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Mechanical influence of thread pitch on orthodontic mini-implant stability

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Abstract: The aim of this study was to evaluate the effect of pitch distance on the primary stability (PS) of orthodontic mini-implants (MIs) in artificial bone. Twenty experimental MIs were allocated to two groups, according to their geometric design: G_1 (30º X 0.6 mm) and G_2 (45º X 0.8 mm), and inserted into artificial bone of different densities: D_1 (0.32 g/cm^3) and D_2 (0.64 g/cm^3). The maximum insertion torque (IT) and removal torque (RT) values were recorded in N.cm. Loss of torque (LT) values were obtained by calculating the difference between the IT and RT. MI mobility was measured by means of a Periotest assessment. Normality and homogeneity were determined by means of the Kolmogorov-Smirnov and Shapiro-Wilk tests, respectively. A two-way ANOVA was used to detect differences between the mini-implant design and density factors. The ANOVA/Tukey tests were used to determine the intergroup difference. Higher IT values were observed for G_2 ($p \leq 0.05$) in D_2. No statistical difference for RT was observed between the groups, whereas G_2 presented higher values only for LT ($p \leq 0.05$). The Periotest values (PTV) were higher for G_1, in comparison with G_2, in D_1. G_1 presented better PS in D_2 (IT, RT and LT), whereas G_2 was found to be more stable in D_1, after evaluation with Periotest.

Keywords: Mechanics; Orthodontic Anchorage Procedures; Materials Testing.

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Introduction

The use of mini-implants represents an advance in contemporary orthodontics, in regard to controlling anchorage, thereby offering more satisfactory and predictable results.[1] The ease of insertion and removal[2] characterizes mini-implants (MI) as temporary anchorage devices (TADs),[3] making them ideal for use in the case of undesirable osseointegration.

Among the main advantages of these devices is the possibility of inserting them in various areas of the maxilla and mandible, as well as in the alveolar bone and areas adjacent to tooth roots.[4,5]

However, failures may occur in using MI.[6] These may be attributed to factors such as: site of insertion,[3] bone overheating promoted by the bur during preparation of the orifice, absence of primary stability, gingival and peri-implant tissue inflammation,[7] the surgical technique, the load application protocol and factors related to the patient, such as smoking and the practice of parafunctional habits.[8]

Artificial synthetic bone materials have been considered good alternatives for the purpose of performing mechanical tests,[9,10] especially when evaluating the primary stability of MI, a factor frequently associated with greater MI success rates.[11,12] MI biomechanical performance as regards primary stability may be evaluated by methods such as: insertion torque (IT),[13] removal torque (RT)[14] and Periotest values (PTV).[15,16]

MI type and bone characteristics[17] are other factors that may affect both the success rate and the MI permanence in the desired site.[18] Variations in design, such as: diameter, length, thread width, pitch and tip format, may have an influence on stability and should be further evaluated.[19,20,21,22] Thread depth and pitch have been associated with the possibility of enhancing the cutting efficiency of the mini-implant, by providing a lower insertion torque. In addition, an increase in the MI surface is related to MI support.[20,23] Therefore, the aim of the present study was to evaluate the effect of pitch distance on the primary stability of orthodontic MIs in artificial bone of different densities.

Methodology

Twenty MIs made of Ti-6Al-4V alloy (Mini-implants for Orthodontic Anchorage, Sistema INP™, São Paulo, Brazil) (1.6 mm X 8 mm) were used, and allocated to groups, according to their experimental geometric design: G_1 (30° X 0.6 mm) (Figure 1) and G_2 (45° X 0.8 mm) (Figure 2). The MIs were inserted into artificial bone developed for the purpose of biomechanical tests (Sawbones™ Pacific Research Laboratories Inc., Washington, USA), made from a block of solid polyurethane foam (180 X 130 mm and 40 mm thick) with different densities. Four test specimens were obtained (130 X 14 X 18 mm) and divided into two groups with the following densities: D_1 (0.32 g/cm^3) and D_2 (0.64 g/cm^3). Five MIs were inserted into the artificial bone according to each screw design. For the purpose of sample calculation, we worked with data from a previous pilot study considering: α = 5% and power of study = 80%. The division of the groups is shown in Table 1.

