to validate the data from previous research on TSF, the authors have conducted a new analysis on load values in the pull-out test and miniscrew design characteristics.

Materials and methods

This study was carried out in two stages: firstly by a detailed study of the geometry of the three miniscrews in commerce and secondly by a pull-out test of all three miniscrews inserted to equal the depth in samples of synthetic bone.

The three miniscrews inserted were as follows:

1. ORTHOImplant (3M Unitek, Monrovia, CA, USA): 1.8 mm diameter and 10 mm length (F1; Figure 1a),

2. Tomas (1.6 mm diameter and 10 mm length; Dentaurum), and

3. Orthoeasy (1.7 mm diameter and 10 mm length; Forestadent). Scanning electron microscopy images were acquired for each TAD to measure the TSF; afterwards, the maximum insertion torque (MIT) was evaluated and thereafter pull-out tests on two differently designed organic bone analogs were carried out using a testing machine with a crosshead speed of 2 mm/minute being applied. One-way analysis of variance with group as factor was performed. Post hoc multiple comparisons Bonferroni test was used. Rank-transformed data were used when asymmetry of data was shown. To assess correlation between characteristics, load, and MIT, Spearman’s rank correlation coefficient was used. A P-value of 0.05 was considered statistically significant. Significant direct correlations were found between TSF and depth and both load and MIT. Particularly, a correlation of 0.90 (P < 0.001) was found between depth and MIT for 2.2 mm cortical thickness. The authors conclude that MIT and maximum load values of pull-out test are statistically related to depth of the thread of the screw and to TSF.
2. Orthoeasy (Forestadent, Pforzheim, Germany): 1.7 mm diameter and 10 mm length (F2; Figure 1b), and
3. Tomas (Dentaurum): 1.6 mm diameter and 10 mm length (F3; Figure 1c).

F1 is a Ti-6Al-4V alloy screw, available in three different lengths (6, 8, and 10 mm); for all those, the apical 4 mm of the screws are conical, whereas the rest of the portion 2, 4, or 6 mm is cylindrical. There is a 0.76 mm hole in the head, which also serves as an O-Ball/O-cap retentive mechanism.

F2 is available as self-tapping or self-drilling with three different lengths (6, 8, and 10 mm). It has a conical collar and a dedicated undercut for fixation of the orthodontic appliance. The head of the screw is bracket-like; there are also four slot markings for the detection of the slot position.

F3 is self-drilling and self-tapping; it is a titanium alloy grade V (Ti-6Al-4V) device; the transgingival neck of the screw (2 mm) is conical and has an integrated depth stop. The head of the screw has a bracket design with double cross slot 0.022” × 0.025”. These screws have three different lengths (6, 8, and 10 mm). Each device was examined via a 20.00 kV scanning electron microscopy (SEM) Hitachi model S-2500 (Hitachi Ltd, Tokyo, Japan), which performs a three-dimensional image processing on a micrometric scale. Images of the head and the shank of each screw were obtained at >20, >80, >100, and >500 magnifications and then converted using Adobe Photoshop CS3 software, which permits linear measurement and manipulation of the images. Method of measurements of the pitch, depth of the thread, and TSF were similar to that used in the preview paper. Mean values were obtained and are reported in millimetres. The distance between the tip of the device and the beginning of the thread was not considered as this measurement depends heavily on the means of microscopic image acquisition and is therefore not a constant value.

After this preliminary phase, the pull-out tests were performed. Blocks of double-layer synthetic bone (BoneSim™ Experimental, BoneSim™, USA) were constructed, featuring a superficial layer with biomechanical characteristics (elasticity, hardness, and density) similar to human cortical bone and a deeper layer with characteristics mimicking the trabecular bone. These blocks differed from those used in the preview test for overall measures, to better fit in the testing machine, and to avoid as better as possible any holding problems during the tests. Two different cortical thicknesses (1.1 and 2.2 mm) were chosen on the basis of the results of a previous study on the cortical thickness of the jaws of adult patients revealed by computed tomography (Silvestrini Biavati et al., 2011).

On each of these samples, the geometric centre was marked. A pilot hole with a calibrated bur (1.1 mm diameter) was first predrilled; thereafter, the TADs were implanted to an intraosseous thread depth of 7 mm. A total of 30 blocks were employed overall, 15 for each cortical thickness and 10 for each type of TAD. Maximum insertion torque (MIT) value was measured for each TAD in centinewtons per metre with a modified torque wrench (Model TT50 SD; MHH engineering Co. Ltd., Bramley, England).

