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Short Communication

Failure load and stress analysis of orthodontic miniscrews with different transmucosal collar diameter

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ABSTRACT

Miniscrews have been introduced in orthodontics as temporary anchorage devices (TADs), in order to move the correct teeth and avoid other elements to slide toward a wrong direction. Moreover the ease of use of TADs encouraged clinicians to use miniscrews also for non-conventional purposes, as fixation in mandibular fracture, mini-implant supported temporary pontics, miniscrew-assisted rapid palatal expanders and distalizers. These applications develop higher forces, so TAD fracture can be an unwanted complication. Some authors analyzed torsional loads but no studies measured forces required to bend the screws and ultimate flexural strength.

Accordingly, in the present report, Ti-6Al-4V TADs were mechanically evaluated. Seven different diameters of screws were tested: 1.3 mm (Aarhus Screw, Medicon), 1.5 mm (Spider Screw, HDC), 1.6 mm (Aarhus Screw, Medicon), 1.7 mm (Ortho Easy, Forestadent), 1.8 mm (Ortho Implant, 3 M), 1.9 mm (Spider Screw, HDC) and 2.0 mm (Storm, Kristal).

The forces to bend the titanium TADs were measured at 0.1 mm, 0.2 mm magnitude of deflections and at maximum load (as peak before screw fracture) in air with a universal testing machine. Statistical analyses were performed.

Both at 0.1 mm and at 0.2 mm deflections and at maximum load, the significantly highest forces were reported with 1.7, 1.8, 1.9, and 2.0 mm TADs. The lowest values were reported with 1.6, 1.5, and 1.3 mm mini-implants. No significant differences were reported between 1.6 mm and 1.7 mm screws. It was found that load values in N versus stress in MPa were not fully comparable when screws with small and larger diameter were compared.

Therefore, when placing a miniscrew for applications that need maximum shear bending resistance, these results would be considered in order to reduce risk of unwanted fracture.

1. Introduction

During orthodontic mechanics, the control of unwanted movements is an important consideration. The resistance to undesirable tooth repositioning is defined as anchorage and can be obtained from teeth, oral mucosa, extra oral devices (Roberts-Harry and Sandy, 2004).

Orthodontic miniscrews have been introduced as a new system for anchorage control. These temporary anchorage devices (TADs) are mini implant inserted into either maxillary or mandibular jaws to help the clinician to move the correct teeth and avoid other teeth to slide toward a wrong direction (McGuire et al., 2006). Over time, titanium miniscrews gained popularity in orthodontics and nowadays they are considered a source of absolute intraoral anchorage for clinical purposes (Tsui et al., 2012). These devices present many advantages, such as easy insertion, immediate load, rapid removal and low cost (Patil et al., 2015). Orthodontic miniscrews achieve stationary anchorage through primarily mechanical retention. However, they can reach partial osseointegration after 3 weeks (Kravitz and Kusnoto, 2007).

Many reports showed multiple clinical applications of TADs. Intrusion (Cao et al., 2013), extrusion (Rodriguez y Baena et al., 2016), tooth sliding (Yamada et al., 2009), space closures (Mesko et al., 2013) and management of occlusal binding (Cantarella et al., 2013) have been treated employing orthodontic miniscrews. Moreover, the ease of use of TADs encouraged clinicians to use miniscrews also for non-

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conventional purposes. In fact TADs maxillomandibular fixation in mandibular fracture (Pires et al., 2011), mini-implant-supported temporary pontics (Wilmes et al., 2014), miniscrew-assisted rapid palatal expanders (Suzuki et al., 2016) and distalizers (El Nigoumi, 2016) have been reported.

These nonconventional applications develop forces which are higher than forces reported when mini implants are used as simple anchorage device (Suzuki et al., 2016). In these cases, miniscrew fracture can be an unwanted complication, which may occur during insertion and removal of the screw, but also if the screw is forced with high loads tangentially to its long axis (Melo et al., 2016). In fact, orthodontic TADs are exposed to three types of stress during clinical use: torsional shear stress, axial shear stress and bending stress (Reicheneder et al., 2008).

It has been demonstrated that torsional loading during screw insertion may cause premature mechanical weakening and needs to be minimized (Jolley and Chung, 2007). When the screw is fully inserted, screw show pronounced plastic deformation and hence fracture risk under subsequent bending loading (Reicheneder et al., 2008). Moreover, also the TAD removal can lead to miniscrew fracture (Suzuki and Suzuki, 2011). The fractures of the miniscrews are often reported in the neck part of the screw, between the body (in correspondence of the terminal part of the endoosseous threaded surface) and the head (after the transmucosal collar) (Kravitz and Kusnoto, 2007; Wilmes et al., 2011). Some authors evaluated torsional forces related to TADs fractures during insertion and removal procedures, showing a great variability of peak torque values (Jolley and Chung, 2007; Suzuki and Suzuki, 2011; Tepedino et al., 2017).

