PONTIFÍCIA UNIVERSIDADE CATÓLICA DE MINAS GERAIS
Programa de Pós-graduação em Odontologia

Gabriela Barros Lopes

PROPRIEDADES MECÂNICAS DE MINI-IMPLANTES UTILIZADOS NA ANCORAGEM EXTRARRADICULAR

Belo Horizonte
2019

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Dissertação apresentada ao Programa de Pós-graduação em Odontologia da Pontifícia Universidade Católica de Minas Gerais, como requisito parcial para a obtenção do título de Mestre em Odontologia, Área de Concentração: Implantodontia.

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Orientador: Prof. Dr. Rodrigo Villamarim Soares

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3- Prof. Dr. Rodrigo Villamarim Soares – PUC Minas

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Coordenador do Programa de Pós-graduação em Odontologia

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“Nada te perturbe, nada te espante, tudo passa, Deus não muda, a paciência tudo alcança; Quem a Deus tem, nada lhe falta: Só Deus basta” (SANTA TERESA D’ÁVILA)

RESUMO

Desde seu surgimento como recurso de ancoragem, os mini-implantes (MI) evoluíram significativamente. Seu posicionamento interradicular inicialmente proposto tem sido modificado para extrarradicular. Apesar de serem amplamente utilizados na atualidade, poucos estudos dedicaram-se a investigar as características dos MI a serem utilizados extrarradicularmente. Partindo desse pressuposto, o objetivo do presente estudo foi avaliar as propriedades mecânicas de MI manufaturados em aço inoxidável e compará-las às de MI convencionais da liga de titânio-alumínio-vanádio. Para isto, os seguintes grupos (n=24) foram criados: G1 MI de aço 8 x 1,5 mm; G2 MI de aço 12 x 2,0 mm e G3 MI de titânio 10 x 1,5 mm. Estes 72 MI foram inseridos na região da crista infrazigomática na maxila e trígono retromolar da mandíbula de 10 porcos. Os testes de *Pull Out*, torque de inserção e percussão, foram realizados, a fim de mensurar a estabilidade primária, resistência à fratura e resistência à tração dos MI. A microscopia eletrônica de varredura (MEV) foi conduzida para a avaliação morfológica dos MI novos e após a fratura. Os valores de torque de inserção e de fratura de G2 foram significativamente maiores que G1 e G3 ($p<0,05$). O teste *pull out* e de percussão apresentou valores similares entre os grupos. A MEV revelou que o ponto de fratura era, predominantemente, na quarta rosca para os MI de aço (G1 e G2) e na sétima rosca para os MI de titânio-alumínio-vanádio (G3). Tendo em vista que G2 apresentou resultados superiores em duas avaliações, e que G1, mesmo sendo mais curto teve resultados similares a G3, os resutados do presente estudo indicam que as propriedades mecânicas dos MI em aço inoxidável são superiores às dos MI na liga titânio-alumínio-vanádio.

Palavras-chave: Procedimentos de ancoragem ortodôntica. Aço inoxidável. Titânio. Ortodontia. Ancoragem.

ABSTRACT

Since its emergence as an anchor feature, mini-implants (IM) have evolved significantly. Its initially proposed interradicular positioning has been modified to extraradicular. Despite being widely used today, few studies have focused on the characteristics of IM to be used extraradicularly. Based on this assumption, the aim of the present study was to evaluate the mechanical properties of MI manufactured in stainless steel and to compare them with conventional MI properties of titanium-aluminum-vanadium alloy. For this, the following groups were created: G1 (n = 24) steel MI 8 x 1.5 mm; G2 (n = 24) MI of steel 12 x 2.0 mm and G3 (n = 24) MI of titanium 10 x 1.5 mm. These 72 MI were inserted into the infrazigomatic crest region in the maxilla and retromolar trine of the mandible of 10 pigs. Pull out, insertion torque and percussion tests were performed to measure primary stability, fracture resistance and tensile strength of the MI. Scanning electron microscopy (SEM) was conducted for morphological evaluation of new MI and after fracture. G2 insertion torque and fracture values were significantly higher than G1 and G3 ($p < 0.05$). The pull out and percussion test presented similar values between the groups. SEM revealed that the fracture point was predominantly on the fourth thread for steel MI (G1 and G2) and on the seventh thread for titanium aluminum vanadium (G3) MI. Considering that G2 presented superior results in two evaluations and that G1, although shorter, had similar results to G3, the results of the present study indicate that the mechanical properties of stainless steel MI are superior to those of titanium alloy aluminum vanadium.