An apposite device was created to guarantee homogeneity and perpendicularity of insertion, as also to permit perfect axial coincidence between screw, bone sample, and dynamometric cell. Component parts of this device are an aluminum frame to house the bone samples, a thread locker to prevent screw penetration over 7 mm, a hollow steel cylinder to encompass each TAD driver, and a cylindrical steel frame to hold these components in the load cell.

A dynamometric device (Instron 8501 plus) featuring a 10 kN load cell was used to carry out the pull-out tests. The software version Plus Windows 98, Series IX version 8, was employed for subsequent data processing. A traction velocity of 2 mm/minute was applied in a controlled environment at 27°C and 70 per cent humidity.

Screw displacement at peak load and the maximum load at the maximal holding point were measured. Digital photographs were taken at regular intervals to illustrate the tests (Figure 2).
Each device was examined again after the test with the SEM to obtain images of the shank of each screw at ×100 and ×500 (Figure 3).

Statistical analysis

A blinded statistical analysis was performed. To evaluate differences between groups for TSF, depth, pitch, load, and MIT, one-way analysis of variance with group as factor was performed. Post hoc multiple comparison Bonferroni test was used. Rank-transformed data were used when asymmetry of data was shown. Prior to rank-transform data, Levene's test for homogeneity of variances was assessed. Results on rank-transformed data were compared with those obtained by Kruskal–Wallis test. To assess correlation between TAD characteristics and load, MIT Spearman's rank correlation coefficient was used. A $P$-value of 0.05 was considered statistically significant. SPSS v.18 (IBM Corp.) was used for computation. Repeatability of measures of depth and pitch was evaluated by means of the intraclass correlation coefficient (ICC) and resulted more than 0.95 for all TADs.

Results

The characteristics of miniscrews, tests on synthetic bone, and differences between TADs regarding their characteristics are shown in Table 1. For depth, pitch, and TSF, differences between groups were statistically significant ($P = 0.002$), and all comparisons between groups had statistically significant results. Regarding load and MIT (Table 1) both for miniscrews placed into 2.2 and 1.1 mm cortical thickness block bone differences between groups were statistically significant ($P < 0.001$). No significant differences were noticed between F1 and F2 in load and MIT for 2.2 mm cortical thickness and in load for 1.1 mm cortical thickness,

Table 1   Descriptive statistics and comparison between groups.

<table>
<thead>
<tr>
<th>Characteristics and test</th>
<th>Characteristics of miniscrews and maximum load and torque values</th>
<th>$P$</th>
<th>Comparison between groups for characteristics of miniscrews and for load and maximum insertion torque (MIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F2                F3                F1                F2−F1       F3−F1       F2−F3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td></td>
<td></td>
<td>0.002        &lt;0.001       0.001       0.001</td>
</tr>
<tr>
<td>Depth (mm)</td>
<td>0.345 (0.029)     0.216 (0.013)   0.114 (0.01)   0.002        &lt;0.001       0.001       0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitch (mm)</td>
<td>0.826 (0.014)     0.894 (0.006)   0.574 (0.006)   0.002        &lt;0.001       &lt;0.001       0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thread shape factor (%)</td>
<td>0.417 (0.038)     0.242 (0.015)   0.198 (0.018)   0.002        &lt;0.001       0.05         0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load (kN; 2.2 mm)</td>
<td>0.74 (0.08)       0.67 (0.10)     0.45 (0.02)     &lt;0.001       0.001         0.006         NS</td>
<td></td>
<td></td>
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<tr>
<td>Load (kN; 1.1 mm)</td>
<td>0.69 (0.12)       0.58 (0.12)     0.34 (0.07)     &lt;0.001       0.001         0.006         NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIT (cN/m; 2.2 mm)</td>
<td>28.2 (1.1)        24.8 (3.4)      18.8 (1.1)     &lt;0.001       &lt;0.001        0.004         NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIT (cN/m; 1.1 mm)</td>
<td>25.8 (2.1)        19 (3.7)        14.4 (2.6)     &lt;0.001       &lt;0.001        0.08          0.033</td>
<td></td>
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</tr>
</tbody>
</table>

NS, non-significant.
whereas the difference was significant for MIT with 1.1 mm cortical thickness (\(P = 0.033\)). Differences between F3 and both F1 and F2 results were always statistically significant except than for comparison between F3 and F2 for MIT in 1.1 mm cortical thickness sample for difference, which was not statistically significant (\(P = 0.08\)). Statistically significant differences between thickness of cortical block bone were found for load (\(P = 0.017\)) and MIT (\(P < 0.001\)).

Significant direct correlations were found between TSF and depth and both load and MIT with no particular differences when 2.2 or 1.1 mm were considered (Table 2). Particularly, a correlation of 0.90 (\(P < 0.001\)) was found between depth and MIT for 2.2 mm thickness. Regarding pitch instead a significant correlation with load for 2.2 mm cortical thickness (\(r = 0.58\); \(P = 0.024\)) was shown, while correlation with others measurement was not significant.

