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Temporary anchorage device stability: an evaluation of thread shape factor

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SUMMARY The resistance to extraction of temporary anchorage devices (TADs) depends on various factors, including miniscrew design, shear strength, and bone density. This research introduces the thread shape factor (TSF) as a new factor for the evaluation of TAD mechanical properties. The authors evaluated three TADs for a total of 27 tests: Mini-impianto autoforante (Leone, 1.75 mm diameter and 8 mm length), Orthoscrew (Leader Ortodonzia, 1.65 mm diameter and 9 mm length), and MAS (Miniscrew Anchorage System, 1.3 mm diameter and 11 mm length). For each TAD, the images were acquired via a 20.00 kV scanning electron microscopy to measure their respective mean depth of thread (*D*), pitch (*P*), and the relationship between the two (TSF). Subsequently, pullout tests on organic bone analogue were carried out using a testing machine; a crosshead speed of 2 mm/minutes was applied. A two-way analysis of variance was performed to evaluate the interaction between the type of miniscrew and the cortical thickness. A *post hoc* analysis for single comparisons was subsequently employed. In addition, if homogeneity of variances was not rejected, Scheffè's test was performed, while Tamhane's test was carried out if the homogeneity of variance assumption was not met. Univariate linear regression models were fitted to evaluate the relationship between the outcomes and TSF, *D*, and *P* separately. A *P* value of 0.05 was considered statistically significant. From univariate linear regression, TSF, *D*, and *P* were statistically significant predictors of `peak load'. The tests showed that TSF has a statistical significance for describing the mechanical competency of TADs.

Introduction

Maximum orthodontic anchorage is useful in numerous clinical situations. Although traditional osteointegrated implants provide good anchorage (Ödman *et al.*, 1988; Roberts *et al.*, 1989; Wehrbein and Merz, 1998), they are too bulky for some applications, and therefore, miniscrews [microscrews or temporary anchorage devices (TADs)] are often preferred (Kanomi, 1997; Ohmae *et al.*, 2001; Miyawaki *et al.*, 2003). Besides their smaller sizes, other advantages of the miniscrews are smooth surface, lower costs, reduced chair-side times, and the possibility of immediate loading (Fritz *et al.*, 2004).

Unlike dental implants, which acquire their stability via osteointegration, miniscrews obtain maximum stability mechanically via primary retention (Melsen and Verna 1999; Brettin *et al.*, 2008). Numerous types of these devices, which generally consist of a single part made from an alloy of titanium and vanadium or aluminium (grade IV titanium) with similar characteristics, are currently on the market (Crismani *et al.*, 2010). From a clinical perspective, these devices consist of two relevant portions: the head, for which various designs are available (bracket like, rounded with slot, etc.), and the threaded shank, which is generally cylindrical, tapered, or a combination of the two, and may be self-tapping (requires prior drilling of a pilot hole) or self-drilling (does not require a pilot hole).

As there is a direct relationship between the shape characteristics of a miniscrew and their resistance to extraction (Clift *et al.*, 1992), the miniscrew design characteristics are analysed in detail here to study the relationship between their pitch, depth of thread, and load values in the pullout test.

Materials and methods

This study was carried out in two stages: first, by a detailed study of the geometry of the three miniscrews in commerce and second, by a pullout test of all three miniscrews inserted to equal the depth in the samples of the synthetic bone.

The three miniscrews inserted were as follows:

1. Mini-impianto autoforante (Leone, Florence, Italy): length, 8 mm and diameter, 1.75 mm (F1; Figure 1).
2. MAS (Miniscrew Anchorage System - Micerium, Avegno, Italy)... (F2; Figure 2).
3. Orthoscrew (Leader Ortodonzia, Italy)... (F3; Figure 3).