Keywords: Orthodontic anchorage procedures. Stainless steel. Titanium. Orthodontics. Anchoring.

SUMÁRIO

1 INTRODUÇÃO

O alcance da "ancoragem absoluta" é um desafio na Ortodontia. Para esta finalidade, inicialmente, foi utilizado um parafuso ou um implante como ancoragem esquelética para facilitar o tratamento ortodôntico (KANG *et al*., 2016). Essa abordagem revolucionou a ortodontia ao longo dos anos, permitindo que a ancoragem estável fosse alcançada com segurança (PITHON; NOJIMA; NOJIMA, 2012).

Os mini-implantes (MI) estão disponíveis em uma variedade de formas, diâmetros, comprimentos e composições de ligas de titânio (BURMANN *et al*., 2015). Os MI ortodônticos manufaturados com a liga titânio/alumínio/vanádio são utilizados como recurso de ancoragem na Ortodontia contemporânea. Surgiram com a proposta de obter previsibilidade nos tratamentos ortodônticos sem que houvesse tanta colaboração por parte dos pacientes. Eles são utilizados no espaço interradicular concomitantemente associado a diversas mecânicas ortodônticas (DALVI; ELIAS, 2015).

A utilização de MI está atrelada a uma infinidade de pontos positivos como: facilidade de inserção, baixo custo e estabilidade ao tecido ósseo (PAIVA *et al.*, 2015). O reposicionamento dos MI, apesar de não ser um procedimento doloroso, gera desconforto ao paciente no que diz respeito à ansiedade. A estabilidade primária do MI, ou seja, a fixação adquirida no momento de inserção do MI no seu leito, é importante, porque a maioria dos incidentes e falhas relacionadas aos parafusos ocorrem no estágio primário (LIM; CHA; HWANG, 2008). Modificações no *design* dos MI podem afetar substancialmente suas propriedades mecânicas, aumentando a estabilidade primária e reduzindo falhas na ancoragem (CHANG *et al.*, 2012; GRACCO *et al.*, 2012). A qualidade óssea, por sua vez, é particularmente importante para os MI ortodônticos, pois eles são retidos por travamento mecânico ao invés da osseointegração (CHANG; LIU; ROBERTS, 2015; McMANUS *et al.*, 2011; WILMES; DRESCHER, 2011).

A inserção dos MI em locais extrarradiculares, como a crista infrazigomática, vem sendo aplicada e permite maior versatilidade aos movimentos ortodônticos, uma vez que a posição alta do parafuso livra as raízes de uma provável interferência com o deslocamento dentário, sendo possível conseguir a distalização de toda a arcada superior (ALMEIDA, 2017). A região de *buccal shelf* tem sido utilizada como sítio de inserção na ancoragem extrarradicular. Ela está localizada na porção posterior da mandíbula, anteriormente à linha oblíqua externa, entre o primeiro e segundo molar, e possui a vantagem de evitar o contato do MI com a raiz dentária durante a movimentação ortodôntica (NUCERA *et al.*, 2017).

Os MI extrarradiculares podem ser usinados em aço inoxidável, que não permite osseointegração, sendo apropriado para uso em situações em que se deseja removê-lo após seu uso temporário, como no caso dos MI. Além disso, possui maior módulo de elasticidade em relação à liga Ti-6Al-4V e maior resistência mecânica que o Ti puro, o que possibilita a confecção de peças com menores dimensões (DALVI; ELIAS, 2015). O aço foi selecionado devido à sua resistência à fratura quando colocado no osso cortical denso (CHANG; LIN; ROBERTS, 2019). Apesar desse pressuposto ser descrito, ainda faltam evidências que o comprovem. Os estudos investigando a establidade dos mini-implantes possuem como foco a medição da força mecânica, incluindo torque de inserção, torque de remoção e teste *Pull Out e* a região de ancoragem pode influenciar estas forças mecânicas (MOTOYOSHI *et al*., 2010; PITHON; NOJIMA; NOJIMA, 2011; SUZUKI; SUZUKI, 2011; TEPEDINO; MASEDU; CHIMENTI, 2017; TSENG *et al*., 2017). Partindo dessas premissas, a proposta do presente estudo foi avaliar as propriedades mecânicas dos MI em aço inoxidável e compará-las à dos MI usinados na liga de titânio/alumínio/vanádio com a perspectiva de utilizá-los como recurso de ancoragem extrarradicular. Para isso, foram realizados testes mecânicos, bem como análise da morfolofigia de ambos os tipos de MI.

