EVALUATION OF FRACTURE TORQUE RESISTANCE OF ORTHODONTIC MINI-IMPLANTS

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ABSTRACT
This study sought to assess the fracture torque resistance of mini-implants used for orthodontic anchorage. Five commercially available brands of mini-implants were used (SIN®, CONEXÃO®, NEODENT®, MORELLI®, and FORESTADENT®). Ten mini-implants of each diameter of each brand were tested, for a total 100 specimens. The mini-implants were subject to a static torsion test as described in ASTM standard F543. Analysis of variance (ANOVA) with the Tukey multiple comparisons procedure was used to assess results. Overall, mean fracture strength ranged from 15.7 to 70.4 N·cm. Mini-implants with larger diameter exhibited higher peak torque values at fracture and higher yield strength, regardless of brand. In addition, significant differences across brands were observed when implants were stratified by diameter. In conclusion, larger mini-implant diameter is associated with increased fracture torque resistance. Additional information on peak torque values at fracture of different commercial brands of mini-implants may increase the success rate of this orthodontic anchorage modality.

Key words: *Dental implants, orthodontics, torque.*

RESISTÊNCIA DE FRATURA AO TORQUE DE MINI-IMPLANTES ORTODÔNTICOS

RESUMO
O objetivo do presente estudo foi avaliar a resistência de fratura ao torque de mini-implantes ortodônticos. Foram utilizadas cinco marcas comerciais (SIN®, CONEXÃO®, NEODENT®, MORELLI® e FORESTADENT®). Para cada diâmetro, de cada marca comercial, foram testados 10 mini-implantes, totalizando 100 amostras. Os mini-implantes foram submetidos a um Ensaio Estático de Torção, conforme a norma técnica ASTM F543. Os resultados foram submetidos à Análise de Variância (ANOVA) complementado pelo teste de comparações múltiplas de Tukey. Os valores médios de resistência de fratura ao torque variaram de 15,7 a 70,4 N·cm e mini-implantes de maior diâmetro apresentaram maiores valores de torque máximo de fratura e de limite de escoamento, independente da marca comercial. Além disso, foram observadas diferenças significativas entre as marcas comerciais quando agrupadas de acordo com o diâmetro. Conclui-se que mini-implantes de maior diâmetro apresentaram maiores valores de resistência de fratura ao torque. Informações sobre o torque máximo de fratura das diferentes marcas comerciais podem aumentar o índice de sucesso deste método de ancoragem ortodôntica.

Palavras-chave: *Implantes dentários; ortodontia; torque.*

INTRODUCTION

The control of loads placed on teeth and their bony foundations is one of the principles of orthodontics[1]. For every action force there is a reaction force of equal size and opposite direction, which causes movement of the anchorage unit[2]. Therefore, management of orthodontic anchorage, which may be defined as the resistance offered by a group of teeth or extraoral supports when a force is applied, thus preventing or limiting unwanted movement, is essential to the success of orthodontic treatment [3, 4]. In recent years, alternative orthodontic anchorage methods have become the focus of substantial research and mini-implants have been introduced into the market, broadening the range of options available [5, 6].

The success of mini-implants is related to their minimally invasive nature, ease of insertion and removal, low cost, immediate loading, versatility, and little discomfort to the patient[6-8]. Overall, their success rate is over 80%.[9] However, failure in the placement of these devices has been reported[10, 11].

Research into factors that interfere with the stability of these devices and their resistance to fracture at insertion and removal has therefore been encouraged[5].

Fracture torques of 5 N·cm to 50 N·cm during implant placement have been reported in the literature[8, 10, 11], although few manufacturers report such reference values. Studies have also suggested that factors associated with mini-implant design, thread profile, and material may also influence outcomes[12-14]. In addition, mini-implants with larger diameter have been found to have superior fracture strength[15].

In view of the foregoing, the present study sought to assess the fracture torque resistance of orthodontic mini-implants from different manufacturers.

MATERIALS AND METHODS

This was a laboratory-based *in vitro* study and may be described as a static torsion test of bone screws. The study was conducted at Laboratório de Ensaios Mecânicos – Soluções em Ensaios de Materiais e Produtos (LEM-SCITEC, Palhoça, SC, Brazil), a facility accredited by the Brazilian National Institute of Metrology, Quality and Technology – Inmetro (CRL 0495).