MI insertion was performed with a torque wrench coupled to a digital torque meter. This made it possible

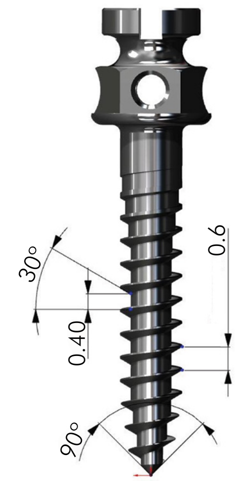

Figure 1: G_1 (30° X 0.6 mm).

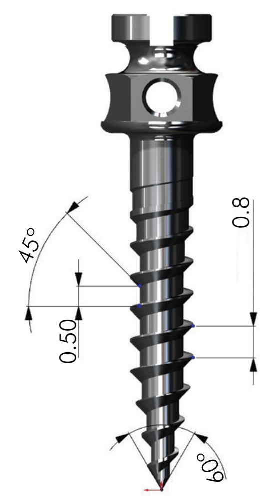

Figure 2: G_2 (45° x 0.8 mm).

Table 1. Division of the experimental groups.

Groups	Geometric Design of MI	Artificial Bone Density
G_1D_1	30° X 0.6 mm	0.32 g/cm^3
G_1D_2	30° X 0.6 mm	0.64 g/cm^3
G_2D_1	45° X 0.8 mm	0.32 g/cm^3
G_2D_2	45° X 0.8 mm	0.64 g/cm^3

to insert the MIs and measure the maximum torque (IT) in N.cm, oriented perpendicular to the bone surface.[24] The insertion site was previously perforated with a lance provided in the Kit from the manufacturer (Sistema INP®, São Paulo, Brazil). A mechanical arm was used to support the torque meter, in order to standardize screw insertion.[2]

Mini-implant stability was measured by the Periotest (Medizintechnik Gulden™ e.K., Modautal, Germany). After the appliance was calibrated, two PTV measurements were made for each test specimen. The second measurement confirmed the validity of the first. If the second measurement presented values higher or lower than two units, in comparison with the first, the appliance was recalibrated and the measurements were taken again. The higher the PTV, the greater the MI mobility; therefore, the lower the MI stability.

The maximum RT values were recorded during mini-implant removal. It was possible to determine the loss of torque (LT) values by determining the difference between the maximum insertion and removal values.[6]

Statistical analysis was performed with the Statistical Package for the Social Science Program (version 17, SPSS Inc., Chicago, USA). The normality and homogeneity of the sample were confirmed by the Kolmogorov-Smirnov and Shapiro-Wilk tests, after which the ANOVA/Tukey tests were used to determine the intergroup difference. A two-way ANOVA test was then used to detect the differences between mini-implant design and density factors.

Results

The results of the comparisons between the groups for variables IT, RT, LT and PTV are expressed in Tables 2, 3, 4 and 5, respectively.

No significant difference was observed between the groups, for IT in D_1. However, higher IT values were observed in D_2 for G_2 ($p \leq 0.05$). The mini-implant design and density factors in the two-way ANOVA test account for 1.5% ($p < 0.0001$) and 96.8% ($p < 0.0001$) of the total variance, respectively.

Table 2. Insertion Torque Values.

Groups	Minimum	Maximum	Mean (N.cm)	Standard Deviation	
G_1D_1	4.2	5.7	5.02[a]	0.68	Two-way ANOVA, density, $p < 0.0001$
G_2D_1	4.6	6	5.40[a]	0.65	
G_1D_2	15.7	17.3	16.64[b]	0.73	
G_2D_2	18.8	19.9	19.50[c]	0.43	

Two-way ANOVA: condition, design; $p < 0.0001$
One-way ANOVA: Different letters indicate statistical difference – $p \leq 0.05$ (ANOVA/Tukey).