2 OBJETIVOS

2.1 Objetivo geral

Avaliar as propriedades mecânicas dos mini-implantes em aço inoxidável e compará-las à dos mini-implantes usinados na liga de titânio/alumínio/vanádio.

2.2 Objetivos específicos

a) avaliar a estabilidade primária, a resistência à fratura, o padrão de fratura e as características morfológicas dos mini-implantes de aço inoxidável e titânio, comparando os dados obtidos.

3 ARTIGO

Mechanical properties of mini-implants used in extra-radicular anchorage

Os resultados desse trabalho foram compilados na forma de artigo a ser submetido ao periódico ***The Angle Orthodontist*** (Qualis A2), de acordo com as normas do periódico, que podem ser acessadas em: https://www.angle.org/page/submit

Mechanical properties of mini-implants used in extra-radicular anchorage

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Keywords: Orthodontic Anchorage Procedures; Stainless steel; Titanium; Orthodontics; Anchoring

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Abstract

Aim: To evaluate the mechanical properties of mini-implants (MI) manufactured in stainless steel and compare them with conventional titanium-aluminum-vanadium alloy MI.

Materials and methods: the following groups were formed: G1 (n = 24) 8 x 1.5 mm steel MI; G2 (n = 24) 12 x 2.0 mm steel MI and G3 (n = 24) 10 x 1.5 mm titanium MI, respectively. The 72 MI were inserted in the infrazigomatic crest region of maxilla and retromolar trigone in the jaw of 10 pigs. Pull-out, insertion torque, fracture and percussion tests were performed in order to measure tensile strength, primary stability and fracture strength of MI. For this purpose, digital torque gauge was used to measure insertion and fracture torque, the universal mechanical testing machine for pull-out testing and the periotest device to measure the micromovement of MI. For morphological and mini-implant component evaluation, scanning electron microscopy (SEM) was performed. D'Agostino & Pearson, Kruskal-Wallis, Dunn post-hoc normality tests were used.

Results: G2 insertion and fracture torques were significantly higher than G1 and G3 ($p < 0.05$). The pull-out and percussion test presented similar values among groups. SEM revealed that the fracture point was predominantly on the fourth thread for steel MI (G1 and G2) and on the seventh thread for titanium-aluminum-vanadium MI (G3).

Conclusion: Considering that G2 presented higher results in two evaluations, and that G1, although shorter, had results similar to G3, the results of the present study indicate that the mechanical properties of stainless steel MI are superior to those of titanium-aluminum-vanadium alloy MI.

Keywords: Orthodontic Anchorage Procedures; Stainless steel; Titanium; Orthodontics; Anchoring

INTRODUCTION

Orthodontic mini-implants (MI) were developed with the purpose of obtaining predictability in orthodontic treatments, being used in the inter-radicular space, concomitantly associated with various orthodontic mechanics[1].

The use of MI is linked to several positive points such as easy insertion, low cost and stability to bone tissues[2,3]. However, since they are positioned between dental roots, the need to reposition them during orthodontic treatment is not uncommon. Although it is not a painful procedure, repositioning generates discomfort to patients regarding anxiety[2,3]. In addition, sometimes MI fail and are occasionally removed for acquiring mobility during treatment[4].

In the search for alternatives to avoid MI replacement, extra-radicular anchorage MI were developed, which are positioned in areas distant from dental roots[5]. Extra-radicular MI can be manufactured in stainless steel, which has been selected as a material due to its fracture resistance when placed in dense cortical bone[6]. Although this assumption has been described, there are few studies comparing the performance and mechanical properties of MI of different materials[7].

In this context, the aim of the present study was to evaluate the mechanical properties of MI manufactured in stainless steel and compare them with those manufactured in titanium aluminum-vanadium alloy with the perspective of using them as extra-radicular anchoring resource. The hypothesis that stainless steel MI has better mechanical strength than those in titanium-aluminum-vanadium alloy was also verified.

MATERIAL AND METHODS

Group formation and MI installation

In the present study, MI were used (n = 72), 36 manufactured in stainless steel (Dat Steel®, Implant System Ltda, São Paulo, Brazil) and 36 manufactured in Ti6Al4V alloy (Morelli® , São Paulo, Brazil), in the dimensions of 8 x 1.5 mm and 12 x 2.0 mm (steel MI) and 10 x 1.5 mm (titanium MI). The groups formed and the tests applied can be observed in Figure 1.

MI were inserted in the infrazigomatic crest region of maxilla and retromolar trigone in the jaw of pigs (*Sus scrofa domesticus*) slaughtered for human consumption. MI insertion was performed by the same operator after the euthanasia of animals. Up to the moment of MI insertion, bone samples were immersed in saline at temperature of -20ºC to maintain their physical and biological properties. Prior to using the substrate for MI insertion, heads were thawed at room temperature.