Five brands of orthodontic mini-implants commercially available on the Brazilian market, with fully threaded, cylindrical, solid shafts, were used. The material from which mini-implants are made is defined by ASTM standard specification F136 (Ti 6Al-4V). It is a titanium alloy containing 6% aluminum and 4% vanadium used for manufacturing medical and dental implants. Ten mini-implants of each diameter of each brand were tested, for a total 100 specimens. Diameters ranged from 1.3 to 2 mm. All implants had a transmucosal profile of 1 mm (Table 1). All specimens had fully threaded cylindrical shafts 8 to 9 mm in length. The following characteristics were assessed in each specimen: mode and site of failure, angle of rupture, resistance to fracture at insertion, and yield torque.

Static torsion testing was performed as described in ASTM standard F543 - *Standard Specification and Test Methods for Metallic Medical Bone Screws* [16]. Each screw was secured in locking pliers to prevent rotation during testing, keeping five threads exposed above the transmucosal profile.

Tests were conducted at a constant speed of 1 rpm, under dry conditions, at a temperature of 20 ± 5º C. A torque (N·m)-angle (°) curve was plotted for each tested specimen, and the test was terminated at the time of screw failure. The equipment used in torsion testing is described in Table 2.

Ten specimens were used as a comparator group for the present study. Taking into consideration a mean fracture torque value of 39.2 N·cm (SD=4), reported in a previous study conducted with 1.7-mm mini-implants[17], the present study has 90% statistical power and a 95% confidence level to detect a 15% difference between groups. The collected data were assessed by analysis of variance (ANOVA) with the Tukey multiple comparisons procedure.

Table 1: Identification of mini-implants evaluated in the study.

Brand	Diameter/length (mm)	Reference	Lot
Neodent® (Curitiba, PR, Brazil)	1.3 x 9 1.6 x 9	109.488 109.497	800076729 800073022
SIN® (São Paulo, SP, Brazil)	1.4 x 8 1.6 x 8 1.8 x 8	POT 1418 POT 1618 POT 1818	M040069950 M070077671 M010063381
Conexão® (Arujá, SP, Brazil)	1.5 x 8 1.8 x 8 2.0 x 8	98758199 98788199 98708199	140379 135536 131059
Morelli® (Sorocaba, SP, Brazil)	1.5 x 8	37.10.202	1732607
ForestaDent® (Pforzhein, Germany)	1.7 x 8	1101A2308	11301454

RESULTS

Rupture was the characteristic mode of failure for the tested mini-implants. Fractures occurred along the free end formed by the five exposed screw threads, with the fracture angle ranging from 89° to 406.8°. On ANOVA with Tukey multiple comparisons, neither failure site nor rupture angle were significantly associated with mini-implant brand or diameter at the 5% significance level.

Table 3 shows the fracture torque resistance and yield torque values of the tested mini-implants. Mean fracture strength at insertion and yield limit ranged from 15.7 to 70.4 N·cm and 9.2 to 53.1 N·cm, respectively. Minimum and peak torque curves obtained during mechanical testing are shown in Figs. 1 and 2.

Significant differences were observed between brands. In addition, mini-implants with larger diameter exhibited superior fracture strength and yield limits, regardless of brand. The worst performance was observed for the specimen with the narrowest diameter (NEODENT® 1.3) and the best performance for the specimen with the largest diameter (CONEXÃO® 2.0).

Table 4 shows the results for mini-implants stratified into three groups by diameter: small (1.3 mm/1.4 mm/1.5 mm), medium (1.6 mm/1.7 mm) or large (1.8 mm/1.9 mm/2.0 mm). Mean fracture strength for small, medium, and large specimens was 25.9 N·cm, 33.9 N·cm, and 54.2 N·cm, respectively. In the small-diameter group, MORELLI® brand mini-implants had the best performance. In the medium-diameter group, the SIN® and NEODENT® brands stood out, whereas in the large-diameter group, CONEXÃO® brand mini-implants exhibited superior resistance to fracture at insertion.

Table 2: Identification of mini-implants evaluated in the study.

