Original Article

Comparison of the primary stability of orthodontic miniscrews after repeated insertion cycles: *An in vitro study*

Felipe Nenen[a]; Nicolás Garnica[b]; Víctor Rojas[c]; Rodrigo Oyonarte[d]

ABSTRACT

Objectives: To compare the primary stability of miniscrews after repeated cycles of insertion through insertion torque (IT) measurements and resonance frequency analysis (RFA).

Materials and Methods: Sixty titanium miniscrews were divided into two groups according to the insertion protocol: one with predrilled sites and the other self-drilled into porcine iliac crest bone specimens. Each group had three cycles of reinsertion. After each insertion, the IT and RFA were measured. The IT was measured by using a torque meter, and the RFA was measured using the Osstell ISQ device. A total of five miniscrews of each group were selected for sequential assessment of the morphology of their tip and threads using scanning electron microscopy after each insertion cycle.

Results: No statistically significant differences were found in the IT values of miniscrews reinserted up to three times in the group with predrilled surgical sites. The IT value increased significantly with the number of reinsertions in the self-drilled group. The RFA value decreased as the number of insertions increased in both groups.

Conclusions: Under the conditions of this in vitro study, reinserting miniscrews deteriorates the integrity of their tip and thread. Reinsertion should be discouraged particularly when insertion sites are not predrilled. (*Angle Orthod.* 2021;91:336–342.)

KEY WORDS: Miniscrews; Reinsertion; Insertion torque; Resonance frequency analysis

INTRODUCTION

Miniscrews are widely used as temporary anchorage devices in orthodontics.[1–4] Primary stability is required for their success, as it affects survival rate.[5] The primary stability of miniscrews results from the mechanical connection and the relationship between the threads of a miniscrew and the surrounding bone immediately after installation. Clinically, this can be quantified through the insertion torque (IT).[6,7] IT values around 10 Ncm are associated with a higher survival rate.[8] An excessively high IT, however, is not necessarily associated with greater long-term stability of a miniscrew because it may generate osseous microdamage and adjacent osteonecrosis.[9] Predrilling a miniscrew insertion site reduces IT,[10] allowing the clinician to control this clinical variable.

The primary stability of miniscrews can also be assessed using resonance frequency analysis (RFA), which has been mainly used for osseointegrated dental implants.[11] RFA measures the frequency at which a device vibrates. An increased vibration frequency of the sensor indicates increased stability of the implant.[12] RFA and IT values in miniscrews appear to be directly correlated.[13]

The success rate of miniscrews has been reported to be greater than 80%,[14] with variations depending on the anatomic site of insertion.[15,16] The presence of thicker cortical bone, as found in extraalveolar insertion sites, such as in the mandible,[17] may generate higher IT values, thus potentially compromising their success rate.[18]

[a] Dental Officer, Chilean Navy, Viña del Mar, Chile.
[b] Private practice, Las Condes, Chile.
[c] Assistant Professor, Department of Orthodontics, Universidad de los Andes, Las Condes, Chile.
[d] Full Professor and Graduate Orthodontic Program Director, Department of Orthodontics, Universidad de los Andes, Las Condes, Chile.
Corresponding author: Dr Rodrigo Oyonarte, Department of Orthodontics, Universidad de los Andes, Monseñor Álvaro del Portillo 12.455, Las Condes, Santiago, Chile
(e-mail: royonarte@miuandes.cl)

