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Influence of the Geometric Characteristics of the Mini-Implants on Mechanicals Properties Using Artificial Bone Similar to Anterior, Middle and Posterior Regions of the Jaws

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Abstract. The objective of this study was to identify the best torque of insertion and removal of mini-implants with a twin screw design (compact and self-drilling) into artificial bones with density and trabecular thickness, similar to anterior, middle and posterior regions of the jaws. Observation of the mini-implants surface using electron microscopy was performed before and after the tests. The torque values obtained during the insertion and removal was measured by digital torque wrench. The analyzed results led to the conclusion that the insertion and removal torques were larger with increase in bone density and cortical thickness. The design of the threads of the mini-implants influenced the insertion torque. Threads with smaller pitch increased the value of insertion torque. The anterior bone drilling installation reduces the insertion torque independent of bone density. Torque increased mainly by increasing the bone density and not necessarily with increased cortical thickness suggesting that the bone density of the trabecular bone must be considered in designing the installation of mini-implants.

Introduction

Some dental treatment with mini-implants (MI) can be considered standard in modern orthodontic practices once they treat conditions that are difficult to correct with conventional orthodontic mechanics [1]. The use of mini-implants are increasingly indicated for orthodontics treatments due advantages such as their small size, many insertion sites, simpler to place surgically, easy orthodontic connection, small or even no waiting period, no need for laboratory work, easier removal after treatment and low cost [2].

The holding power of mini-implants depends on the site of insertion, due the differences in bone quality and thickness in the maxilla and mandible [3]. The clinical awareness in relation to bone density and to thickness of the cortical shows the need to consider these characteristics in the definition of the mini-implant geometry design in the dental treatment plan [4]. A relationship between cortical bone thickness and primary stability of mini-implant should be considered in the planning [5], because, without primary stability, adequate secondary stability cannot be achieved [6,7]. The cortical bone has a higher modulus of elasticity when compared with cancellous bone. The cortical bone in the alveolar region in body of the maxilla tends to be thicker, less dense, and less stiff. There are significant differences between sites in thickness and density on regions of the maxilla [8].

The cortical bone thickness of maxilla or mandible are measured using the computed tomography images, in order to evaluate the areas for application of mini-implants and to suggest a clinical guide for installation. Kim and Park, 2012, compared the mandibular bone thickness of fifteen men and women [9]. The cortical bone in the mandibular buccal and lingual areas was thicker in men than in women. In men, the mandibular lingual cortical bone was thicker than the buccal cortical bone, except between the 1st and 2nd molars on both sides. In women, the mandibular lingual cortical bone was thicker in all regions when compared to the buccal cortical bone. The mandibular buccal cortical bone thickness increased from the canine to the molars. The mandibular lingual cortical bone was thickest between the 1st and 2nd premolars, followed by the areas between the canine and 1st premolar, between the 2nd premolar and 1st molar, and between the 1st molar and 2nd molar.

The thin cortical bone thickness is found frequently in between incisors [10]. In the alveolar process, one can expect approximately 1 mm or more of cortical bone thickness in the posterior dentition area. The recommended safe locations for mini-implant of diameter equal or less than 1.6 mm placement are between the second premolar and the first molar in the maxillary buccal alveolar bone, the maxillary posterior palatal alveolar bone, and the buccal alveolar bones from the first premolar to the second molar in the mandible [6]. The stability of a mini-implant is more affected by bone thickness than by the length of the mini-implant. When the cortical bone is thicker and the mini-implant is longer, the stability of the mini-implant is increased. The cortical bone is thicker in the mandible than in the maxilla on both buccal and lingual sides. A mini-implant may be longer in the maxillary arch than in the mandibular arch [11]. Mini-implants are often installed at a distance from cervical line of 5 mm to 8 mm. The cortical bone thickness of the maxilla and mandible were described by Hu et al, 2009 [11].

The mini-implants are composed of titanium Ti6Al4V alloy [12]. The diameter of the mini-implant is restricted by the available inter-radicular space. The recommended diameter of mini-implants to be placed in inter-radicular spaces is 1.2 mm to 1.6 mm. This depends on the location and the availability of inter-radicular space. More, long mini-implants are undesirable for safety reasons. The recommended length of mini-implants is 6 to 7 mm [6].

