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ORIGINAL ARTICLE

Mechanical Properties of Mini-Implants Used in Extra-Radicular Anchorage

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ABSTRACT
Objective: To evaluate the mechanical properties of mini-implants (MIs) manufactured from stainless steel and compare them with conventional titanium-aluminum-vanadium alloy MIs. **Material and Methods:** The following groups were formed: G1 (n=24), 8×1.5 mm steel MIs; G2 (n=24), 12×2.0 mm steel MIs; and G3 (n=24), 10×1.5 mm titanium MIs. The 72 MIs were inserted in the infra zygomatic crest region of the maxilla and retromolar trigone in the jaw of 10 pigs. Pull-out, insertion torque, fracture and percussion tests were performed in order to measure the tensile strength, primary stability and fracture strength of MIs. A digital torque gauge was used to measure insertion and fracture torque, a universal mechanical testing machine was used for pull-out testing and a periotest device was used to measure the micromovement of MIs. For morphological and MI component evaluation, scanning electron microscopy (SEM) was performed. D'Agostino & Pearson, Kruskal-Wallis, and Dunn post-hoc and normality tests were used. **Results:** G2 insertion and fracture torques were significantly higher than G1 and G3 insertion and fracture torques ($p<0.05$). The pull-out and percussion tests presented similar values among the groups. SEM revealed that the fracture point was predominantly on the fourth thread for steel MIs (G1 and G2) and on the seventh thread for titanium-aluminum-vanadium MIs (G3). **Conclusion:** The mechanical properties of stainless steel MIs are superior to those of titanium-aluminum-vanadium alloy MIs.

Keywords: Orthodontic Anchorage Procedures; Stainless Steel; Titanium; Orthodontics.

Introduction

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

The use of MIs 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 this is not a painful procedure, repositioning generates discomfort to patients through anxiety [2,3]. In addition, sometimes MIs fail and are occasionally removed for acquiring mobility during treatment [4].

In the search for alternatives to avoid MI replacement, extra-radicular anchorage MIs were developed, which are positioned in areas distant from dental roots [5]. Extra-radicular MIs can be manufactured from 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 MIs of different materials [7].

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

Material and Methods

Group Formation and MI Installation

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

Figure 1. Flowchart.

MIs were inserted in the infra zygomatic crest region of the 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 the animals. Up to the moment of MI insertion, bone samples were immersed in saline at a temperature of -20 °C to maintain their physical and biological properties. Prior to using the substrate for MI insertion, heads were thawed at room temperature.

The regions where MIs were inserted were standardised, consisting of the infra zygomatic crest region of the maxilla and the 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).

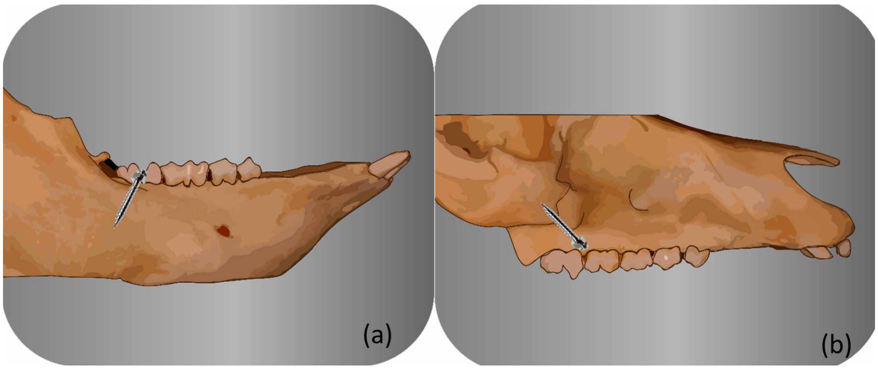

Figure 2. MI insertion position in the Buccal Shelf region (a) and infra zygomatic crest (b).