Discussion

Pull-out strength, a fundamental parameter for primary retention of TADs, is linked to bone density, volume, and cortical thickness (Choi et al., 2009; Wang et al., 2010). In this in vitro experiment, pull-out test of three different miniscrews was provided in a synthetic bone analog. Thread aspects after the tests showed no fractures at SEM analysis (\(>500\) images) for all the TADs nor any deformation or cracks. The authors chose to have standard and repeatability setting to obtain optimal conditions for better understanding how only the characteristics of screws affect the pull-out load and insertion torque value (MIT). The overall quantity of the thread within the bone was equal for all the samples. Bone samples guaranteed homogeneity of test blocks avoiding possible bias on the testing substrate (cadaver bone and animal model; Mortensen et al., 2009; Pickard et al., 2009; Veltri et al., 2010).

TADs with higher TSF value provided greater primary stability than was provided by lower TSF value screws. The present study showed and confirmed (Migliorati et al., 2011) a direct relationship between geometrical aspects of the screw thread and pull-out load values. This result agreed the theory stated in 1996 (Chapman et al., 1996) and underlined the key determinant of the design of the screw in achieving a great mechanical stability in a porous material. Other studies analysed how pitch and longitudinal fluting affect the primary stability of the screw and found that pull-out strength significantly increases as pitch decreases. This is partially in contrast with our results, in which both maximum load and MIT values were mainly related to the depth of the thread and TSF. Regarding pitch, a significant correlation with load for 2.2 mm cortical thickness (\(r = 0.58\); \(P = 0.024\)) was shown, while correlation with other measurement was not significant. Throughout treatment, the stability of an orthodontic miniscrew depends on peri-implant soft tissues, miniscrew design, surgical technique, force load, and bone density (Miyawaki et al., 2003). In these test series, two different cortical thicknesses showed a significant importance concerning pull-out load values and placement torque: 2.2 mm cortical thickness provided a significantly higher resistance to extraction force and a bigger MIT as well. This proportion was still strongly correlated with TAD’s geometry.

Placement torque has been shown to be a valid parameter for assessing the quality of the recipient bone (Motoyoshi et al., 2006, 2007). Moreover, a recent study (Suzuki and Suzuki, 2011) stated that lower value of MIT was more favourable to osseointegration; in fact, adequate MIT values enhance the primary stability of miniscrew implants, thus avoiding negative tissue responses during the healing and loading periods (Huja et al., 2005). Results from these in vitro tests also showed that MIT is strictly correlated to TADs geometry: the bigger the depth of the thread the bigger was the MIT value as well as that for the TSF.

Further study is necessary to fully understand how a viscous–elastic material, such as the bone, with two significantly different layers (cortical and marrow bones), reacts to the insertion of a rigid block of titanium such as a screw; in particular which kind of tension and compression load can be generated by a specific thread design and how the bone elastically reacts to these loads. In vitro studies like these should succeed a repeatability and standard condition in which all parameters of the test could be controlled and checked.

Table 2  Correlation between TADs characteristics and load and MIT. MIT, maximum insertion torque.

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Load (2.2 mm)</th>
<th>MIT (2.2 mm)</th>
<th>Load (1.1 mm)</th>
<th>MIT (1.1 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rho</td>
<td>0.702</td>
<td>0.898</td>
<td>0.733</td>
<td>0.772</td>
</tr>
<tr>
<td>P-value</td>
<td>0.004</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Pitch (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rho</td>
<td>0.580</td>
<td>0.446</td>
<td>0.497</td>
<td>0.425</td>
</tr>
<tr>
<td>P-value</td>
<td>0.024</td>
<td>0.095</td>
<td>0.059</td>
<td>0.115</td>
</tr>
<tr>
<td>TSF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rho</td>
<td>0.700</td>
<td>0.902</td>
<td>0.743</td>
<td>0.764</td>
</tr>
<tr>
<td>P-value</td>
<td>0.004</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Conclusions

This in vitro study of three different TADs led the authors to draw the following conclusions:

1. Statistically significant differences were found between the three devices with regard to the pull-out tests and MIT.
2. A statistically significant difference was found between miniscrew pull-out strength and cortical thickness.
3. There is a direct correlation between the increase in TSF and the miniscrew pull-out strength and MIT.

References


Silvestrini Biavati A et al. 2011 Three-dimensional tomographic mapping related to primary stability and structural miniscrew characteristics. Orthodontics and Craniofacial Research 14: 88–99