The regions where MI were inserted were standardized, consisting of the infrazigomatic crest region of maxilla and buccal shelf region, which comprises the posterior portion of the mandible, anteriorly to the external oblique line, between the first and second molars (Figure 2).

Mechanical Tests and morphological evaluation

Mini-implants were then inserted to assess primary stability (insertion torque measurement), where the MI insertion key was adapted to the digital torque gauge (Lutron TQ-8800, Taipei, Taiwan) (Figure 3). Bone tissue was kept attached to a grip that kept it stable during insertion so that mini-implants could all be inserted in the same place and by the same operator. Insertion torque was measured by manual MI rotation with digital torque gauge until its complete insertion was achieved. Then, the maximum torque value was measured. Once the insertion torque was measured, blocks containing bone tissue and the mini-implant (5 x 5 cm) were then obtained. Bone block removal was performed with a low-speed steel disc under saline cooling.

With sets containing bone block and the mini-implant, the pull-out test was performed in a universal mechanical testing machine (Oswaldo Filizola AME-2kN, São Paulo, São Paulo, Brazil). To perform the tensile test, two devices were coupled to the machine: one in the form of a crowbar coupled in the upper part and used for grasping the MI and the other in the lower portion, which served as a base to fix the specimen and keep the MI perpendicular to the ground. For MI removal, speed of 5 mm / min in a load cell of 500 kgf was used.

Fracture torque was performed, as well as the insertion torque evaluation; the only difference was that torsion in this situation was prolonged until its fracture and not only until bone insertion.

Then, the resonance test was evaluated by electromechanical percussions, in which the degree of mobility of the MI was measured. For this, the device tip (Periotest®, model 3218, Medizintechnik Gulden, Modautal, Germany) was stabilized parallel to the bone surface and perpendicular to the MI, which in turn was kept at distance of 2 mm from the tip, according to manufacturer's recommendations. For each specimen, 16 percussions were performed for approximately 4 seconds. The value (PTV) was displayed on the device monitor and transferred to a spreadsheet. The index varies on a scale from -8 to +50, and values between -8 and +9 indicate that teeth are fixed on osseointegrated implants; between +10 and +19 indicate palpable mobility; between +20 and +29, visible mobility; and between +30 and +50, mobility caused by tongue or lip pressure. The lower the PTV, the lower the mobility and the greater the implant stability.

To evaluate the mini-implant fracture pattern, scanning electron microscopy (SEM) was performed (JEOL - SM-IT300 - JEOL, Tokyo, Japan).

Statistical analysis

Initially, data were submitted to the D'Agostino & Pearson normality test, which showed non-normal distribution. The Kruskal-Wallis test, followed by the Dunn post-hoc test, was used to assess the existence of differences in “torque insertion”, “percussion”, “pull-out” and “fracture torque” variables among the three different MI types. The significance level was set at 5%. Analyses were performed using GraphPad Prism 6.05 software (GraphPad Software, San Diego, California, USA).

RESULTS

Results corresponding to insertion torque, percussion, pull-out and fracture torque can be seen in table 1. The insertion torque, as well as the fracture test, showed that G2 presented values significantly higher than G1 and G3 ($p < 0.05$). The pull-out and percussion test showed absence of significant differences among groups (G1, G2 and G3). SEM revealed that the fracture point was predominantly on the fourth thread for steel MI (G1 and G2) and on the seventh thread for titanium aluminum vanadium MI (G3) (Figure 4).

DISCUSSION

MI insertion in extra-radicular sites, such as the maxillary infrazigomatic crest, has been applied and allows greater versatility to orthodontic movements[5,6]. The buccal shelf region in the mandible, in turn, has also been used as insertion site for extra-radicular anchorage[8,9]. Therefore, evaluating the mechanical properties of extra-radicular MI is of extreme importance in view of the absence of studies proving differences among MI manufactured in different materials.

The insertion torque measurement is an important parameter and is related to the mini-implant primary stability[4,15,17,19,20]. MI dimensions influenced the insertion torque values, considering that the larger the MI diameter, the higher the insertion torque values.

Considering that primary stability is one of the key factors for the clinical success of MI[8,10-13], its evaluation can be performed by methods such as periotest, pull-out and insertion/removal torque. It is defined as mechanical bone stability immediately after MI insertion[14-17] and it should be noted that cortical bone is an important factor in MI stability[11,14,15,17,18]. In the present study, it was observed that the primary stability of 12 x 2.0 mm steel MI was superior to the other evaluated MI.