Accepted: October 2020. Submitted: May 2020.
Published Online: December 30, 2020

 DOI: 10.2319/050120-375.1

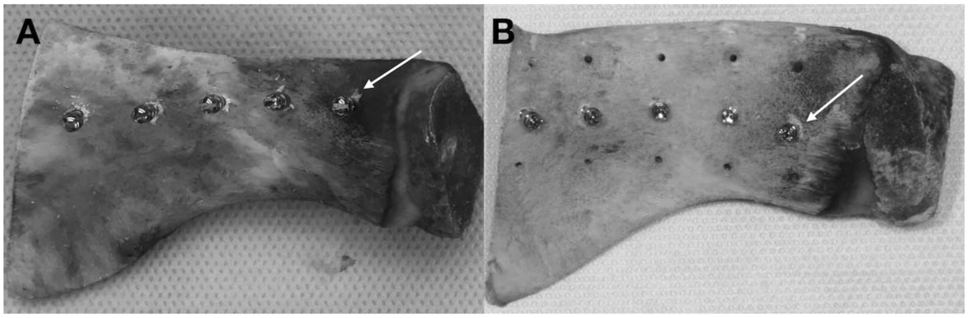

Figure 1. (A) Iliac crest specimen (n = 6) corresponding to the self-drilled group. The arrow indicates a miniscrew inserted for the first time. (B) Iliac crest specimen (n = 6) corresponding to the predrilled group. The arrow indicates a miniscrew inserted for the second time.

Although miniscrews are classified as single-use medical devices, there are some situations in which they may be reinserted, mainly related to unsatisfactory placement at insertion in dense extra-alveolar sites. Given the characteristics of these anatomical sites, miniscrews may eventually require a modification in their position or angulation either for soft-tissue or hard-tissue considerations.

Evidence[13,19,20] regarding the effects of reinsertion of orthodontic miniscrews on the primary stability and morphology of the threads and tip of reinserted miniscrews is lacking. Therefore, the objective of the present in vitro study was to measure the primary stability of miniscrews inserted with and without pilot hole predrilling by means of IT and RFA and to assess their morphological characteristics after three cycles of reinsertion in porcine iliac crest specimens using scanning electron microscopy (SEM).

MATERIALS AND METHODS

Twenty fresh porcine iliac crest bones were acquired from a commercial source, and the cortical bone thickness was evaluated immediately using cone-beam computed tomography (Carestream System 8100 3D, Rochester, NY). After identifying the cortical bone thickness in each osseous structure, 12 iliac crests were selected, and specimens approximately 30- × 50-mm in size were prepared. Operative sites for miniscrew insertion were selected according to their similarity in cortical bone thickness ranging from 2 to 3 mm.

Sixty titanium alloy (TiAl6V4) self-drilling miniscrews measuring 1.6 mm in diameter and 8 mm in length were sterilized and randomly allocated according to whether the surgical site was prepared by predrilling a pilot hole in the porcine iliac crest specimen. Therefore, two experimental groups were created, each including 30 miniscrews distributed into six iliac crests. These were coded with numbers and letters and then assigned either to the self-drilled group or to the predrilled group, with each bone specimen receiving five miniscrews (Figure 1). The bone samples were prepared to allow sequential reinsertion of each miniscrew on three occasions. In the predrilled group, three pilot holes were drilled for each miniscrew, using a bone drill (Ø 1.1 mm, length 4 mm), which was used at a right angle to the bone surface until its active surface was fully inserted.

The miniscrews were inserted with an electric motor (Orthonia Torque Driver, model 111-ED-010, RMO, Denver, Colo) at 90° against the bone surface by a single operator (Dr Nenen). All miniscrews were removed with the same electric motor in reverse mode, allowing their preparation for a second and third reinsertion cycle at different predefined sites in the bone sample. The miniscrews were steam sterilized in sealed bags before each insertion. The entire experiment was performed on 4 consecutive days from the time the bones were acquired, and they were kept in individual containers with 0.9% saline solution at 3°C.

Assessment of Primary Stability

After each insertion cycle, the IT value, expressed in Ncm, was obtained by an independent operator (Dr Rojas) using a torque driver[21] (Kanon Indicator disk-type torque driver; Nakamura Manufacturing, Matsudo, Japan; Figure 2).