Internal reference	Description	Manufacturer/model	Certificate of calibration
IM 0143	Single-axis torsion testing machine – Servo Mecânica 9	OF (OFCME 30 Nm)	—
IM 0144	Motion control motor	OF	INMETRO DIMCI 0789/2014 23/04/2015
IM 0145	Torque measurement system – 2Nm-Maq 9	OF (OFTCN 20 KC) S371806/2013	K&L 20/08/2014
IM 0036	Digital caliper, 300 mm	INSIZE (IS11137-300)	CERTI 0244/14 05/02/2015

Table 3: Mean (standard deviation) fracture torque resistance and yield torque of orthodontic mini-implants.

Brand – diameter (mm)	Fracture torque resistance (N·cm)	Yield torque (N·cm)
SIN® – 1.4	26.1^{EF} (0.6)	17.3^{E} (0.6)
SIN® – 1.6	36.1^{D} (2.7)	24.5^{C} (1.9)
SIN® – 1.8	50.2^{B} (1.5)	33.6^{B} (1.0)
FORESTADENT® – 1.7	28.1^{E} (0.5)	20.1^{D} (0.8)
MORELLI® – 1.5	37.7^{D} (2.9)	25.2^{C} (2.8)
CONEXÃO® – 1.5	24.2^{F} (1.2)	16.3^{E} (1.6)
CONEXÃO® – 1.8	45.9^{C} (0.8)	32.7^{B} (1.5)
CONEXÃO® – 2.0	70.4^{A} (3.1)	53.1^{A} (3.7)
NEODENT® – 1.3	15.7^{G} (0.7)	9.2^{F} (0.4)
NEODENT® – 1.6	37.5^{D} (0.8)	23.1^{C} (0.9)

Means followed by different capital letters indicate significant differences according to ANOVA followed by the Tukey multiple comparisons test, at a significance level of 5%.

Table 4: Mean (standard deviation) fracture torque resistance of orthodontic mini-implants, stratified into three groups by diameter.

	Fracture torque resistance (N·cm)					
Brand	**Small diameter 1.3–1.5 mm**		**Medium diameter 1.6–1.7 mm**		**Large diameter 1.8–2.0 mm**	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
SIN®	26.1B	0.7	36.1A	2.7	50.2B	1.4
ForestaDent®	-	-	28.2B	0.5	-	-
Morelli®	37.7A	2.9	-	-	-	-
Conexão®	24.3B	1.2	-	-	58.2A	12.8
Neodent®	15.7C	0.7	37.5A	0.8	-	-

In each diameter group, means followed by different capital letters indicate significant differences according to ANOVA followed by the Tukey multiple comparisons test, at a significance level of 5%.

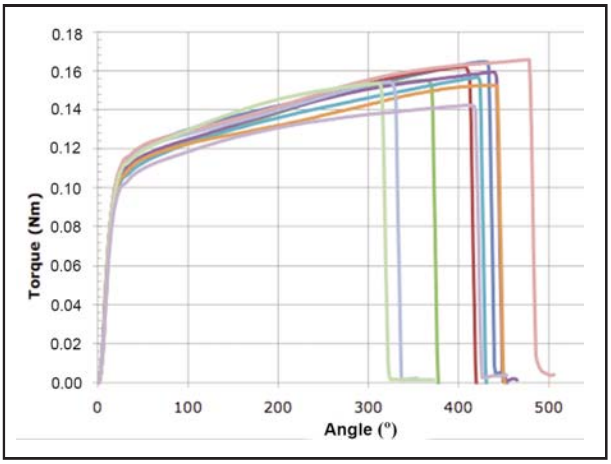

Fig. 1: Torque curve obtained for the 10 specimens with the lowest fracture resistance (Neodent® 1.3x9 mm).

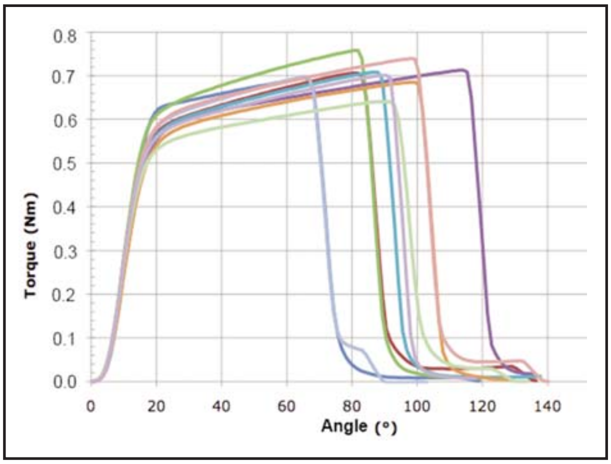

Fig. 2: Torque curve obtained for the 10 specimens with the highest fracture resistance (Conexão® 2.0x8 mm).

