Tilted orthodontic micro implants: a photoelastic stress analysis

Seçil Çehreli, Ayça Arman Özçirpici and Alev Yılmaz
Department of Orthodontics, School of Dentistry, Başkent University, Ankara, Turkey

Correspondence to: Seçil Çehreli, Department of Orthodontics, Faculty of Dentistry, Başkent University, 11. Sok. No: 26 06490, Bahçelievler, Ankara, Turkey. E-mail: dtsecel_yuksekbilgili@hotmail.com

SUMMARY The aim of this study was to examine peri-implant stresses around orthodontic micro implants upon torque-tightening and static load application by quasi-three-dimensional photoelastic stress analysis. Self-tapping orthodontic micro implants were progressively inserted into photoelastic models at 30, 45, 70, and 90 degrees and insertion torques were measured. Stress patterns (isochromatic fringe orders) were recorded by the quasi-three-dimensional photoelastic method using a circular polariscope after insertion and 250 g static force application. Torque-tightening of implants generated peri-implant stresses. Upon insertion, 90 degree placed implants displayed the lowest and homogeneous stress distribution followed by 30, 70, and 45 degree tilted implants. Static loading did not dramatically alter stress fields around the implants tested. The highest alteration in stress distribution was observed for the 90 degree placed implant, while 70 degree tilted implant had the lowest stresses among tilted implants. Torque-tightening of orthodontic micro implants creates a stress field that is not dramatically altered after application of static lateral moderate orthodontic loads, particularly at the cervical region of tilted implants.

Introduction
Optimum and stable anchorage is the main prerequisite for the orthodontic treatment. Skeletal anchorage provided by orthodontic micro implants has proven to be a predictable treatment option requiring low patient compliance (Roberts et al., 1984; Kanomi, 1997; Costa et al., 1998). The most frequent insertion site of these devices is the lateral side of the alveolar ridge (Fabroni et al., 2004). A perpendicular placement can potentially lead to root damage, Park and co-workers introduced the oblique placement technique (Park et al., 2001). Although the correlation between insertion (cutting) torque and survival of orthodontic micro implants is still a topic of debate (Motoyoshi et al., 2006), recent studies suggest that very acute insertion angles (30 degrees) lead to low insertion torque, whereas angles between 60 and 70 degrees result in remarkably higher insertion torques, optimum primary stability, and improvement in resistance to pull-out forces (Wilmes et al., 2008; Florvaag et al., 2010).

As in many other areas of scientific research, the kinds of information obtained under differing experimental conditions can lead to uncertainty in the correct clinical interpretation and approach to be taken (Esposito et al., 2001). The results of numerical analyses on orthodontic micro implants may be questionable because no study has so far implemented in vivo data obtained from humans or some critical elements such as friction at the bone-implant interface (contact definition) and insertion torque into numeric models (van Staden et al., 2008; Stahl et al., 2009; Gracco et al., 2009; Sung et al., 2010). A photoelastic stress analysis study showed that vertically aligned orthodontic mini screws create a stress field upon insertion that is merely altered after moderate orthodontic loading (Gracco et al., 2009). The magnitude of peri-implant stress/strain is crucial as experimental studies have shown that high strain concentrations may cause incapacity to repair bone breakdown (microfracture) and may lead to implant failure (Frost, 1994; Melsen and Lang, 2001). Owing to increasing clinical applications of orthodontic micro implants, there is a growing need to unravel the cascade of biomechanical events around these anchorage devices. The purpose of this study was, therefore, to study peri-implant stresses around orthodontic micro implants upon torque-tightening and static load application by quasi-three-dimensional photoelastic stress analysis.