On the other hand, to our knowledge, no studies evaluated static bending stress and forces of orthodontic miniscrews. Accordingly, the purpose of the present investigation was to assess and compare forces needed to bend (0.1 mm and 0.2 mm) and to fracture TADs of seven different diameters under static load. The null hypothesis of the study was that there is no significant difference among the various diameters of the miniscrews tested.

2. Materials and methods

Various Ti-6Al-4V alloy orthodontic miniscrews were evaluated in the present study (Fig. 1). Seven different diameters were tested (Table 1): 1.3 mm (Aarhus Screw, Medicon, Tuttlingen, Germany), 1.5 mm (Spider Screw, HDC, Sarcedo, Italy), 1.6 mm (Aarhus Screw, Medicon, Tuttlingen, Germany), 1.7 mm (Ortho Easy, Forestadent, Pforzheim, Germany), 1.8 mm (Ortho Implant, 3 M, Monrovia, CA, USA), 1.9 mm (Spider Screw, HDC, Sarcedo, Italy), 2.0 mm (Storm, Kristal, Trezzano S/N, Italy).

Ten unused TADs for each diameter were selected. Screws were secured in a jig of a Universal testing machine (Instron, Norwood, MA, USA) and tested in air. As showed in Fig. 2 mini implants were fixed so the part between the trans mucosal head collar and the endosseous body of the screw was exposed to perpendicular bending and shear load.

Fig. 1. Miniscrews with different diameters tested in the present investigation. 1: 1.3 mm Medicon – 2: 1.5 mm HDC – 3: 1.6 mm Medicon – 4: 1.7 mm Forestadent – 5: 1.8 mm 3 M – 6: 1.9 mm HDC – 7: 2.0 mm Kristal.

Table 1
Characteristics of the screws tested.

Name	Manufacturer	Diameter	Length	Material	n
Aarhus Screw	Medicon	1.3 mm	12.3 mm	Titanium Ti-6Al-4V (Grade 5)	10
Spider Screw	HDC	1.5 mm	10 mm	Titanium Ti-6Al-4V (Grade 5)	10
Aarhus Screw	Medicon	1.6 mm	10.2 mm	Titanium Ti-6Al-4V (Grade 5)	10
Ortho Easy	Forestadent	1.7 mm	10 mm	Titanium Ti-6Al-4V (Grade 5)	10
Ortho Implant	3M	1.8 mm	10 mm	Titanium Ti-6Al-4V (Grade 5)	10
Spider Screw	HDC	1.9 mm	10 mm	Titanium Ti-6Al-4V (Grade 5)	10
Storm	Kristal	2.0 mm	10 mm	Titanium Ti-6Al-4V (Grade 5)	10

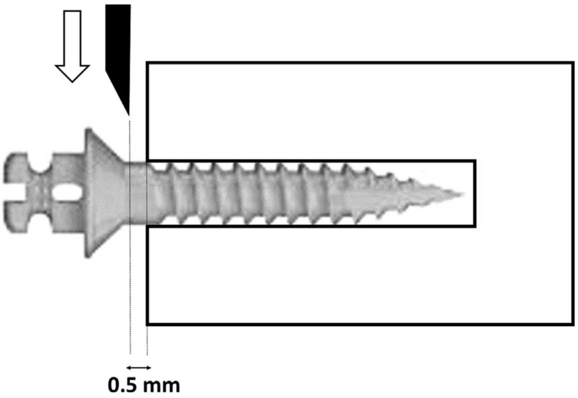

Fig. 2. Schematic figure of the loading test set-up. Span length: 0.5 mm from the tip to the block.

Force required to bend the screws for the magnitudes of deflection of 0.1 mm (groups 1–7) and 0.2 mm (groups 8–14) with a 0.5 mm span length from the tip to the block. Moreover, ultimate load to fracture the screw was recorded (groups 15–21).

The crosshead speed was set at 1.0 mm per minute (Cacciafesta et al., 2007, 2008). The load values were recorded in newton.

Predominant stress was assumed to be shear stress and it was calculated with formula

$\tau = F / A$
τ: the shear stress
F: the force applied (N)
A: the cross-sectional area of material with area parallel to the applied force vector.

Additionally the bending stress (MPa) was calculated for each specimen with formula:

$\sigma = My/I_x$
σ: bending stress in N/mm^2.
M: moment of neutral axis N mm
y: perpendicular distance to neutral axis in mm
I_x: second moment area of neutral axis in m^4

Data were submitted to statistical analysis using a computer software (R version 3.1.3, R Development Core Team, R Foundation for Statistical Computing, Wien, Austria). Descriptive statistics including mean, standard deviation, minimum, median, and maximum were calculated for the 21 groups. The normality of the data was calculated using the Kolmogorov-Smirnov test. An analysis of variance (ANOVA) and Tukey tests were applied to find differences among the force values of the various groups. Linear regression analysis between the variables of diameter of the screw and bending load were performed to assess