Several factors affect the pullout strength of mini-implants: bone density, morphological characteristics, insertion methods with or without predrilling [13,14] and variations in the design configuration. The insertion depth and diameter of the mini-implant influence the insertion torques, greater depth results in higher insertion torques therefore greater primary stability [15]. The mini-implant length should generally be as short as possible. Since both cortical bone thicknesses as depth are sufficient, the length not must be a factor for the selection of the screw length [16]. A high thread number and depth combined with a low pitch within the same implant length increase the surface area of the implants positively, affecting pullout strength and stress distribution upon loading [17]. There is a linear positive correlation between pullout strength and artificial bone density. The geometric characteristic of the threaded part of mini-implants is important to increasing the intra-osseous surface area associated with primary stability. Optimized surface chemistry and topography may promote the cellular response and increase secondary stability. The mini-implants showed significantly higher pullout strength with the 20 PCF (per cubic feet) bone density group [12]. The modification of thread may provide better mechanical stability. The dual-thread may be less harmful to the surrounding bone tissue because of the low insertion torque, it may need improvement for reducing the long insertion time to decrease the stress to the around tissue, dual-thread shape also shows higher removal torque on the broad range than the cylindrical and taper shapes [17]. The MIT values can be controlled by choosing a mini-implant diameter and lead angle of the thread according to the assessed thickness of cortical bone and the available space [18].

The objective of the present study was to identify the best insertion torque and removal of mini-implants inserted in artificial bone with densities similar to anterior, middle and posterior regions of the jaws.

Experimental

To estimate the influence of the density bone in primary stability, mini-implants (Conexão, São Paulo, Brazil) were inserted into artificial bones (Sawbones, Pacific Research Laboratories Inc USA and Nacional Ossos, São Paulo, Brazil), certificated by ASTM F-1839-08 (American Society for Testing and Materials). Test blocks were made of solid rigid polyurethane foam with densities and thickness similar the cortical and trabecular human bone [10,12,17] of anterior, medium and posterior jaws areas (see Fig. 1). The mechanical properties of the solid rigid polyurethane foam were defined for each jaws area based in literature [4,10-12,17] and are described in Tab. 1. The Tab. 2 shows the testing groups used in the present study. The mini-implants had chemical the chemical composition (mass %) of Ti (86,1%) Al (9,8%) and V (4,1%), corresponding to the Ti6Al4V alloy [12], data were obtained using energy dispersion (EDS) in a scanning electron microscopy (SEM).

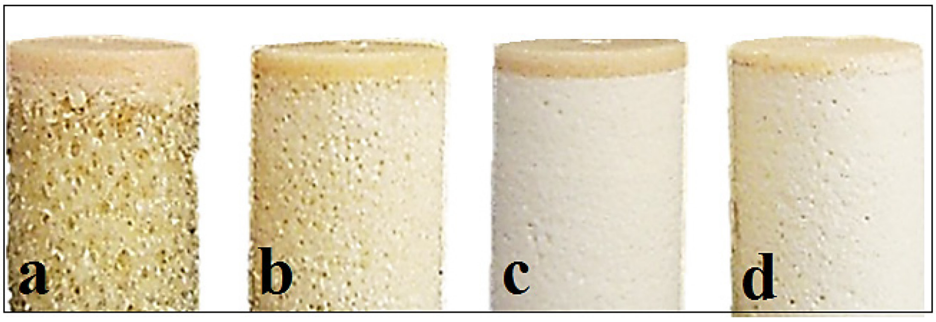

Fig. 1. Test blocks made of solid rigid polyurethane foam with foam with densities and thickness similar the cortical and trabecular bone of jaws area. **a**: Artificial bone block test 2 mm cortical thickness, 12.5 PCF - 20 g/cm³ bone density representing posterior maxilla area; **b**: 1.5 mm cortical thickness, 20 PCF - 32 g/cm³ bone density representing anterior maxilla area; **c**: 1.5 mm cortical thickness, 40 PCF- 64 g/cm³ bone density representing medium and posterior mandible area; **d**: 1.0 mm cortical thickness, 40 PCF - 64 g/cm³ bone density representing anterior mandible area.