Materials and methods
Diameter 1.4 × 7 mm self-tapping orthodontic micro implants (SH-14-07, AbsoAnchor, Dentos Inc., Daegu, Korea) were used. At the outset, the impression of a 0.5 × 1.5 × 1.5 cm plexiglas block was made using a polyether impression material (Impregum F; Espe Dental AG, Seefeld, Germany) to fabricate standard experimental models. Two models were cast with a photoelastic resin (PL-2; Measurements Group, Raleigh, North Carolina, USA) for each test and inspected in the field of a circular polariscope to ensure a stress-free (maximum 0.45 fringe order) preliminary condition (Kinni et al., 1987; Çehreli et al., 2004a). The Young's modulus and Poisson's ratio of the PL-2 resin are 0.21 GPa and 0.42, respectively. Implant sockets were prepared at 30, 45, 70, and 90 degrees using a twist drill...
(Ø 1 mm, AbsAanchor; Dentos Inc.) at 225 rpm connected to a torque-controlled physiodispenser (Osseoset 100, NobelBiocare, W&H Dentalwerk, Bürmoos GmbH, Austria) and under profuse physiologic saline cooling. Each implant was progressively inserted into its respective socket with utmost care to avoid creation of permanent stresses in the models. Only stress-free models (maximum 0.45 fringe order) were used for the analysis (Figure 1).

Due to the geometry of the models, load distribution was analysed by the quasi-three-dimensional photoelastic technique (Kinni et al., 1987; Cehreli et al., 2004a). The model is three-dimensional, but the fringes are observed and analysed in two dimensions (Caputo and Standlee, 1987). In general, photoelasticity demonstrates the quality, quantity, and distribution of force in an object by fringe patterns that appear as a series of successive and contiguous different-coloured bands (isochromatics) in which each band represents a different degree of birefringence corresponding to the underlying stress in the tested part. The contour of an isochromatic fringe is determined by the flow of stresses in that particular region and represents equal differences in principal stresses. Hence, the colour of each band uniquely identifies the birefringence, or fringe order (and stress level), everywhere along that band (Table 1). The number of fringes indicates the stress or strain magnitudes, and the fringes being close to each other demonstrate higher stress concentrations at that region.

In the present approach, the analyses were executed at two stages. Initially, the peri-implant stresses around the implant were determined upon torque-tightening of the implant into its socket. In this regard, a custom-made manual torque device equipped with strain gauges was used. The technical details of the torque device and calibration experiments are explained elsewhere (Cehreli et al., 2004b). In brief, the strain-gauge signals during torque-tightening of the implant were delivered to a data acquisition system (ESAM Traveller 1; Vishay Micromeasurements Group, Raleigh, North Carolina, USA) and were displayed in a computer by a special software (ESAM; ESA M esttechnik GmbH, Olching, Germany) at a sample rate of 10 kHz. Then, the strain data were converted to torque units (Ncm) using the general formula:

\[ \text{Torque} = K \times \varepsilon \]

where \( K \) is the calibration constant and \( \varepsilon \) is the strain-gauge reading. For quantification of insertion torque, the custom-made torque device was connected to the hand driver (SHD-S AbsAAnchor; Dentos Inc.), which was mounted to the implant. The measurements were undertaken when the implant was placed into final position by an approximately half-turn of the torque device to clockwise direction. Each model was placed in the circular polariscope to record isochromatic fringe orders by a digital camera (Canon, EOS 450 D; Canon Inc., Tokyo, Japan). The digital images having a resolution of approximately 12.2 megapixels were transferred to a computer to determine the isochromatic fringes in magnified images using software (Adobe Photoshop 7.0; Adobe Systems Inc., USA) at cervical, middle, and the apical thirds of the implants (Cehreli et al., 2004a). Then, 250 g static lateral load was applied to each implant using elastic chain (Clear elastic chain 15”; ref no: 400-316; Ortho Organizer Inc., California, USA). The magnitude of load was measured using a gauge (Correx, Haagstreit, Bern, Switzerland) and photoelastic analysis was undertaken following the same method.