The RFA was obtained by a single operator (Dr Garnica) using an Osstell ISQ device (Osstell, Gothenburg, Sweden), which translated the vibration frequency of the miniscrews by means of a SmartPeg (Osstell) into an implant stability quotient (ISQ) value (Figure 3A). The final ISQ value of each miniscrew was obtained by averaging the five values delivered by the device at four cardinal points (up, down, right, and left) added to the top of the head of the SmartPeg. To allow the use of a SmartPeg with the miniscrews, a custom-made adapter was created by laser welding an implant analog to the stem of the miniscrew driver (Figure 3B and C). The data collection process was carried out by blinded operators.

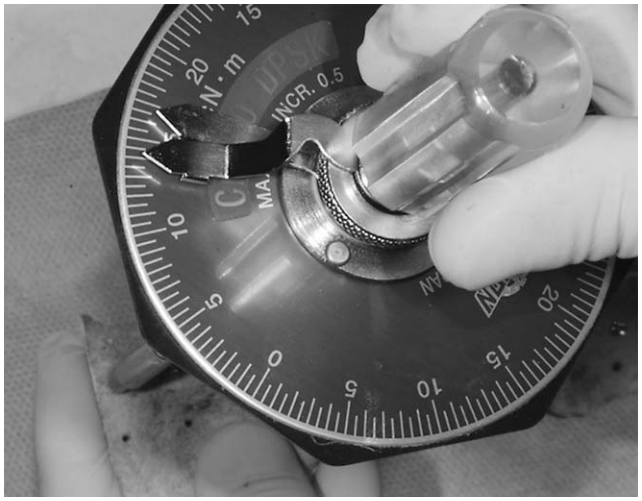

Figure 2. Torque meter used to register the insertion torque.

SEM Analysis

Five miniscrews from each group after the first insertion cycle were selected according to the average IT value to assess their structural integrity, focusing on their tip and apical third threads, using a scanning electron microscope (SEM; JEOL model JSM-IT300LV, South Korea) under 30×, 100×, and 150× magnification. These miniscrews were inserted following the experimental insertion protocol and examined sequentially under SEM after the second and third reinsertion cycles. The SEM images of each miniscrew were evaluated semiquantitatively by two independent operators (Table 1) using a scale from 1 to 4, ranging from no structural deformation to severe deformation of the tip and threads.

Table 1. Appraisal of the Structural Surface of the Miniscrews Observed Under Scanning Electron Microscope

Score	Description
1	Thread and tip of the miniscrew with unscathed structure
2	Presence of undercuts on the threads of the miniscrew without alterations in its tip
3	Presence of undercuts and attrition on the tip of the miniscrew or presence of obvious undercuts on the threads
4	Evident structural damage of the tip and/or severe damage to the miniscrew threads

Statistical Analysis

The data were tabulated and analyzed using statistical software (STATA 15, StataCorp LLC, College Station, Tex), obtaining descriptive statistics and inferential analyses. Significance levels for all tests were set at $\alpha = .05$. The normality of the IT and ISQ data was assessed using the Shapiro-Wilk test. In the predrilled group, the data were normally distributed, except for the ISQ values of the third reinsertion cycle. In contrast, in the self-drilled group, only the IT data of the first insertion cycle and the ISQ data of the first and second insertion cycles were normally distributed. The Friedman test, *t*-test, and Mann-Whitney test were used to compare the data between groups and among the insertion cycles.

Kappa analysis was conducted to evaluate interexaminer reliability of the appraisal of structural integrity of the miniscrews observed under SEM. With these data, only descriptive statistics were performed.

RESULTS

Descriptive statistics and the results of the Shapiro-Wilk test for the IT and ISQ values of both study groups