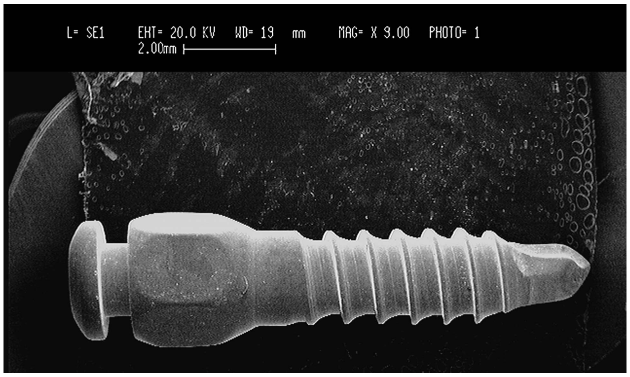

Figure 1 Device F1: SEM image at magnification ×9.

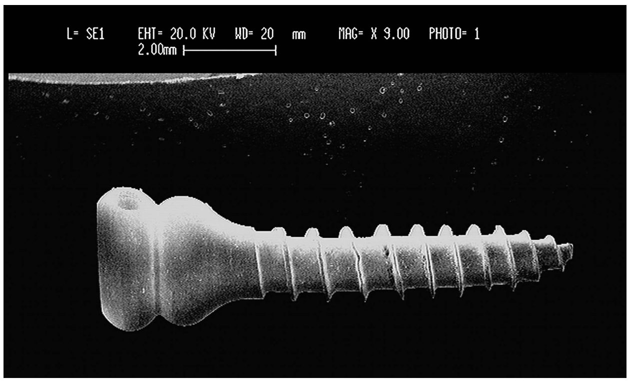

Figure 2 Device F2: SEM image at magnification ×9.

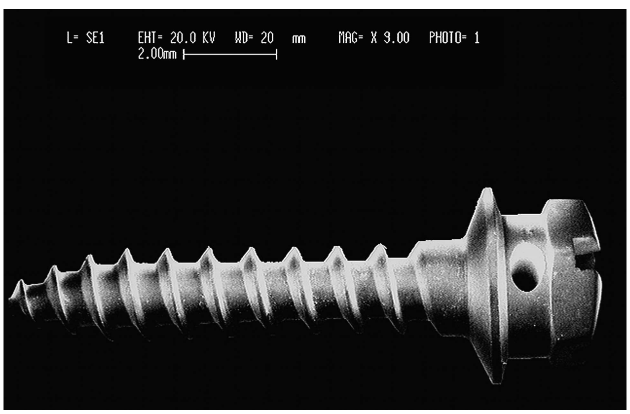

Figure 3 Device F3: SEM image at magnification ×9.

F1 (Leone), made of surgical stainless steel, is self-drilling and self-tapping. The endosseous portion of the implant has a tapered apical part (length, 2 mm) for drilling into the bone and a spiral threaded portion (diameter, 1.75 mm and length, 6 mm) that serves as anchorage. Two transmucosal heights of screw head are available, both mushroom shaped, to facilitate the application of an elastic traction and a coiled spring.

F3 is a grade IV titanium device with a threaded cylindrical shank of diameter 1.65 mm and lengths 7, 9, and 11 mm. Its neck may be of different lengths, and it features a bracket-like head with slot.

F2 is a grade IV titanium, self-tapping miniscrew, and is available in two diameters (1.3 and 1.5 mm). Its spherical head features a circular groove, which permits the attachment of auxiliaries.

Following prior attachment to a biadhesive conductive strip, each device was examined via a 20.00 kV scanning electron microscopy Stereoscan 360 (Stereoscan, Cambridge, UK), which performs a three-dimensional image processing on a micrometric scale. Images of the head and the shank of each screw were obtained at ×9, ×50, ×150, and ×200 magnifications and were then converted using the Adobe Photoshop CS3 software, which permits linear measurement and manipulation of the images.

Using Adobe, the distance between each crest (pitch) along the length of the threaded shank of each device was measured, excluding the thread of the tip, and the respective depths of thread, the perpendicular height from crest to root, were calculated. Mean values were obtained and are reported in micrometres.