MI alloy length and type directly affect their mechanical properties[7]. In this study, this relationship was observed, since differences among groups were found. 12 x 2.0 mm steel MI showed greater insertion torque and fracture than 8 x 1.5 mm steel MI and 10 x 1.5 mm titanium MI.

In other studies, Exposto et al.[21] and Wilmes and Drescher[19] stated that screws with smaller diameters have higher risk of fracture and are less stable, while those with larger diameter have higher anchoring strength. Chang et al.[10] reported that the main MI failure factors include type, diameter, patient age, mandibular plane angle, cortical bone thickness, insertion torque and type of orthodontic movement.

For Pithon, Nojima and Nojima[11], MI diameter do not have a decisive influence on primary stability, but rather their shape and the regions of the oral cavity in which they are inserted. For Marquezan et al.[22], the primary stability of MI was not different for different bone types. In contrast, Wilmes and Drescher[19] reported that cortical thickness, MI design and size, as well as implant site preparation have a major impact on insertion torques and, therefore, on primary MI stability.

In the studies by Lim, Cha and Hwang[15] and Pithon, Figueiredo and Oliveira[23], the maximum insertion torque increased with increasing MI length and increasing cortical bone thickness[24]. Wilmes and Drescher [19] reported that in order to achieve satisfactory insertion torque, to avoid MI fracture and excessive bone stress, a combination of pre-perforation diameter and MI must be chosen according to insertion site and bone density.

In the present study, the insertion torque of 12 x 2.0 mm steel MI (G2) was higher than the other groups (G1 - 8 x 1.5 mm steel MI and G3 - 10 x 1.5 mm titanium MI) and similar between 8 x 1.5 mm steel MI and 10 x 1.5 mm titanium MI groups (G1 and G3). In the study by Morarend et al. (2009), MI inserted into larger diameter (2.5 mm) monocortical bone provide greater anchorage strength compared to smaller diameters (1.5 mm) in both mandible and maxilla. However, those of 1.5 mm in diameter when inserted into bicortical bone were similar to those of 2.5 mm in monocortical bone.

The tensile torque, in turn, measures the force strength required for MI removal after orthodontic treatment[4]. This test consists of extracting the mini-implant from bone tissue at constant speed, allowing evaluating the maximum force required to remove the implanted device[11]. The resulting starting force has been described in the orthopedic, maxillofacial and orthodontic surgery fields as a fundamental biomechanical parameter that contributes to the primary stability of screws[2]. Pithon, Nojima and Nojima[11] reported that the tensile forces presented by MI inserted in different regions of the maxilla and mandible of pigs were higher than those for clinical purposes (between 0.3 and 4.0 N), validating their use in these regions.

In this study, steel and titanium MI had similar performance in the applied pull-out tests. According to Dalvi and Elias[1], tensile tests showed that F138 steel and Ti-6Al-4V MI showed similar behavior when removed from 2 mm cortical bone, while Ti-6Al-4V MI when removed from 3 mm cortical bone showed significantly higher torques. For Gracco et al.[2], the body shape of MI influenced the tensile strength and, consequently, the primary MI stability.

Fractures due to MI insertion and removal stress are associated with the material in which they are made, geometric design and bone quality[25]. Modifications in MI design can substantially affect their mechanical properties[10]. In contrast, for Tseng et al.[17], long-term MI stability was not directly affected by design. MI fractures are usually generated by torsional stress caused by their small diameter[1,25]. In this study, larger diameter (2.0 mm) MI performed better than those of smaller diameter (1.5 mm). Pithon, Figueiredo and Oliveira[23] did not find any influence of MI length on fracture resistance during MI flexion.

Percussion test (Periotest®) is a reliable indicator for measuring implant stability at both conventional and immediate loads [12]. However, for Hosein et al.[13], it should be used in combination with other mechanical tests. In the present study, percussion test evaluation did not reveal significant differences among groups evaluated; however, in the study by Tseng et al.[17], 2.0 x 11 mm titanium MI showed higher resonance values than 2.0 x 12 mm titanium MI and 2.0 x 12 mm steel MI. Nienkemper et al.[26] also observed, through Periotest, that it has linear relationship between primary stability and MI insertion depth, and also with the MI size[27] and that Periotest values measured 3 weeks after implant insertion were smaller than those measured at insertion[28].