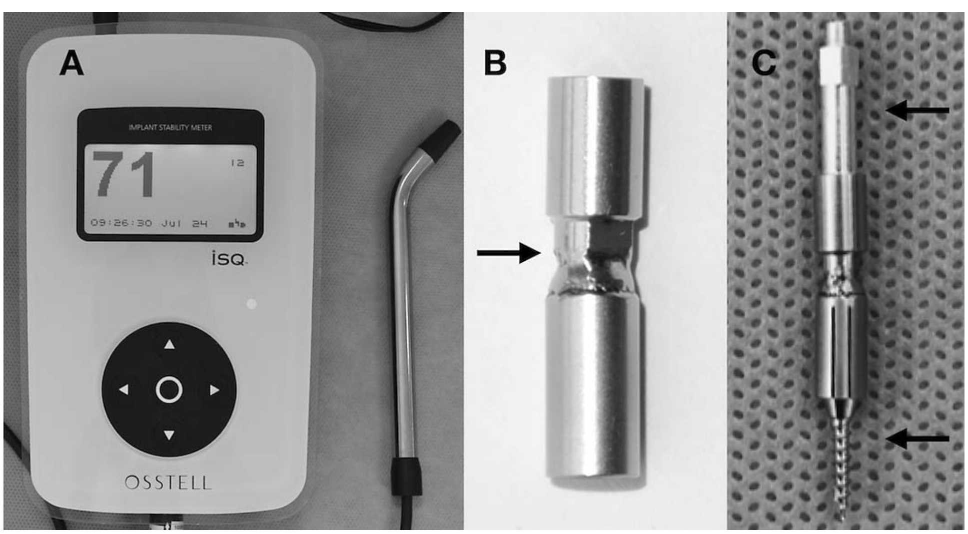

Figure 3. (A) Osstell ISQ device. (B) SmartPeg adapter device. The arrow indicates the laser-welded junction of both the miniscrew driver stem and implant analog structures. (C) SmartPeg adapter device attached at its lower aspect to the miniscrew and at its upper part to the SmartPeg.

Table 2. Insertion Torque Values (Ncm) for Predrilled and Self-Drilled Groups

Insertion No.	Group	Mean	SD	P50	P25	P75	IQR	n	*P*
First	Predrilled	11.5	4.5	11.5	8.0	15.0	7.0	30	.87031
	Self-drilled	13.0	5.0	12.5	9.0	18.0	9.0	30	.15146
Second	Predrilled	12.5	5.0	11.5	8.5	19.0	10.5	30	.20362
	Self-drilled	15.0	5.0	17.0	11.0	19.5	8.5	30	.00339**
Third	Predrilled	13.0	5.0	13.5	8.0	19.0	11.0	30	.82042
	Self-drilled	17.0	4.5	20.0	14.5	20.0	5.5	30	.00009****

** $P < .01$; **** $P < .0001$.

Table 3. Implant Stability Quotient Values for Predrilled and Self-Drilled Groups

Insertion No.	Group	Mean	SD	P50	P25	P75	IQR	n	*P*
First	Predrilled	47.9	1.2	48.0	46.8	48.8	2.0	30	.69903
	Self-drilled	49.3	1.9	49.4	48.4	50.6	2.2	30	.11412
Second	Predrilled	47.9	1.2	48.3	46.8	48.8	2.0	30	.24826
	Self-drilled	45.7	1.8	45.6	44.4	47.2	2.8	30	.61871
Third	Predrilled	43.2	3.5	43.3	41.2	46.0	4.8	30	.01333*
	Self-drilled	40.5	5.3	41.8	39.4	43.2	3.8	30	.00001****

* $P < .05$; **** $P < .0001$.

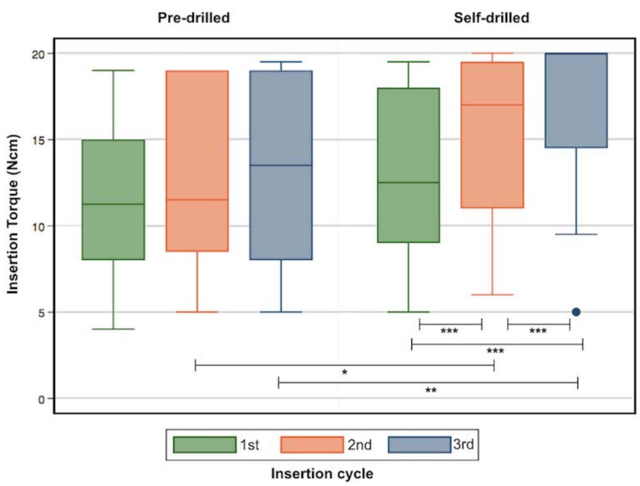

Figure 4. Comparison of the insertion torque of miniscrews after three cycles of insertion in both the predrilled and self-drilled groups. * $P < .05$; *** $P < .01$; **** $P < .001$.