FORESTADENT® brand mini-implants, despite having a larger diameter than MORELLI® brand specimens, were less resistant to fracture at insertion. Fig. 3 illustrates the relationship between fracture torque resistance and yield torque values and the different diameters of the tested mini-implants. Both variables increased with increasing implant diameter, in similar distribution patterns. The results show that the yield torque is immediately below the fracture limit.

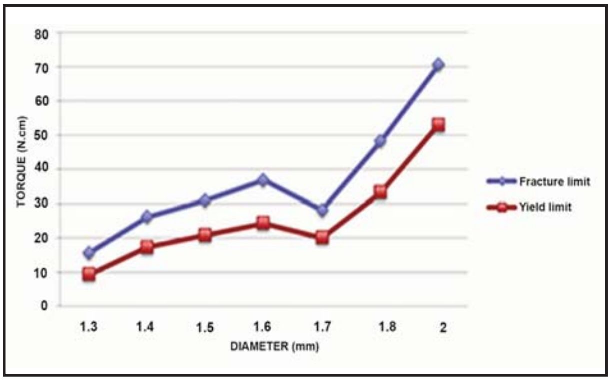

Fig. 3: Mean torque values for fracture and yield limit and their association with mini-implant diameter.

DISCUSSION

Conventional orthodontic anchorage systems have biomechanical limitations and are dependent on patient compliance[18]. The ease of insertion and removal and the high success rate of mini-implants have encouraged their adoption as an efficient method for skeletal anchorage[5,19-21]. However, differences in torsional strength and peak fracture torque between different commercial brands have prompted additional research, with a view to enhancing clinical safety and reducing failure rates [22-24].

The usual length of orthodontic mini-implants ranges from 5 to 12 mm, while diameter and transmucosal profile usually range from 1.2 to 2 mm and from 0 to 3 mm, respectively[10,11,25]. Studies have shown that a progressive increase in implant diameter provides improved primary stability due to increased bone contact area[4,26-30], but also increases the risk of damage to surrounding structures, particularly to the roots of adjacent teeth[31-33].

Mini-implants with smaller diameter and length, however, have increased risk of fracture due to lower mechanical resistance. Despite its importance to peri-implant health, the transmucosal profile has no influence on resistance to fracture at implant insertion [34,35].

In the present study, static torsion testing was performed in accordance with ASTM standard F543. This method ensures replicability of the study and prioritizes mechanical analysis of the specimen, regardless of substrate. Mechanical data are obtained from the specimen alone, without external interference, as the implant is isolated and secured in a clamp. Conversely, studies performed in acrylic, porcine bone, and artificial bone are subject to interference from other variables [32,33, 36, 37].

In addition, a previous study evaluated titanium alloy quality and microstructure of the mini-implant brands tested herein[14]. According to the authors, these devices were free from internal structural defects and compliant with current standards[14].

In the present study, the characteristic mode of failure was mini-implant rupture. Site of failure along the exposed threads and angle of rupture were not associated with brand or diameter of the devices evaluated. Technically, fracture sites may occur randomly, as all screw threads are subject to the same strain condition and intensity. The rupture angle should preferably be high, as this would allow the practitioner to detect during insertion that the implant is undergoing elastic deformation and not driving into bone, halt the procedure, and alter the technique accordingly before fracture occurs.

Mean fracture torque resistance ranged from 15.7 to 70.5 N·cm. These values are consistent with those reported in studies that employed similar methods. Lima *et al.*[15] observed values ranging from 30 to 36 N·cm in 1.6-mm NEODENT® implants, whereas Wilmes *et al.*[11], in a study of 41 commercially available brands 1.3 to 2 mm in diameter, reported values ranging from 10.9 to 64.1 N·cm.

Our results also showed that fracture strength is directly related to mini-implant diameter. Mini-implants with larger diameter exhibited higher fracture torque resistance, regardless of manufacturer. In the present study, the CONEXÃO® 2.0-mm mini-implants performed best overall. According to Barros *et al.*[13], a 0.1-mm increase in mini-implant diameter significantly reduces the risk of fracture. Toyoshima and Wakabayashi[38] also observed that increasing diameter improves fracture torque resistance.