Scanning electron microscopy (SEM) was performed on intact and posttest MI (Figure 4). The fracture point was predominantly on the fourth thread for steel MI (G1 and G2) and on the seventh thread for titanium aluminum vanadium MI (G3) (Figure 4). In the study by Pithon, Figueiredo and Oliveira [23], 6 mm, 8 mm and 10 mm titanium MI fractured in similar regions between the first and second threads. Comparing nTi, cpTi and Ti-6Al-4 V MI, Serra et al. [29] observed that all had similar fracture process and torsion strength was higher in nTi and Ti-6Al-4V mini-implants.

With this study, it was possible to evaluate the performance of steel and titanium MI for extra-radicular use. In addition, its clinical relevance lies in the fact that it is the first to evaluate the mechanical properties of steel and titanium MI inserted in the extra-radicular regions of pigs, similar to those of humans. However, the limitation of this study was due to the non-measurement of cortical thickness of regions in which MI were installed, as well as limitations inherent to *in vitro* studies and mechanical assays, suggesting the conduction of human trials to prove the results.

CONCLUSIONS

The results of the present study indicate that the mechanical properties of stainless steel MI are superior to that of titanium aluminum-vanadium MI. Thus, the hypothesis that steel MI have higher mechanical strength than titanium ones has been proven.

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Legend of Figures

Figure 1. Flowchart.

Figure 2. MI insertion position in the Buccal Shelf region (a) and infrazigomatic crest (b).

Figure 3. Digital torque gauge (Lutron TQ-8800, Taipei, Taiwan).

Figure 4: Scanning Electron Microscopy of intact MI.12x magnification

(a) 8 mm steel MI; (b) 12 mm steel MI; (c) 10 mm titanium MI.

Scanning Electron Microscopy of MI after fracture. 14 and 30x magnification. (d) 8 mm steel MI; (e) 12 mm steel MI; (f) 10 mm titanium MI.

Figure 1.

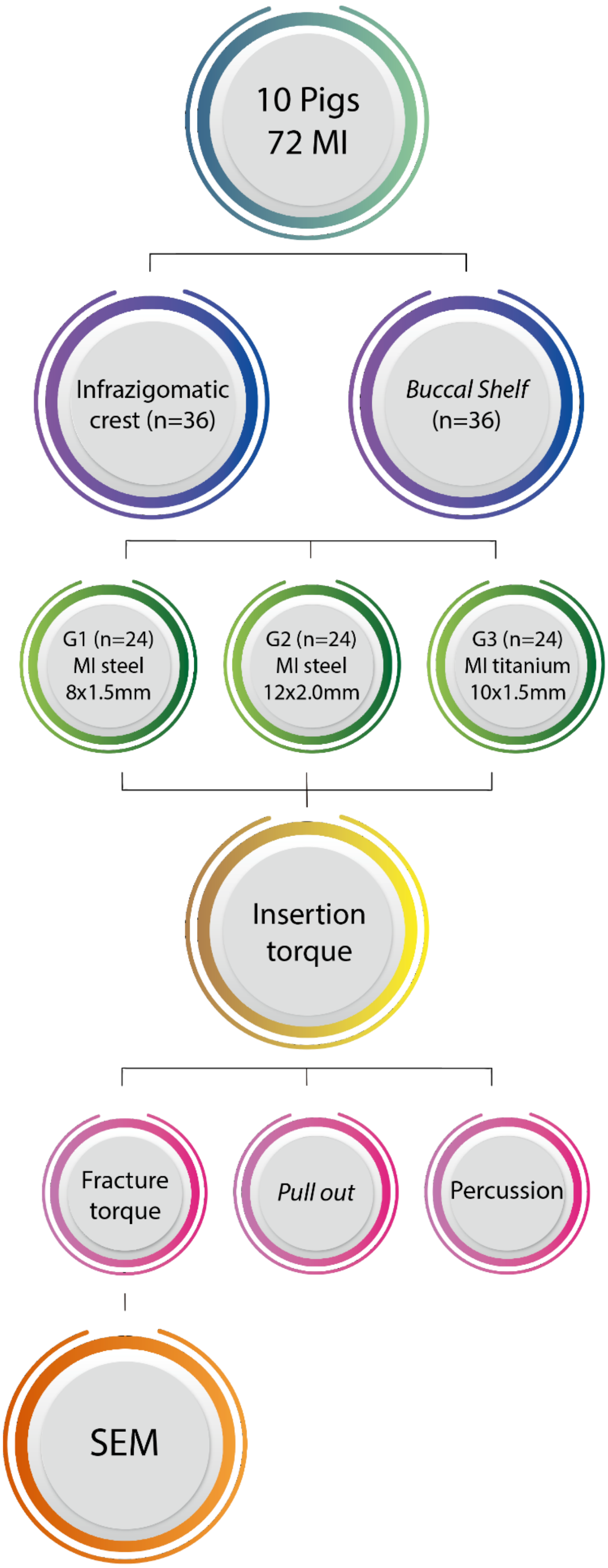

10 Pigs
72 MI
Infrazigomatic crest (n=36)
Buccal Shelf (n=36)
G1 (n=24) MI steel 8x1.5mm
G2 (n=24) MI steel 12x2.0mm
G3 (n=24) MI titanium 10x1.5mm
Insertion torque
Fracture torque
Pull out
Percussion
SEM

Figure 2.