Subsequently, the relationship between the mean thread depth and the pitch was calculated for each screw and expressed as a thread shape factor (TSF; Figure 4); TSF is calculated by D/P and is expressed as percent. 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 pullout tests were performed. Blocks of double-layer synthetic bone (BoneSim™Experimental, BoneSim™, Newaygo, Michigan, 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. Three different cortical thicknesses (1.1, 1.4, and 2.2 mm diameter) were created 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.*, 2010).

On each of these samples, the geometric centre was marked, and the TADs were implanted to an intraosseus thread depth of 6 mm at these points. Particularly, F1, whose tip features 2 mm without threads, was inserted to an overall depth of 8 mm. A total of 27 blocks were employed overall, 9 for each cortical thickness and 9 for each type of TAD.

An apposite device was created to guarantee homogeneity and perpendicularity of insertion and to permit perfect axial coincidence between screw, bone sample, and dynamometric cell. Component parts of this device are an aluminium frame to house the bone samples, a thread locker to prevent screw penetration over 6 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 pullout tests. The software version Plus Windows 98, Series IX version 8, was employed for subsequent data processing.

A traction velocity of 2 mm/minutes was applied in a controlled environment at 27°C and 70 per cent humidity.

Screw displacement at peak load, the maximum load at the maximal holding point, and the breaking load were measured. Digital photographs were taken at regular intervals to illustrate the tests (Figure 5).

Statistical analysis

Firstly, Shapiro–Wilk's normality test and Levene's test of homogeneity of variance were executed, and if these assumptions were rejected, an opportune transformation of data was applied or ranked transformed data were used.

Then, a two-way analysis of variance (ANOVA) with interaction was performed to evaluate the differences between the miniscrew types and the cortical thickness.

Finally, a *post hoc* analysis for single comparisons was employed, followed by Scheffè's test, for homogeneity of variances not rejected; or Tamhane's test if the homogeneity of variance assumption was not met.

Repeatability of measures of depth and pitch was evaluated by means of the intraclass correlation coefficient (ICC); means and standard deviations are reported.

Moreover, the one-way ANOVA was fitted to evaluate whether TSF, depth, and pitch, considered as covariates, were correlated to peak and breaking loads.

A *P* value of 0.05 was considered statistically significant. SPSS version 17 was used for analysis.

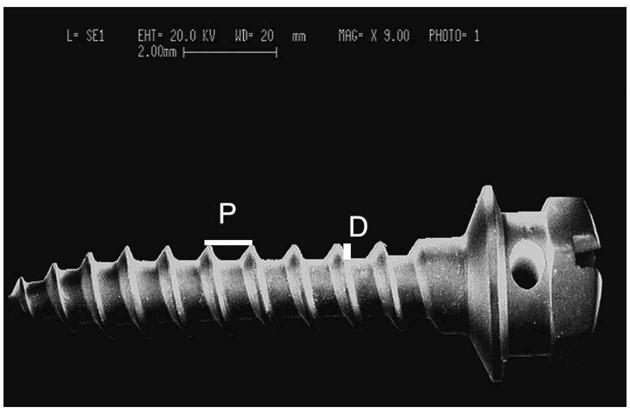

Figure 4 *P*: miniscrew thread pitch, *D*: miniscrew thread depth, and thread shape factor is expressed as *D*/*P*.

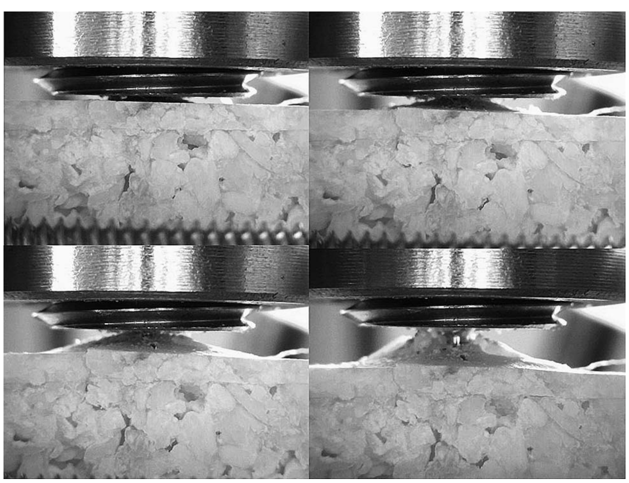

Figure 5 Sequence of pictures of a single pullout test.