Table 3. Removal Torque Values.

Groups	Minimum	Maximum	Mean (N.cm)	Standard Deviation	
G_1D_1	1.9	2.5	2.26[a]	0.23	Two-way ANOVA, density, $p < 0.0001$
G_2D_1	1.1	2.5	1.64[a]	0.54	
G_1D_2	7.8	9.8	8.76[b]	0.77	
G_2D_2	6.5	11	8.46[b]	2.08	

Two-way ANOVA: condition, design; $p = 0.3855$
One-way ANOVA: Different letters indicate statistical difference – $p \leq 0.05$ (ANOVA/Tukey).

Table 4. Loss of Torque Values.

Groups	Minimum	Maximum	Mean (N.cm)	Standard Deviation	
G_1D_1	2	3.3	2.76[a]	0.52	Two-way ANOVA, density, $p < 0.0001$
G_2D_1	3	4.9	3.76[a]	0.84	
G_1D_2	5.9	9.4	7.88[b]	1.34	
G_2D_2	8.4	13.2	11.04[c]	2.07	

Two-way ANOVA: condition, design; $p = 0.0030$
One-way ANOVA: Different letters indicate statistical difference – $p \leq 0.05$ (ANOVA/Tukey).

Table 5. Periotest Values (PTV).

Groups	Minimum	Maximum	Mean	Standard Deviation	
G_1D_1	21	27	23.40[a]	2.30	Two-way ANOVA, density, $p < 0.0001$
G_2D_1	15	19	16.80[b]	1.64	
G_1D_2	9	14	11.20[c]	2.16	
G_2D_2	9	13	11.00[c]	1.58	

Two-way ANOVA: condition, design; $p = 0.0013$
One-way ANOVA: Different letters indicate statistical difference – $p \leq 0.05$ (ANOVA/Tukey).

No difference was observed between the groups ($p \geq 0.05$), for the RT variable. The design factor accounts for 0.43% of the total variance in the two-way ANOVA test, but the effect of this factor is not considered significant ($p = 0.3855$). The density factor, however, accounts for 90.8% of the total variance, which was highly significant ($p < 0.0001$).

G_2 presented a significant difference only in D_2 ($p \leq 0.05$), for the LT variable. The design and density factors assessed by the two-way ANOVA test account for 8.7% ($p = 0.0030$) and 77.4% ($p < 0.0001$) of the total variance, respectively.

The PTV values were higher for the screw design of G_1, in comparison with G_2, when bone density was lower, indicating lower stability for G_1, whereas there was no difference for D_2 between the groups ($p \geq 0.05$). Both design and density factors assessed by the two-way ANOVA test were considered very significant: 10% ($p = 0.0013$) and 70.4% ($p < 0.0001$) of the total variance, respectively.

Discussion

In the present study, a synthetic material was chosen to ensure that natural bone variables would not influence the results for the mini-implant geometric characteristics.[25] Considering that previous studies have proven the impact of the cortical bone on mini-implant stability,[26,27] it was decided that the tests would be performed with artificial bone, representing the medullary bone area. Studies such as these are important, especially in the case of patients with an absence of satisfactory cortical thickness and bone quality, as found by Martinelli *et al.*[5] The densities chosen ($D_1 = 0.32$ g/cm^3 and $D_2 = 0.64$ g/cm^3) correspond to the mean bone density in the posterior (0.31 g/cm^3) and anterior (0.55 g/cm^3) regions of the maxilla.[28]

Distinct thread angulations had to be established for each group, in order to maintain the same length of the devices and vary the distance of the pitch. Therefore, G_1 threads presented an angulation of 30° with a 0.6 mm pitch, whereas G_2 threads presented an angulation of 45° with a 0.8 mm pitch.