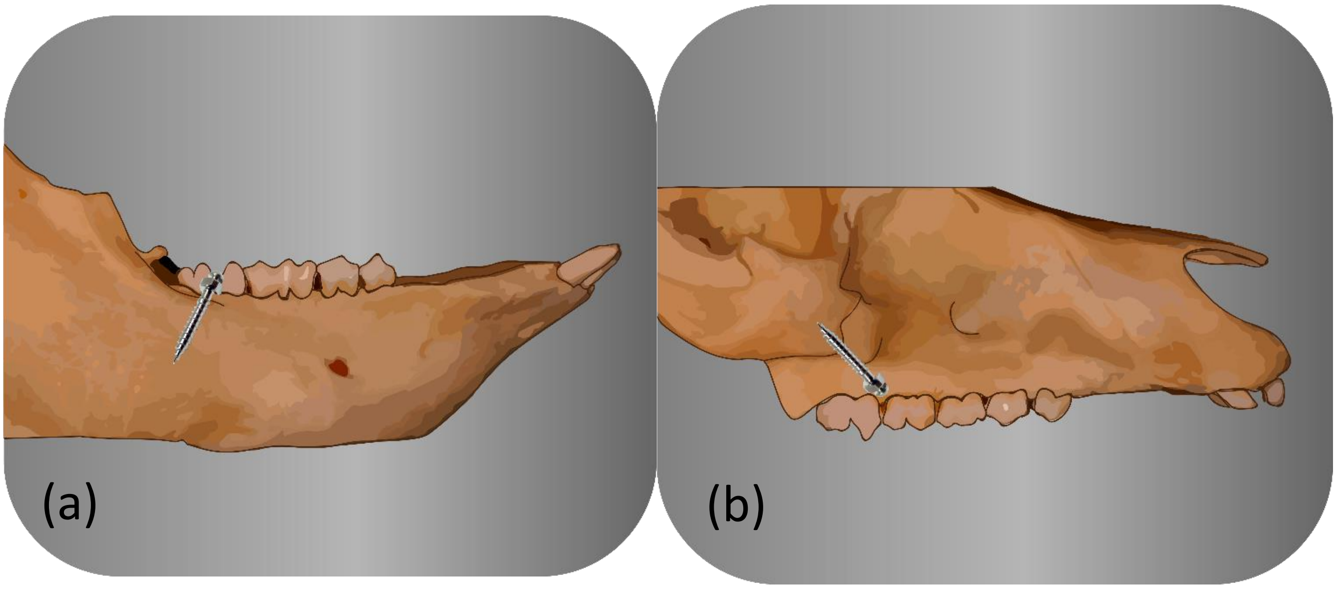
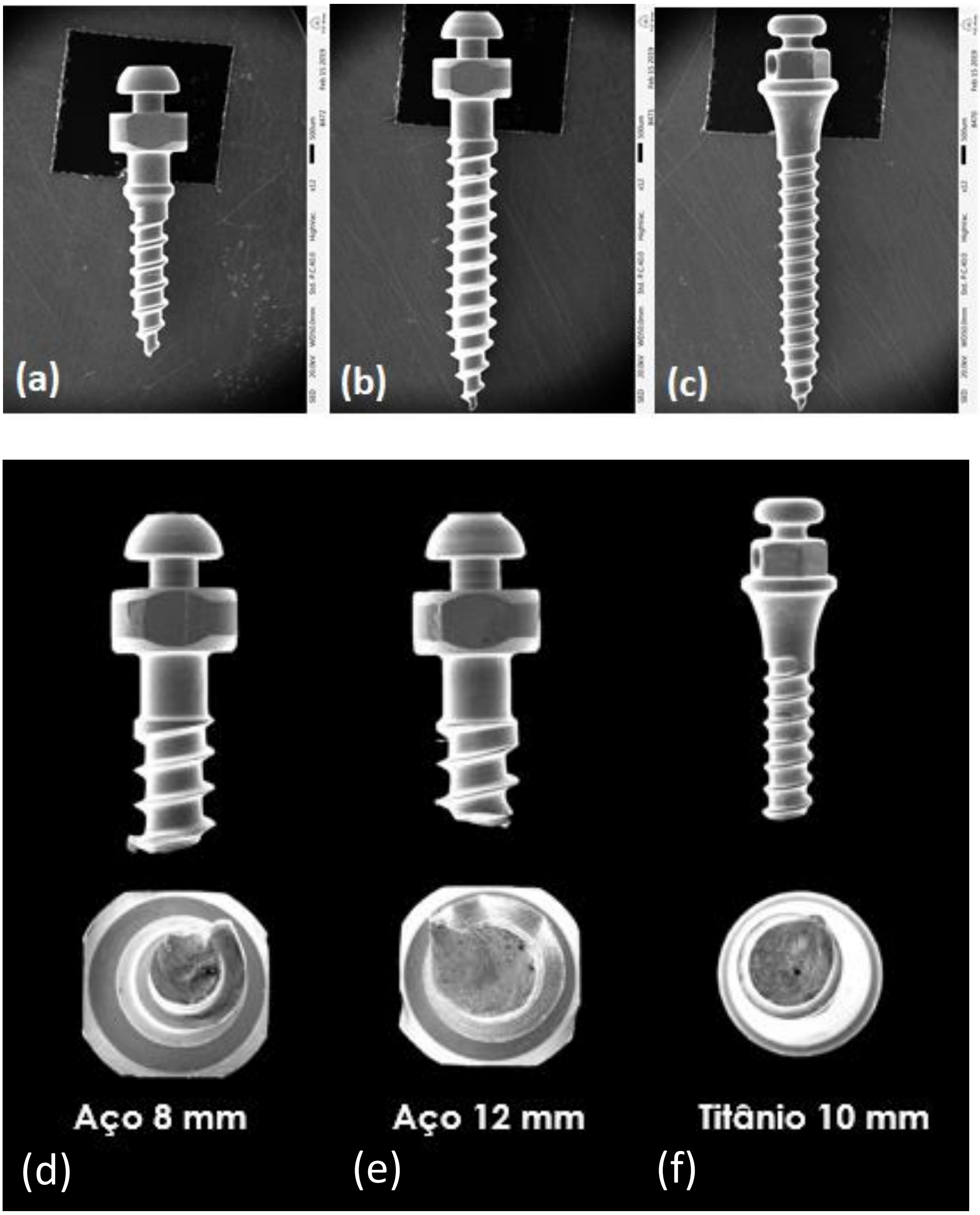