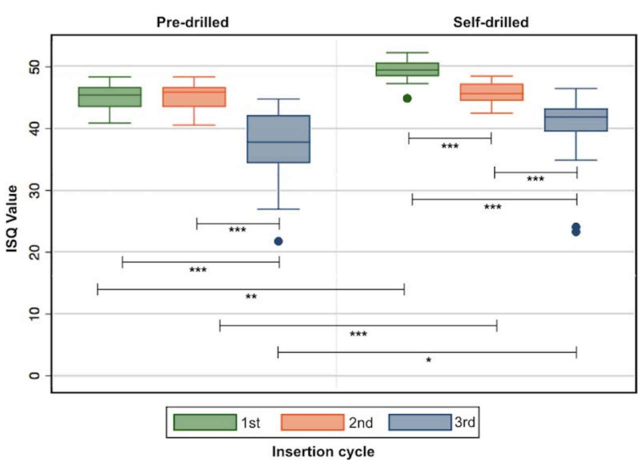

Figure 5. Comparison of the ISQ values of miniscrews after three cycles of insertion in both the predrilled and self-drilled groups. ** $P < .05$; *** $P < .01$; **** $P < .001$.

are presented in Tables 2 and 3. They showed that IT values tended to increase with reinsertion cycles, whereas ISQ values tended to decrease.

The Friedman test showed no statistically significant differences for IT after three insertion cycles in the predrilled group ($P = .081$). The self-drilled group displayed significant differences among the different cycles of insertion ($P = .0001$). When both study groups were compared, no significant differences were found between the IT values of the first insertion cycle ($P = .1817$). However, there were significant differences for the second and third insertion cycles ($P = .039$; Figure 4).

Significant differences between ISQ values in the predrilled group were found between the first and third cycles and between the second and third cycles of reinsertion ($P = .0001$). When the ISQ values were compared among the different cycles of the self-drilled group, significant differences were found between all of the insertion cycles ($P = .0001$). Intergroup comparisons of the ISQ values yielded significant differences among the miniscrews at the first ($P = .006$), second ($P = .0001$), and third ($P = .014$) insertion cycles (Figure 5).

Upon conducting the structural surface evaluation under SEM, the Cohen's Kappa coefficient for the observers was 0.9. The miniscrews showed an increase in their deformation score (i.e., greater structural damage as the number of insertions increased) as insertion cycles increased (Figure 6), especially in the self-drilled group, in which evident deformation of the tip and damage of the threads could be observed (Figure 7).

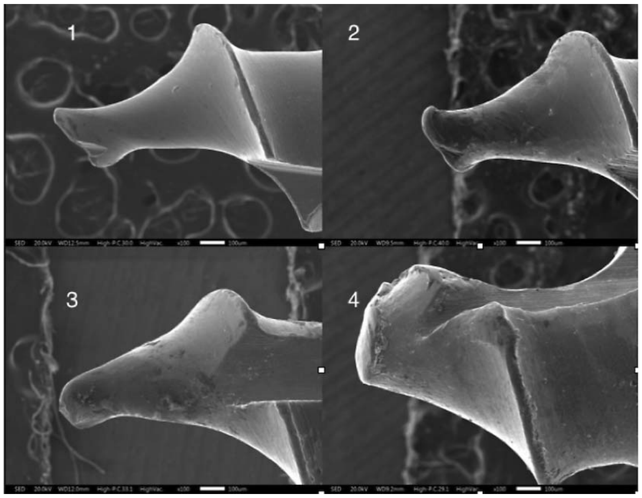

Figure 6. Examples of the score assigned to the miniscrews according to the structural surface evaluation of their tips and threads under scanning electron microscope (100×).