The IT was used in the study to evaluate primary stability,[2,29,30] which is influenced by the morphological characteristics of the mini-implants.[18] It was demonstrated that the G_1 and G_2 screws had similar IT values in the lower density bone sample. When the density was greater, the G_2 screws had a higher IT (19.50 N.cm) than that of G_1 screws (16.64 N.cm) ($p \leq 0.05$). These results, in reference to the IT variable in D_2 bone (0.64 g/cm^3), may be explained by the design of the screws used, which differed in angulation and pitch distance. G_2 had more close-fitting contact with the adjacent tissues, therefore, demanding higher insertion torque, compared with G_1.

When evaluating the IT results independently of the screw design, higher IT was obtained when the bone density was greater, corroborating the finding that insertion of screws into bone of greater density generates higher stability values.[30]

An appropriate insertion torque allows ideal initial anchorage to be achieved; conversely, excessive torque increases the failure rate.[13] The levels of insertion torque obtained in the present study (5.02-19.50 N.cm) exceeded the ideal range of torque recommended for obtaining stability in human bone (5-10 N.cm). This variance may be attributed to the physical characteristics inherent to artificial bone.[29]

As regards RT, no difference was observed between the two screw designs, in bone of the same density. G_1 and G_2 behaved in a similar manner in D_1, and showed lower RT values than in D_2. In addition, it may be observed that the RT values obtained in the present study were lower than the IT values, a result that had been expected seeing that this was an *in vitro* trial, and that there was no influence exerted by either secondary stability or osseointegration factors.

The LT variable showed a difference between the two screw designs, only when the denser bone was used. G_1 showed lower loss of torque in comparison with G_2. When the IT and RT variables were analyzed separately, one could note that the higher IT in G_2 did not afford greater primary stability, since the RT values proved the same for both groups. Therefore, G_1 presented better general performance in denser bone, in comparison with the other group. The IT and RT variables appear more sensitive in detecting differences in primary stability between screws, when using bone of greater density.

The Periotest appliance proved more sensitive in detecting differences in screw stability when D_1 was used, in which higher values were observed for G_1 ($p \leq 0.05$), therefore, lower screw stability. The result indicates that G_2 showed better primary stability in bone of less density considering the disposition of the pitch at 45° and the longer distance of the pitches, favoring less bone cutting.

The Periotest was developed with the objective of measuring the level of periodontal integration of the tooth and the rigidity at the bone/implant interface.[31] Some studies have assessed its efficacy in measuring the primary stability of implants, and have observed that this method was capable of evaluating variations in bone composition.[15,16]

When evaluating the types of trials that were conducted, one observes that the IT and RT are tests in which the force is applied in the axial direction, whereas the Periotest evaluates stability in the laterolateral direction; therefore, these tests can be considered complementary. Moreover, it was observed that the tests performed in the axial direction were sensitive only for greater density, whereas the laterolateral test was capable of presenting statistical results at lower density.

Laterolateral tests are of notable importance, considering that the forces exerted on these devices, when used in a clinical setting, commonly occur in this direction.

The results indicated that the angle of the design and the distance of the pitch were significant enough to influence the primary stability, even when only the corresponding portion of the medullary bone is present. Nevertheless, the design of this study must be reproduced in an *ex vivo* or *in vivo* model to validate the results found with artificial bone. Moreover, other studies that take other variables into consideration should be performed, such as the cortical and bone maturation that occurs at the bone/implant interface during the healing period.[26]

Conclusion

The variation in mini-implant pitch distance was significant enough to influence all of the variables that measured primary stability (IT, RT and PTV).

In analyzing the IT and RT stability measurements (gauged in the axial direction), the MI pitch distance variation influenced stability only in greater density bone. In contrast, in analyzing the PTV measurement (that uses laterolateral forces), the difference in stability was observed between the groups only in lower density bone.

The mini-implants with a shorter pitch distance and an insertion angle of 30° (G_1) presented better primary stability in artificial bone of greater density.

The mini-implants with a longer pitch distance and an insertion angle of 45° (G_2) were found to be more stable in artificial bone of lower density, after evaluation with the Periotest.

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