Yield torque represents the time point at which alloy deformation shifts from elastic (reversible) to plastic (irreversible). Optimally, in clinical practice, dentists should always work within the elastic limit of the alloy, thus preventing permanent deformation of the device. The higher the yield limit of a device, the greater its ability to resist plastic deformation. According to the results obtained, the yield limit behaves similarly to and is immediately below the fracture limit of these devices. Therefore, manufacturers should adopt this limit as a reference value, as it represents the point at which fatigue and deformation occur; devices torqued beyond this limit may be at increased risk of fracture during removal. Further research into this mechanical parameter is warranted before this paradigm can be adopted and thus increase operator safety.

Stratification of the mini-implants into groups by diameter revealed differences across the tested brands. MORELLI® and CONEXÃO® brand devices exhibited the best fracture torque resistance in the small-diameter and large-diameter groups, respectively.

The use of mini-implants for orthodontic anchorage is effective and widespread in clinical practice. However, the success of this method depends largely on primary stability. Fracture torque thus plays a critical role in clinical protocols involving placement of these devices. Precise information on the peak fracture torque and yield limit of mini-implants should be made available by manufacturers. In addition, torque-sensing instruments should always be coupled to mini-implant drivers in order to ensure measurement of the forces applied.

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REFERENCES

1. Petrey JS, Saunders MM, Kluemper GT, Cunningham LL, Beeman CS. Temporary anchorage device insertion variables: effects on retention. Angle Orthod 2010; 80:446-453.
2. Kim HJ, Yun HS, Park HD, Kim DH, Park YC. Soft-tissue and cortical-bone thickness at orthodontic implant sites. Am J Orthod Dentofacial Orthop 2006; 130:177-182.
3. Tseng YC, Hsieh CH, Chen CH, Shen YS, Huang IY, Chen CM. The application of mini-implants for orthodontic anchorage. Int J Oral Maxillofac Surg 2006; 35:704-707.
4. Lim SA, Cha JY, Hwang CJ. Insertion torque of orthodontic miniscrews according to changes in shape, diameter and length. Angle Orthod 2008; 78:234-240.
5. Park HS, Jeong SH, Kwon OW. Factors affecting the clinical success of screw implants used as orthodontic anchorage. Am J Orthod Dentofacial Orthop 2006; 130: 18-25.
6. Mattos CT, Ruellas ACO, Elias CN. Is it possible to re-use mini-implants for orthodontic anchorage? Mat Res 2010; 13:521-525.
7. Cheng SJ, Tseng IY, Lee JJ, Kok SH. A prospective study of the risk factors associated with failure of mini-implants used for orthodontic anchorage. Int J Oral Maxillofac Implants 2004; 19:100-106.
8. Florvaag B, Kneuertz P, Lazar F, Koebke J, Zoller JE, Braumann B, Mischkowski RA. Biomechanical properties of orthodontic miniscrews. An in-vitro study. J Orofac Orthop 2010; 71:53-67.
9. Papadopoulos MA, Papageorgiou SN, Zogakis IP. Clinical effectiveness of orthodontic miniscrew implants: a meta-analysis. J Dent Res 2011; 90:969-976.
10. 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; 40:697-703.
11. Wilmes B, Panayotidis A, Drescher D. Fracture resistance of orthodontic mini-implants: a biomechanical in vitro study. Eur J Orthod 2011; 33:396-401.
12. Kim JW, Baek SH, Kim TW, Chang YI. Comparison of stability between cylindrical and conical type mini-implants. Mechanical and histological properties. Angle Orthod 2008; 78:692-698.
13. Barros SE, Janson G, Chiqueto K, Garib DG, Janson M. Effect of mini-implant diameter on fracture risk and self-drilling efficacy. Am J Orthod Dentofacial Orthop 2011; 140:e181-192.
14. 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; 28:42-47.
15. Lima GM, Soares MS, Penha SS, Romano MM. Comparison of the fracture torque of different Brazilian mini-implants. Braz Oral Res 2011; 25:116-121.
16. American Society for Testing and Materials. ASTM F543-00, Standard Specification and Test Methods for Metallic Medical Bone Screws, ASTM International, West Conshohocken, PA, 2002.
17. Pithon MM, Nojima MG, Nojima LI. In vitro evaluation of insertion and removal torques of orthodontic mini-implants. Int J Oral Maxillofac Surg 2011; 40:80-85.
18. Papadopoulos MA, Tarawneh F. The use of miniscrew implants for temporary skeletal anchorage in orthodontics: a comprehensive review. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 103:e6-15.
19. Chen CH, Chang CS, Hsieh CH, Tseng YC, Shen YS, Huang IY, Yang CF, Chen CM. The use of microimplants in orthodontic anchorage. J Oral Maxillofac Surg 2006; 64:1209-1213.
20. Moon CH, Lee DG, Lee HS, Im JS, Baek SH. Factors associated with the success rate of orthodontic miniscrews placed in the upper and lower posterior buccal region. Angle Orthod 2008; 78:101-106.
21. Wiechmann D, Meyer U, Buchter A. Success rate of mini- and micro-implants used for orthodontic anchorage: a prospective clinical study. Clin Oral Implants Res 2007; 18:263-267.
22. Buchter A, Wiechmann D, Koerdt S, Wiesmann HP, Piffko J, Meyer U. Load-related implant reaction of mini-implants used for orthodontic anchorage. Clin Oral Implants Res 2005; 16:473-479.
23. Mah J, Bergstrand F. Temporary anchorage devices: a status report. J Clin Orthod 2005; 39:132-136; discussion 136; quiz 153.
24. Melsen B. Mini-implants: Where are we? J Clin Orthod 2005; 39:539-547.
25. Wilmes B, Rademacher C, Olthoff G, Drescher D. Parameters affecting primary stability of orthodontic mini-implants. J Orofac Orthop 2006; 67:162-174.
26. Wu X, Deng F, Wang Z, Zhao Z, Wang J. Biomechanical and histomorphometric analyses of the osseointegration of microscrews with different surgical techniques in beagle dogs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 106:644-650.
27. Heidemann W, Terheyden H, Gerlach KL. Analysis of the osseous/metal interface of drill free screws and self-tapping screws. J Craniomaxillofac Surg 2001; 29:69-74.
28. Kim JW, Ahn SJ, Chang YI. Histomorphometric and mechanical analyses of the drill-free screw as orthodontic anchorage. Am J Orthod Dentofacial Orthop 2005; 128:190-194.
29. Schatzle M, Mannchen R, Zwahlen M, Lang NP. Survival and failure rates of orthodontic temporary anchorage devices: a systematic review. Clin Oral Implants Res 2009; 20:1351-1359.
30. Chen Y, Kyung HM, Gao L, Yu WJ, Bae EJ, Kim SM. Mechanical properties of self-drilling orthodontic micro-implants with different diameters. Angle Orthod 2010; 80:821-827.