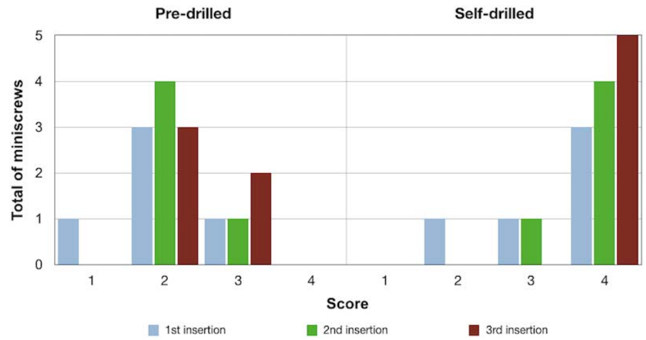

Figure 7. Score assigned according to Figure 6 to the structural surface of the miniscrews observed under scanning electron microscope after three cycles of insertion in both the predrilled and self-drilled groups.

DISCUSSION

Miniscrews are classified as single-use devices, and reinsertion is not recommended. However, from a practical and economic perspective, the sterilization and reinsertion of a miniscrew in the same patient might be an option if the initial insertion path intersects a dental root, if primary stability is not achieved because of poor bone quality, or if a root comes into contact following orthodontic movement. As eventual miniscrew deformation after reinsertion may affect their biomechanical characteristics,[19] the present study was carried out to assess the effect of reinsertion on primary stability and on miniscrew integrity using a model to assess the limits of extreme mechanical usage. The results found would encourage careful use of orthodontic miniscrews.

The results showed that IT values did not differ significantly between self-drilled and predrilled groups at the first insertion. This was consistent with the conclusions of a clinical study that compared primary stability between self-tapping and self-drilling miniscrews.[22] However, IT values increased with the number of insertion cycles. These differences in IT were statistically significant in the self-drilled group. Conversely, in the predrilled group, the increase in IT values was not statistically significantly different. This phenomenon may be related to the morphological alterations observed on the surface of the reinserted miniscrews. It is unlikely that the sterilization process affected IT values, because no direct correlation was previously found between IT values[23] or the mechanical resistance of the miniscrews[20,24] and the number of sterilization cycles in experimental settings. The difference in IT between the experimental groups can be explained by the drilling of a pilot hole, which decreased bone resistance, thus diminishing the IT value in the predrilled group.

To carry out the RFA assessment, the Osstell device was used, which delivered an ISQ value. The higher the ISQ value, the greater the primary stability of a dental implant. Because RFA is considered a valuable tool for clinically assessing stability, in vitro studies have evaluated the ISQ value in orthodontic miniscrews by modifying the head of the miniscrew or manufacturing a device to connect the Smartpeg to the miniscrew.[25–27] In the present study, a custom-made SmartPeg adapter device was used. It is known that the height of the dental implant relative to the bone affects the reading of the ISQ value.[28,29] Therefore, the use of adapters of this kind on miniscrews may reduce ISQ readings but still offer consistent values within each experimental setting, exhibiting good agreement (±5 ISQ units)[30] and allowing a closer assessment of primary stability in combination with IT data.

ISQ values have been reported to be directly correlated with the thickness of the cortical bone[26] and are also affected by the diameter of the miniscrews, the insertion protocol, and the height of the SmartPeg connected to its miniscrew adaptor.[30] In an in vitro study on porcine iliac crest, the ISQ value was recorded using a custom-made miniscrew-Smartpeg connection system,[25] reporting an average ISQ value of 40.9, which was similar to the ISQ value reported in the present study.