The mini-implants were observed under a digital measuring microscope (scanning electron microscopy - SEM) to identify morphological characteristics, including thread depth, pitch and chemical composition. The mini-implants shape had three thread design: compacting threads denominate compact thread (CT), normal thread (NT) and self-drilling (SDT). The CT had three upper threads modifying design, showing less deep and shorter distance between the threads (pitch) than the NT that comprised the design of the remaining MI threads, besides the self-drilling portion that had a conical shape (see Fig. 2). The geometry characteristics of mini implants were selected according to the interroot distance and length of insertion site similarly as in human jaws [17]. Different lengths and diameters were necessary; however, all were the same threads design. The mechanical study was realized in two steps: without predrilling group and with predrilling group. The mini-implants were inserted perpendicular to the bone block surface just below the collar into the cortical bone, according to the manufacturers' instructions, 10 per bone group and implant type [12] followed classification described in Tabs. 1 and 2.

Each mini-implant was screwed into one bone sample. The bone punch was used for cortical perforation, as guide for mini-implant insertion in both groups. First step, 60 mini implants were inserted in the bone block without predrilling and in the second step others 60 mini-implants were inserted as predrilling of a pilot hole of diameter of 1 mm. The mini-implants were inserted and removed with digital torquemeter and rotation equipment. The torque force (in N.cm) versus elapsed time (in seconds) for each group was digitally recorded. The surface of the mini-implants was observed using a scanning electron microscopy (SEM) after the removal.

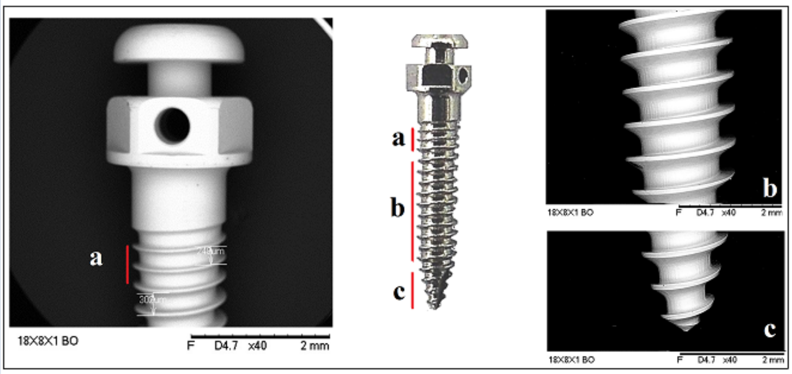

Fig. 2. Electron backscattered image obtained using scanning electron microscopy (SEM). a: Mini-implant measuring 18x8x1 mm. The three first compacts threads (CT) had a pitch of 2.4 µm. The depth of the CT (a) was smaller than the depth of the NT as pitch of 3.02 µm (b).; b: normal threads (NT); c: self-drilling conical shape.

Table 1. Geometrical characteristics of the used mini-implants and test blocks. The artificial bone density were similar as the trabecular and cortical bone thickness of posterior, medium and anterior jaws area.

Jaws area		Geometric characteristics of the mini-implants			Mechanical properties of the solid rigid polyurethane foam		
		Dimension MI	Predrilling numbers	Without predrilling	Trabecular bone density in PCF (g/cm^3) and maker		Cortical bone (mm)
Maxilla area	Posterior	1.8x8x2	10	10	12.5	(0.20) Sawbones	(2.0) Sawbones
	Medium	1.8x6x2	10	10	20	(0.32) Nacional Ossos	(1.5) Sawbones
	Anterior	1.5x6x1	10	10	20	(0.32 Nacional Ossos	(1.5) Sawbones
Mandible area	Posterior	1.8x8x1	10	10	40	(0.64) Nacional Ossos	(1.5) Sawbones
	Medium	1.8x8x1	10	10	40	(0.64) Nacional Ossos	(1.5) Sawbones
	Anterior	1.5x6x2	10	10	40	(0.64) Nacional Ossos	(1.0) Sawbones

Table 2. Characteristics of four analyzed groups. The classification was based in density trabecular and thickness cortical of the bone block test.