**Results**

Insertion torques of implants, isochromatic fringe orders upon torque tightening, and 250 g lateral load application...
are presented in Table 2. Regardless of the angle of insertion, torque-tightening of implants resulted in peri-implant stresses that were more concentrated around the middle and apical thirds. The lowest isochromatic orders at the cervical region was observed for the 90 and 45 degree tilted implants followed by 70 and 30 degree tilted implants (Figure 2a–2d). The stress distribution around the 90 degree placed implant was homogeneous on both sides, whereas higher compressive stresses were generally observed towards the tilted side of 30, 45, and 70 degree implants. Isochromatic fringe orders were lowest around 90 degree placed implant at the middle third region followed by 70, 45, and 30 degree tilted implants. Likewise, 90 degree placed implants displayed the lowest stress field around its apical third, 30 and 70 degree tilted implants had comparable level of compressive stresses, and 45 degree implant had slightly higher stresses among the implant angles tested.

As a sequel of lateral loading, the largest amount of change in isochromatic fringe orders was observed for the 90 degree placed implant as to the unloaded situation. There was not any increase in fringe orders at the middle and apical thirds, although stress intensity increased at the axis of rotation located between middle and apical thirds of the implant (Figure 3a). There was a slight increase in stresses at both compressive and tension sides for 30 and 70 degree tilted implants at the cervical third and only on the tension side of 45 degree tilted implant (Figure 3b–3d). While compressive continued to increase towards the apex of the 30 degree tilted implant, tensile stresses cervical third to the middle third, then decreased. A decrease of tensile stresses

Table 2 Torque values and isochromatic fringe orders around implants upon torque-tightening and 250 g static lateral load application.

<table>
<thead>
<tr>
<th>Implant angulation</th>
<th>Torque (Ncm)</th>
<th>Cervical third</th>
<th>Middle third</th>
<th>A pical third</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Torque-tightening</td>
<td>250 g Load</td>
<td>Torque-tightening</td>
<td>250 g Load</td>
</tr>
<tr>
<td></td>
<td>Left*</td>
<td>Right *</td>
<td>Tension**</td>
<td>Compression**</td>
</tr>
<tr>
<td>30°</td>
<td>4.89</td>
<td>3.10</td>
<td>1.82</td>
<td>2.35</td>
</tr>
<tr>
<td>45°</td>
<td>4.62</td>
<td>1.82</td>
<td>1.08</td>
<td>1.22</td>
</tr>
<tr>
<td>70°</td>
<td>5.38</td>
<td>2.35</td>
<td>1.82</td>
<td>2.00</td>
</tr>
<tr>
<td>90°</td>
<td>4.69</td>
<td>1.82</td>
<td>1.82</td>
<td>1.22</td>
</tr>
</tbody>
</table>

*Side according to the images captured in the circular polariscope.
**Side according to the direction of load application.

Figure 2 (a) Isochromatic fringe orders around the 90 degree placed implant after torque tightening. (b) Isochromatic fringe orders around the 30 degree placed implant after torque tightening. (c) Isochromatic fringe orders around the 45 degree placed implant after torque tightening. (d) Isochromatic fringe orders around the 70 degree placed implant after torque tightening.
was observed from middle third to apical third around the 70 degree tilted implant. The isochromatic fringe orders did not change for the 45 degree tilted implant towards apical, but the concentration of the stresses slightly increased.

Discussion

Among photoelastic stress analysis methods, quasi-three-dimensional is the most appropriate method for analysing stresses around a loaded three-dimensional implant embedded in a model simulating bone (Kinni et al., 1987; Caputo and Standlee, 1987). In this technique, the stresses do not need to be uniform through the thickness of the model along any vector of light propagation. The technique does not impose the restriction of planar stress distribution, which is accepted as a limitation of the technique. Besides, it is not known whether the technique has sufficient numerical resolution to discern stress differences in close proximity of an implant. Nevertheless, correct measurement of stresses could be accomplished using high-resolution images (Cehreli et al., 2004a).