Mechanical Tests and Morphological Evaluation

MIs were 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 attached to a grip that kept it stable during insertion so that MIs could all be inserted in the same place and by the same operator. Insertion torque was measured by manual MI rotation with a 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 (5×5 cm) were then obtained. Bone block removal was performed with a low-speed steel disc under saline cooling.

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

With sets containing bone block and the MI, the pull-out test was performed in a universal mechanical testing machine (Oswaldo Filizola AME-2kN, São Paulo, SP, Brazil). To perform the tensile test, two devices were coupled to the machine: one in the form of a crowbar coupled to 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, a speed of 5 mm/min in a load cell of 500 kg was used.

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

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

To evaluate the MI 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 and the fracture test showed that G2 presented values significantly higher than G1 and G3 ($p<0.05$). The pull-out and percussion tests showed no significant differences among groups (G1, G2 and G3). SEM revealed that the fracture point was predominantly on the fourth thread for steel MIs (G1 and G2) and on the seventh thread for titanium-aluminum-vanadium MIs (G3) (Figure 4).

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.

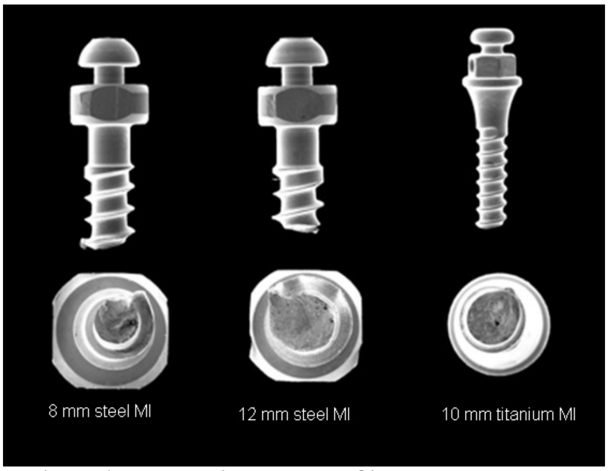

Figure 4. Scanning Electron Microscopy of intact MIs at 12x magnification.

Discussion

MI insertion in extra-radicular sites, such as the maxillary infra zygomatic 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 an insertion site for extra-radicular anchorage [8,9]. Therefore, evaluating the mechanical properties of extra-radicular MIs is extremely important given the absence of studies proving differences among MIs manufactured from different materials.

Considering that primary stability is one of the key factors for the clinical success of MIs [8,10-13], its evaluation can be performed using 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]. The present study observed that the primary stability of 12×2.0 mm steel MIs was superior to the other evaluated MIs.

The insertion torque measurement is an important parameter related to the MI 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. MI alloy length and type directly affect their mechanical properties [7]. In the current study, this relationship was observed, since differences among groups were found: 12×2.0 mm steel MIs showed greater insertion torque and fracture than 8×1.5 mm steel MIs and 10×1.5 mm titanium MIs.

In other studies, Exposto et al. [21] and Wilmes and Drescher [19] stated that screws with smaller diameters have a higher risk of fracture and are less stable, while those with larger diameters 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 et al. [11], it is not the MIs' diameter that has 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 MIs 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 et al. [15] and Pithon et al. [23], the maximum insertion torque increased with increasing MI length and increasing cortical bone thickness [24]. Wilmes and Drescher [19] reported that to achieve satisfactory insertion torque and avoid MI fracture and excessive bone stress, a combination of pre-perforation diameter and MI must be chosen according to the insertion site and bone density.

In the present study, the insertion torque of 12×2.0 mm steel MIs (G2) was higher than the other groups (G1: 8×1.5 mm steel MIs and G3: 10×1.5 mm titanium MIs) and similar between 8×1.5 mm steel MI and 10×1.5 mm titanium MI groups (G1 and G3). In the 2009 study by Morarend et al. [25], MIs 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 inserted into bicortical bone were similar to those of 2.5 mm in monocortical bone.