Results

The means and the standard deviations of both peak load and breaking are shown in Table 1. Shapiro–Wilk's test rejected the normal assumption for both peak load (P = 0.008) and breaking load (P = 0.012). A log transformation was executed on the data and Shapiro–Wilk's test on the not-rejected normality of transformed data (P = 0.447 for log of peak load and P = 0.514 for the log of breaking load). Levene's test revealed the not-rejected homogeneity of variances for both log-transformed peak load (P = 0.23) and breaking (P = 0.10).

Regarding 'peak load', statistically significant differences between miniscrews were revealed (P = 0.005), while no differences were found between thicknesses (P = 0.25; Table 2). The effect of the miniscrews was not found to be conditioned by levels of thickness (P = 0.63). Significant differences were found about TADs F1 and F2 (P = 0.01) as well as F3 and F2 (P = 0.025).

Concerning 'breaking load', statistically significant differences between TADs were revealed (P = 0.015), whereas differences between thicknesses were found to be at the limit

Table 1 Means and standard deviations for different temporary anchorage devices (TADs) and thickness. SD, standard deviation.

TAD	Thickness (mm)	Load at peak		Load at break	
		Mean	SD	Mean	SD
F1	11	0.34	0.04	0.13	0.03
	14	0.31	0.09	0.11	0.03
	22	0.30	0.02	0.10	0.01
	Total	0.32	0.05	0.11	0.02
F2	11	0.33	0.06	0.13	0.01
	14	0.31	0.05	0.11	0.02
	22	0.37	0.10	0.13	0.04
	Total	0.34	0.07	0.13	0.03
F3	11	0.51	0.13	0.18	0.05
	14	0.37	0.04	0.13	0.01
	22	0.42	0.04	0.14	0.01
	Total	0.43	0.09	0.15	0.03
Total	11	0.39	0.12	0.14	0.04
	14	0.33	0.06	0.12	0.02
	22	0.36	0.07	0.13	0.03
	Total	0.36	0.09	0.13	0.03

of statistical significance ($P = 0.07$). The effect of interaction between the miniscrew and the thickness was not statistically significant ($P = 0.90$). However, statistically significant differences were found when comparing F1 and F2 ($P = 0.017$), while the comparison of 11- and 14 mm cortical thicknesses approached statistical significance ($P = 0.08$).

All ICCs ranged between 0.80 and 0.99; means and standard deviations for all miniscrews are reported in Table 3.

Regarding ANOVA (Table 4), the log-transformed peak load and the breaking load were employed. TSF, depth, and pitch were statistically significant predictors of 'peak load', while TSF and depth were statistically significant predictors of 'breaking load'. Pitch, on the other hand, was found to be of borderline significance.

Discussion

Like screws, the miniscrews were conceived to transform a torsional couple into a compression force (Manghi, 1966). The geometry of the screw thread, specifically the relationship between the thread depth and the pitch, expressed as the TSF, influences the resistance to extraction (Chapman *et al.*, 1996) in a porous material (like bone) when the diameter and the material of the screw are known. An increase in TSF, which can be achieved by increasing the thread depth or reducing the pitch, increases the resistance of the screw (Clift *et al.*, 1992).

Concerning miniscrews in particular, a recent study has stated that factors involved in the resistance to extraction and compression forces are the type of material, device diameter, length of thread, and shear strength of the material into which the screw is inserted (Pickard *et al.*, 2010). Other studies showed that the pullout 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 contrast to these findings, the tests carried out in this study on different cortical thicknesses revealed no statistically significant differences with any of the three devices considered. Each screw was tested by inserting it to a known depth perpendicularly into a known thickness of synthetic cortical bone under identical conditions. Often, in the literature, the exact quantity of the thread inserted into the bone sample is not mentioned, but in this study, to determine the effect of the thread geometry on the pullout load, the variable thread length was eliminated by inserting each TAD to the same thread depth. Thus, the only factors to influence the pullout load are device diameter and thread geometry, i.e. pitch, depth, and TSF.