31. Kang YG, Kim JY, Lee YJ, Chung KR, Park YG. Stability of mini-screws invading the dental roots and their impact on the paradental tissues in beagles. Angle Orthod 2009; 79:248-255.
32. Chen YH, Chang HH, Chen YJ, Lee D, Chiang HH, Yao CC. Root contact during insertion of miniscrews for orthodontic anchorage increases the failure rate: an animal study. Clin Oral Implants Res 2008; 19:99-106.
33. Chen Y, Shin HI, Kyung HM. Biomechanical and histological comparison of self-drilling and self-tapping orthodontic microimplants in dogs. Am J Orthod Dentofacial Orthop 2008; 133:44-50.
34. Araújo TM, Nascimento MHA, Bezerra F, Sobral MC. Ancoragem esquelética em Ortodontia com miniimplantes. R Dental Press Ortodon Ortop Facial 2006; 11:126-156.
35. Nova MFP, Carvalho FR, Elias CN, Artese F. Avaliação do torque para inserção, remoção e fratura de diferentes mini-implantes ortodônticos. Rev Dental Press Ortodon Ortop Facial 2008; 13:76-87.
36. Wilmes B, Ottenstreuer S, Su YY, Drescher D. Impact of implant design on primary stability of orthodontic mini-implants. J Orofac Orthop 2008; 69:42-50.
37. Katic V, Kamenar E, Blazevic D, Spalj S. Geometrical design characteristics of orthodontic mini-implants predicting maximum insertion torque. Korean J Orthod 2014; 44:177-183.
38. Toyoshima Y, Wakabayashi N. Load limit of mini-implants with reduced abutment height based on fatigue fracture resistance: experimental and finite element study. Int J Oral Maxillofac Implants 2015; 30:e10-16.