The tensile torque measures the force strength required for MI removal after orthodontic treatment [4]. This test consists of extracting the MI from bone tissue at a constant speed, allowing evaluation of 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 et al. [20] reported that the tensile forces presented by MIs inserted in different regions of the maxilla and mandible of pigs were higher than those for clinical purposes (0.3–4.0 N), validating their use in these regions.

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

Fractures due to MI insertion and removal stress are associated with the material from which they are made, geometric design and bone quality [10,26]. 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 [1,26]. In the current study, larger diameter (2.0 mm) MIs performed better than those of a smaller diameter (1.5 mm). Pithon et al. [23] did not find any influence of MI length on fracture resistance during MI flexion.

The percussion test (Periotest®) is a reliable indicator for measuring implant stability at both conventional and immediate loads [12]. However, according to 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 the groups evaluated. However, in the study by Tseng et al. [17], 2.0×11 mm titanium MIs showed higher resonance values than 2.0×12 mm titanium MIs and 2.0×12 mm steel MIs. Nienkemper et al. [27] also observed, through Periotest, that there is a linear relationship between primary stability and MI insertion depth and between primary stability and MI size [28] and that Periotest values measured three weeks after implant insertion were smaller than those measured at insertion [29].

Scanning electron microscopy (SEM) was performed on intact and post-test MIs (Figure 4). The fracture point was predominantly on the fourth thread for steel MIs (G1 and G2) and on the seventh thread for titanium-aluminum-vanadium MIs (G3). In the study by Pithon et al. [23], 6 mm, 8 mm and 10 mm titanium MIs fractured in similar regions between the first and second threads. Comparing nTi, cpTi and Ti-6Al-4 V MI, Serra et al. [30] observed that all samples had a similar fracture process and the torsion strength was higher in nTi and Ti-6Al-4V MIs.

With the current study, it was possible to evaluate the performance of steel and titanium MIs for extra-radicular use. In addition, its clinical relevance relies in the fact that it is the first study to evaluate the mechanical properties of steel and titanium MIs inserted in the extra-radicular regions of pigs, which are similar to those of humans. However, the limitation of this study was the non-measurement of cortical thickness of regions in which

MIs were installed, as well as limitations inherent to *in vitro* studies and mechanical assays, suggesting the conduction of human trials are necessary to prove the results.

Conclusion

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

Authors' Contributions

GBL	https://orcid.org/0009-0003-7627-0955	Formal Analysis, Data Curation and Visualization.
MMP	https://orcid.org/0000-0002-8418-4139	Conceptualization, Methodology, Software and Writing - Original Draft.
CMM	https://orcid.org/0000-0003-1911-2910	Software, Validation, Writing - Review and Editing and Visualization.
LIN	https://orcid.org/0000-0001-8486-9704	Formal Analysis, Writing - Original Draft, Writing - Review and Editing and Funding Acquisition.
MCRH	https://orcid.org/0000-0003-0192-5614	Methodology, Software, Investigation and Project Administration.
DDO	https://orcid.org/0000-0003-4323-0562	Methodology, Investigation and Data Curation.
RVS	https://orcid.org/0000-0001-7698-7532	Conceptualization, Resources and Data Curation.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

References

[1] Dalvi AC, Elias CN. Implantes ortodônticos de aço inoxidável. RMC 2015; 32:53-63. [In Portuguese].

[2] Gracco A, Giagnorio C, Incerti Parenti S, Alessandri Bonetti G, Siciliani G. Effects of thread shape on the pullout strength of miniscrews. Am J Orthod Dentofacial Orthop 2012; 142(2):186-90. https://doi.org/10.1016/j.ajodo.2012.03.023

[3] Paiva LGJ, Garcia RR, Júnior HC, Santana FF, Carvalho G, Estrela CB. Utilização de mini-implantes em intrusão de molares na recuperação de espaço protético inferior para reabilitação com implantes dentários. Rev Odontol Bras Central 2015; 24(69):88-91. https://doi.org/10.36065/robrac.v24i69.720 [In Portuguese].