Hence, the authors confirmed the fact that TADs with greater TSF (F3) have significantly greater pullout loads with respect to other devices (F1 and F2); therefore, there is a directly proportional relationship between the load and the TSF.

Another difference between this and previous pullout studies was the choice of materials; the authors of the

Table 3 Means and SD of depth (μm), pitch (μm), and thread shape factor (TSF; %) for all temporary anchorage devices.

Comparison	Depth	Pitch	TSF
F1	173.5 (8.5)	917.2 (65.5)	0.19 (0.01)
F2	192.6 (17.2)	825.5 (28.2)	0.23 (0.02)
F3	275.7 (9.3)	1043 (30.6)	0.27 (0.01)

Table 4 Results of analysis of variance for thread shape factor (TSF), depth, and pitch.

Factors	Load at peak	Load at break
	P	*P*
TSF	0.002	0.004
Depth	0.001	0.004
Pitch	0.005	0.05

Table 2 Main effects of analysis of variance and multiple comparisons for Scheffè *post hoc* test. CI, confidence interval; SD, standard deviation; TAD, temporary anchorage devices.

Factor	Comparison	Load at peak					Load at break				
		Mean difference	95% CI		*P*		Mean difference	95% CI		*P*	
			Lower	Upper				Lower	Upper		
TAD	F2–F1	0.02	−0.07	0.10	0.9		0.02	−0.02	0.05	0.52	0.015
	F3–F1	0.11	0.03	0.20	0.01	0.005	0.04	0.01	0.07	0.017	
	F3–F2	0.10	0.01	0.19	0.025		0.02	−0.01	0.06	0.15	
Thickness (mm)	11–14	0.06	−0.03	0.15	0.25		0.02	−0.004	0.06	0.078	0.07
	11–22	0.03	−0.06	0.12	0.76	0.25	0.01	−0.02	0.05	0.38	
	14–22	−0.03	−0.12	0.06	0.63		−0.01	−0.04	0.02	0.61	

present study used synthetic bone, whereas organic material has been preferred by other authors (Mortensen *et al.*, 2009; Pickard *et al.*, 2009; Veltri *et al.*, 2010). This, however, can suffer from a lack of homogeneity, making it difficult to gather essential data regarding screw capacity, i.e. design and resistance to pullout load. In fact, intraevaluation variability of the substrate can have a negative influence on test results, and repeatability cannot therefore be guaranteed. Thus, the authors chose to use a synthetic homogeneous material to avoid interference by uncontrollable variables when studying the geometric characteristics of TADs.

Numerous factors appear to determine miniscrew implantation success but are still subject to debate: factors linked to the operator (surgical technique; Garfinkle, 2005), implant site anatomy (cortical thickness, bone density, and keratinized gingiva; Miyawaki *et al.*, 2003; Cheng *et al.*, 2004; Motoyoshi *et al.*, 2006), biomechanics applied (quantity, duration, and vectors of the force applied; Miyawaki *et al.*, 2003; Garfinkle, 2005; Park *et al.*, 2006), degree of periimplantal inflammation (Park *et al.*, 2006), and type of screw (diameter and length; Cheng *et al.*, 2004; Park *et al.*, 2006). To this list, TSF can now be added, which can be instrumental in describing the mechanical properties of miniscrews, especially as regards primary stability.

Conclusions

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

1. There were statistically significant differences between the three devices as regards the pullout tests.
2. There is no difference between miniscrew pullout strength and cortical thickness.
3. There is a direct correlation between the increase in TSF and the miniscrew pullout strength.
4. F3 was the TAD most resistant to extraction.

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