So far, hybrid models made of different photoelastic resins have been used in an attempt to resemble bone (Fanuscu et al., 2003). Still, fabrication of stress-free models is unattainable using photoelastic materials with different physical properties as different polymerization contraction rates result in permanent stresses at the interface of the resins. The photoelastic resin PL-2 (Vishay Micromeasurements) has been frequently employed as bone simulant to examine load distribution. The rationale for using a material with a Young’s modulus lower than actual bone is that generation of isochromatic fringes in stiffer materials requires application of higher loads, as the optical coefficients of such resins are three to four times higher than the PL-2 resin. Moreover, the distance between isochromatic fringes decreases in stiffer materials and considering that the technique relies on standard photography with the use of macro lenses, determination of fringe orders becomes a hard task in the vicinity of the implants.

In this study, stress-free models were used to examine torque- and orthodontic load-induced peri-implant stresses. The preparation as well as handling of photoelastic materials is demanding and relies on some crucial factors such as delicate heating/mixing of the resin, setting of the resin, trimming of the models, if necessary, and preparation of implant sockets in this study. A slight temperature changes and force application could easily create permanent stresses in the resin, preparation of implant sockets were carried out with utmost care and each model was inspected in the polariscope to ensure a stress-free preliminary condition.

Regardless of the implant angulation, torque-tightening of the implants generated compressive stresses along the implant body with highest magnitude located at the apical third. A similar observation was reported by Gracco et al. (2009) in a photoelastic stress analysis, although the authors did not quantify the cutting-torque that created the stress field. As expected, the most homogenous stress field with lowest fringe orders was observed for the 90 degree placed implant. After lateral loading, however, there was a difference.
in compressive as well as tensile stresses around the implant neck suggesting that the amount of displacement of the implant head towards the load direction was higher than other implants tested. A static the loading was commenced to the opposite side of implant tilt, angulated implants (30, 45, 70 degrees) showed slight amount of apical displacement, which led to increase in stress magnitude and/or concentration towards the apical part for tilted implants, in comparison with their unloaded state. Alteration in fringe orders were observed for the 90 degree implant, considering that lateral loading did not lead to embedment, but tilting of the implant. Likewise, Gracco et al. (2009) could not discriminate the impact of moderate orthodontic loading on vertically aligned implants. They found that the stress field was altered after application of higher loads (1.5 and 2 N) as the implant length increased. In the present study, the intrusion phenomenon was more prominent for the 30 degree implant because a more acute angle is created between the implant axis and direction of load. As orthodontic implants are immediately loaded upon placement and osseointegration is not a prerequisite, the amount of tilt, regardless of the magnitude of applied torque may be a crucial factor.

The present analysis suggests that 90 degree placed implants might not be considered as a good candidate to bear immediate static load. Although studies on bone biology suggest that static loads within the physiologic milieu do not jeopardize bone tissue (Turner, 1998), large displacement at the implant neck coupled with lack of osseointegration, particularly in low-density bone, might jeopardize 90-degree implant survival by apical downgrowth of the epithelium through the interface. One should, however, take into account that the amount of implant angulation in bone alone would not lead to implant failure since extremely tilted oral implants can unevenly withstand dynamic forces (Krekmanov et al., 2000).

Among tilted implants, the most favourable stress field seems to appear around the 70 degree tilted implant, followed by the 45 and 30 degree tilted implants. A static load of 60–70 degree tilted implants also create higher insertion torque values (Wilmes et al., 2008), like in the preset study, 70 degree tilted implants may be a good candidate to bear immediate orthodontic load.

Conclusions

Under the experimental conditions of the present study, the following conclusions were drawn:

1. Torque-tightening of orthodontic micro implants result in initial peri-implant stress fields.
2. 250 g static orthodontic loading does not lead to dramatic changes in peri-implant stress magnitudes and concentrations.
3. Under static lateral loading, 90 degree placed implants created the most unfavourable stress field followed by 30, 45, and 70 degree tilted implants at the collar region.

References


Frost H M 1994 Wolff’s law and bone’s structural adaptations to mechanical usage: an overview for clinicians. Agle Orthodontics 64: 175–188