[4] Motoyoshi M, Uemura M, Ono A, Okazaki K, Shigeeda T, Shimizu N. Factors affecting the long-term stability of orthodontic mini-implants. Am J Orthod Dentofacial Orthop 2010; 137(5):588.e1-5; discussion 588-9. https://doi.org/10.1016/j.ajodo.2009.05.019

[5] Almeida MR. Biomecânica de distalização dento alveolar com mini-implantes extra-alveolares em paciente Classe I com biprotrusão. Rev Clín Ortod Dental Press 2017; 16(6):61-76. https://doi.org/10.14436/1676-6849.16.6.061-076 [In Portuguese].

[6] Chang CH, Lin JS, Roberts WE. Failure rates for stainless steel versus titanium alloy infrazygomatic crest bone screws: A single-center, randomized double-blind clinical trial. Angle Orthod 2019; 89(1):40-6. https://doi.org/10.2319/012518-70.1

[7] Scribante A, Montasser MA, Radwan ES, Bernardinelli L, Alcozer R, Gandini P, et al. Reliability of orthodontic miniscrews: bending and maximum load of different Ti-6Al-4V titanium and stainless steel temporary anchorage devices (TADs). Materials 2018; 11(7):1138. https://doi.org/10.3390/ma11071138

[8] Nucera R, Lo Giudice A, Bellocchio AM, Spinuzza P, Caprioglio A, Perillo L, et al. Bone and cortical bone thickness of mandibular buccal shelf for mini-screw insertion in adults. Angle Orthod 2017; 87(5):745-51. https://doi.org/10.2319/011117-34.1

[9] Chang C, Liu SS, Roberts WE. Primary failure rate for 1680 extra-alveolar mandibular buccal shelf mini-screws placed in movable mucosa or attached gingiva. Angle Orthod 2015; 85(6):905-10. https://doi.org/10.2319/092714.695.1

[10] Chang JZ, Chen YJ, Tung YY, Chiang YY, Lai EH, Chen WP, et al. Effects of thread depth, taper shape, and taper length on the mechanical properties of mini-implants. Am J Orthod Dentofacial Orthop 2012; 141(3):279-88. https://doi.org/10.1016/j.ajodo.2011.09.008