Group	Jaws area	MI	Trabecular bone density PCF (g/cm^3)		Cortical bone thickness mm
1	Posterior/medium mandible	1.8x8x1	40	0.64	1.5 mm
2	Posterior maxilla	1.8x8x2	12.5	0.20	2.0 mm
3	Medium/anterior maxilla	1.5x6x1	20	0.32	1.5 mm
4	Anterior mandible	1.5x6x2	40	0.64	1.0 mm

Results and Discussion

The maximum insertion torque (MIT) and the maximum removal torque (MRT) were measured in each group using a torque tester at a controlled speed of rotations. The MIT and MRT were higher in the group with highest density of trabecular bone. The group 1 was the highest value of insertion torque of 24 N.cm (Fig. 3) in 10 mechanic tests with the block of the highest density and mini-implant with the highest length/diameter. The lowest insertion torque value of 10 N.cm was obtained by group 2. The recommended optimal MIT value was between 5 N.cm and 10 N.cm for improved clinical results. The MIT for group 1 was 22.4 N.cm of group 2 was 10.1 N.cm. In the region of compact thread (CT) the time for the torque was smaller than self-drilling thread (STD). The group 1 was the highest value of removed torque of 18.4 N.cm. The lowest value insertion torque was 10 N.cm obtained by group 2. The MRT of group 1 was 18.9 N.cm and the MRT of group 2 was 9.1 N.cm. The comparison testing mean insertion and removal curves between group 1 and group 2 are shown in Fig. 3 and Fig. 4, respectively.

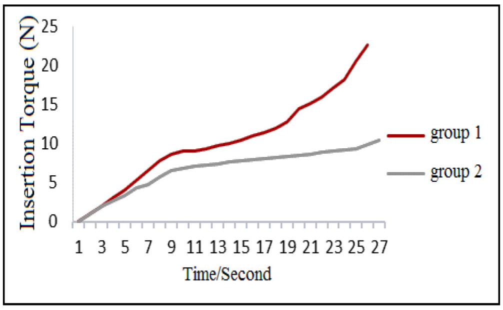

Fig. 3. Mean value insertion torque of group 1 and group 2. The group 1 was the highest value of insertion torque of 24 N.cm. The lowest value insertion torque was 11 N.cm obtained in group 2.

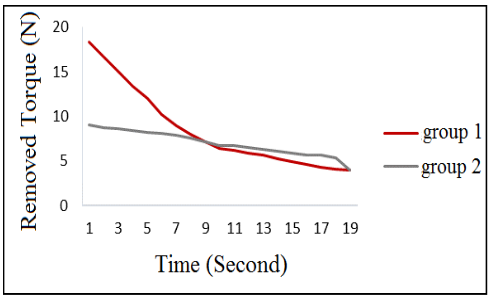

Fig. 4. Mean value removal torque of group 1 and group 2. The group 1 was the highest value of removed torque of 18.4 N.cm. The lowest value insertion torque was 10 N.cm obtained in group 2.

The MRT of group 4 was 11.9 N.cm and the trabecular bone density was lower than group 1 with MTR of 22.9 N.cm, most probability due mini-implant diameter (6 mm) and thickness cortical bone (1 mm) was the lowest in group 4, suggesting that the diameter and length of mini-implant or the cortical bone thickness influenced the primary stability, see Fig. 5. Similarly, the group 3 (similar anterior maxilla area) was MIT of 10.9 N.cm and MRT of 10.3 N.cm, discreetly lower than group 4 (similar anterior mandible area) with MIT 11.9 N.cm and MRT of 10.6 N.cm. The mini-implants had equals size and the thickness cortical bone block the group 4 was only 0.5 mm lower, although the trabecular bone block density was denser with 40 PCF compared as group 3 with 20 PCF. It was evident the influence of the mechanicals properties of artificial bone, on the other hand no was clean if trabecular bone density had more influence than cortical bone thickness. The MIT was greater MRT when compared the results of all groups, with or without predrilling.