Figure 3.

Figure 4.



Steel 8 mm **Steel 12 mm** **Titanium 10 mm**

Table 1. Median, minimum and maximum values of each variable and comparison among groups

Tests	Groups		
	G1 (8 x 1.5 mm steel)	**G2 (12 x 2.0 mm steel)**	**G3 (10 x 1.5 mm titanium)**
Insertion torque (N/cm²)	32.8 (24.4-43.6)[a]	61.7 (34.3-78.3)[b]	34.65 (19.5-40.7)[a]
Percussion (without unit)	3.0 (2.0-5.0)[a]	3.0 (2.0-7.0)[a]	3.0 (3.0-3.0)[a]
Pull-out (N/cm²)	356.4 (325.7-391.2)[a]	376.3 (348.8-415.6)[a]	354.8 (320.9-391.5)[a]
Fracture torque (N/cm²)	33.2 (28.6-38.3)[a]	64.6 (59.5-78.3)[b]	35.7 (32.5-40.7)[a]

[a, b] Different letters indicate statistically significant differences among groups ($p < 0.05$). P values were obtained by Kruskal-Wallis test followed by Dunn post-hoc test for comparison between pairs.

4 CONSIDERAÇÕES FINAIS

Na busca de alternativas que evitassem a recolocação dos MI radiculares, surgiram os MI de ancoragem extrarradicular. Estes são instalados em regiões mais posteriores, ficando distantes das raízes dentárias. Os MI usinados em aço inoxidável se propõem a fornecer características funcionais superiores aos da liga titânio/alumínio/vanádio. Os resultados do presente estudo indicam que as propriedades mecânicas dos MI em aço inoxidável foram superiores às dos MI na liga titânio-alumínio-vanádio. Os valores de torque de inserção e fratura foram significativamente superiores nos grupos de MI de aço quando comparados aos MI das ligas de titânio. Assim sendo, os MI de aço inoxidável possuem maior resistência mecânica que os da liga titânio-alumínio-vanádio.

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