[11] Pithon MM, Nojima MG, Nojima LI. Primary stability of orthodontic mini-implants inserted into maxilla and mandible of swine. Oral Surg Oral Med Oral Pathol Oral Radiol 2012; 113(6):748-54. https://doi.org/10.1016/j.tripleo.2011.06.021
[12] Seifi M, Matini NS. Evaluation of primary stability of innovated orthodontic miniscrew system (STS): An ex-vivo study. J Clin Exp Dent 2016; 8(3):e255-9. https://doi.org/10.4317/jced.52676
[13] Hosein YK, Dixon SJ, Rizkalla AS, Tassi A. A comparison of the mechanical measures used for assessing orthodontic mini-implant stability. Implant Dent 2017; 26(2):225-31. https://doi.org/10.1097/ID.0000000000000514
[14] Tepedino M, Masedu F, Chimenti C. Comparative evaluation of insertion torque and mechanical stability for self-tapping and self-drilling orthodontic miniscrews - an in vitro study. Head Face Med 2017; 13(1):10. https://doi.org/10.1186/s13005-017-0143-3
[15] Lim SA, Cha JY, Hwang CJ. Insertion torque of orthodontic miniscrews according to changes in shape, diameter and length. Angle Orthod 2008; 78(2):234-40. https://doi.org/10.2319/121206-507.1
[16] Pithon MM, Nojima MG, Nojima LI. In vitro evaluation of insertion and removal torques of orthodontic mini-implants. Int J Oral Maxillofac Surg 2011; 40(1):80-5. https://doi.org/10.1016/j.ijom.2010.09.013
[17] Tseng YC, Wu JH, Ting CC, Chen HS, Chen CM. Evaluation of mechanical strengths of three types of mini-implants in artificial bones. Kaohsiung J Med Sci 2017; 33(2):96-101. https://doi.org/10.1016/j.kjms.2016.11.001
[18] Miyawaki S, Koyama I, Inoue M, Mishima K, Sugahara T, Takano-Yamamoto T. Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. Am J Orthod Dentofacial Orthop 2003; 124(4):373-8. https://doi.org/10.1016/s0889-5406(03)00565-1
[19] Wilmes B, Drescher D. Impact of bone quality, implant type, and implantation site preparation on insertion torques of mini-implants used for orthodontic anchorage. Int J Oral Maxillofac Surg 2011; 40(7):697-703. https://doi.org/10.1016/j.ijom.2010.08.008
[20] Meursinge Reynders RA, Ronchi L, Ladu L, van Etten-Jamaludin F, Bipat S. Insertion torque and success of orthodontic mini-implants: a systematic review. Am J Orthod Dentofacial Orthop 2012; 142(5):596-614.e5. https://doi.org/10.1016/j.ajodo.2012.06.013
[21] Exposto CR, Oz U, Westgate PM, Huja SS. Influence of mini-screw diameter and loading conditions on static and dynamic assessments of bone-implant contact: An animal study. Orthod Craniofac Res 2019; 22(Suppl 1):96-100. https://doi.org/10.1111/ocr.12293
[22] Marquezan M, Souza MM, Araujo MT, Nojima LI, Nojima Mda C. Is miniscrew primary stability influenced by bone density? Braz Oral Res 2011; 25(5):427-32. https://doi.org/10.1590/s1806-83242011000500009
[23] Pithon MM, Figueiredo DS, Oliveira DD. Mechanical evaluation of orthodontic mini-implants of different lengths. J Oral Maxillofac Surg 2013; 71(3):479-86. https://doi.org/10.1016/j.joms.2012.10.002
[24] Marquezan M, Mattos CT, Sant'Anna EF, de Souza MM, Maia LC. Does cortical thickness influence the primary stability of miniscrews?: A systematic review and meta-analysis. Angle Orthod 2014; 84(6):1093-103. https://doi.org/10.2319/093013-716.1
[25] Morarend C, Qian F, Marshall SD, Southard KA, Grosland NM, Morgan TA, et al. Effect of screw diameter on orthodontic skeletal anchorage. Am J Orthod Dentofacial Orthop 2009; 136(2):224-9. https://doi.org/10.1016/j.ajodo.2007.07.031
[26] Burmann PF, Ruschel HC, Vargas IA, de Verney JC, Kramer PF. Titanium alloy orthodontic mini-implants: scanning electron microscopic and metallographic analyses. Acta Odontol Latinoam 2015; 28(1):42-7. https://doi.org/10.1590/S1852-48342015000100006
[27] Nienkemper M, Santel N, Honscheid R, Drescher D. Orthodontic mini-implant stability at different insertion depths: Sensitivity of three stability measurement methods. J Orofac Orthop 2016; 77(4):296-303. https://doi.org/10.1007/s00056-016-0036-2
[28] Nienkemper M, Wilmes B, Panayotidis A, Pauls A, Golubovic V, Schwarz F, et al. Measurement of mini-implant stability using resonance frequency analysis. Angle Orthod 2013; 83(2):230-8. https://doi.org/10.2319/043012-354.1
[29] Uemura M, Motoyoshi M, Yano S, Sakaguchi M, Igarashi Y, Shimizu N. Orthodontic mini-implant stability and the ratio of pilot hole implant diameter. Eur J Orthod 2012; 34(1):52-6. https://doi.org/10.1093/ejo/cjq157
[30] Serra G, Morais L, Elias CN, Semenova IP, Valiev R, Salimgareeva G, et al. Nanostructured severe plastic deformation processed titanium for orthodontic mini-implants. Mater Sci Eng C Mater Biol Appl 2013; 33(7):4197-202. https://doi.org/10.1016/j.msec.2013.06.012