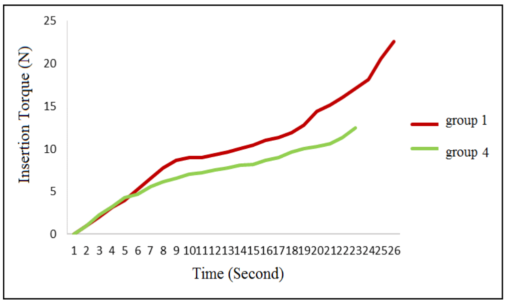

Fig. 5. Mean insertion torque of group 1 compared to group 4. The group 1 (similar medium and posterior mandible area) was MIT of 22.9 N.cm and the group 4 (similar anterior mandible area) showed MIT of 11.9 N.cm. The highest insertion torque in group 1 was 24 N.cm and group 4 was 12 N.cm.

The removal torque decreased discreetly in all groups with torque range of 1 s of elapsed time to 2 s. The mechanical trial of group 2 showed a long interval to decrease the torque as range 4 s to 8 s, even though the long MI, due the trabecular bone has a lower density. A short interval was observed when the compact threads (CTs) were inserted in cortical bone alike occurred when CTs were removed. This suggests the important influence of cortical bone in stability primary in the presence the bone density. The correlation between the thread pitch and the interval time in insertion was relationship with the increase of torque.

The mechanical testing was realized with predrilling (1 mm) in 60 bone test blocks and 60 mini-implants, according protocol used in mechanical testing without predrilling (see Tab. 1). The results demonstrated a no linear data progression when compared with without predrilling. The MIT was lower than the date obtained as mechanical trial without pre--drilling. The MRT occasionally was greater than MIT when compared with predrilling, the exception was in group 2 where the density bone was lower than all groups. The mechanical resistance of mini-implants was analyzed compared the electron backscattered image obtained by scanning electron microscopy (SEM) before and after mechanical testing. The image obtained before showed insignificant artifices (Fig. 6 arrows in red) in edge, that were removed in mechanical trial by friction as bone block, however no were detected fractures or any significant deformation, demonstrating adequate mechanical strength to the highest torque value of 24 N.cm obtained in the present study.

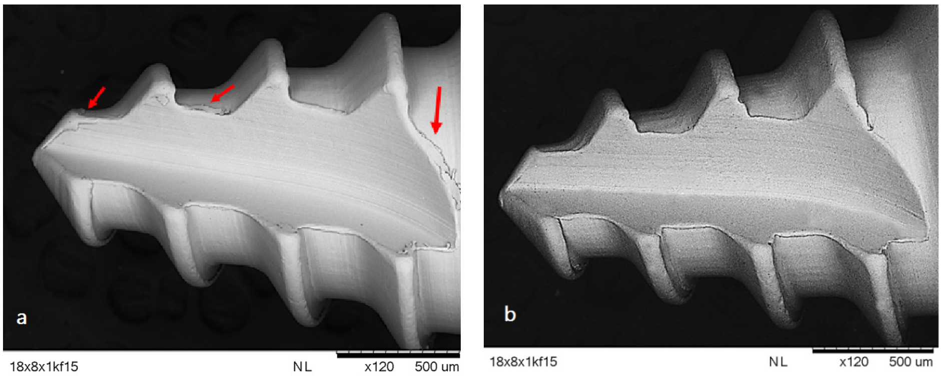

Fig. 6. a: Electron backscatter image obtained in a scanning electron microscope before insertion in the block test, conical shape of MI 18x8x2 showing a slight surface wear, see red arrows. b: Electron backscatter image after removal, conical shape of MI 18x8x2.

Conclusion

The maximum insertion torque (MIT) identified to the mandible without predrilling areas were: posterior 23 N.cm, middle 23 N.cm and posterior 12 N.cm.

The maximum insertion torque (MIT) identified to the maxilla without predrilling areas were: posterior 11 N.cm, middle 11 N.cm and posterior 11 N.cm.

The characteristics the mini-implants influence in value the insertion torque.

The thread design can have influence in maximum insertion torque.

The design and Ti6V4V alloy resisted on strength than were submitted the mini-implants and no were detected distortions or fracture.

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