With regard to the RFA assessment, significant differences were found between the self-drilled and predrilled groups at each insertion cycle. Previously, in vitro studies reported a direct correlation between the ISQ value and the IT values in single-insertion scenarios.[26,27] Consistently, in the present study, IT and ISQ values tended to be directly correlated in the first insertion cycle. However, in the second and third insertion cycles, these values tended to be inversely correlated; specifically, the ISQ values of the self-drilled group decreased considerably compared with those of the predrilled group. This can be explained by the fact that self-drilled group miniscrews suffered more damage and/or structural deformation mainly at the tip but also at the threads, making their insertion difficult and generating a higher IT value. In addition, this morphological alteration occurred when traversing the bony cortex, making intimate adaptation of the miniscrew with the surrounding bone difficult. This phenomenon may explain the lower ISQ values the in ascending series of insertions.

The SEM examination revealed deformation of the tip and threads of the miniscrews with an increasing number of insertions. This was more evident in miniscrews inserted without pilot holes (self-drilled group), but miniscrews inserted for the second time with predrilled pilot holes still exhibited a slight increase in structural damage under microscopic evaluation.

The results suggest that morphological distortion of the miniscrews affects the IT as well as the ISQ values in both the self-drilled and predrilled groups, thus affecting the primary stability of reinserted miniscrews despite the presence of high recorded IT values. Therefore, the reinsertion of orthodontic miniscrews should be discouraged, especially if no pilot drilling is performed.

CONCLUSIONS

- The reinsertion of self-drilled orthodontic miniscrews progressively increases IT and reduces ISQ values, affecting primary stability.
- The reinsertion of orthodontic miniscrews produces morphological deformation of their tips and threads, which is more severe when a self-drilling technique is used.
- It is not advisable to reinsert orthodontic miniscrews.

ACKNOWLEDGMENTS

We acknowledge Dr Sebastián Miranda, Mrs Marcela Urbina, and Mrs Rocio Orellana for their valuable support during the experimental phase of this study.

REFERENCES

1. Kanomi R. Mini-implant for orthodontic anchorage. *J Clin Orthod*. 1997;31:763–767.
2. Bae SM, Park HS, Kyung HM, Kwon OW, Sung JH. Clinical application of micro-implant anchorage. *J Clin Orthod*. 2002; 36:298–302.
3. Park HS, Kyung HM, Sung JH. A simple method of molar uprighting with micro-implant anchorage. *J Clin Orthod*. 2002;36:592–596.
4. Kim TW, Kim H, Lee SJ. Correction of deep overbite and gummy smile by using a mini-implant with a segmented wire in a growing Class II Division 2 patient. *Am J Orthod Dentofacial Orthop*. 2006;130:676–685.
5. Chen Y, Kyung HM, Zhao WT, Yu WJ. Critical factors for the success of orthodontic mini-implants: a systematic review. *Am J Orthod Dentofacial Orthop*. 2009;135:284–291.
6. Melsen B, Costa A. Immediate loading of implants used for orthodontic anchorage. *Clin Orthod Res*. 2000;3:23–28.
7. Motoyoshi M, Hirabayashi M, Uemura M, Shimizu N. Recommended placement torque when tightening an orthodontic mini-implant. *Clin Oral Implants Res*. 2006;17:109–114.
8. 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;142:596–614.e5.
9. Nguyen MV, Codrington J, Fletcher L, Dreyer CW, Sampson WJ. The influence of miniscrew insertion torque. *Eur J Orthod*. 2018;23:37–44.
10. 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;137:588.e1–588.e5.
11. Meredith N, Alleyne D, Cawley P. Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. *Clin Oral Implants Res*. 1996;7: 261–267.
12. Pagliani L, Sennerby L, Petersson A, Verrocchi D, Volpe S, Andersson P. The relationship between resonance frequency analysis (RFA) and lateral displacement of dental implants: an in vitro study. *J Oral Rehabil*. 2013;40:221–227.
13. Suzuki EY, Suzuki B, Aramrattana A, Harnsiriwattanakit K, Kowanich N. Assessment of miniscrew implant stability by resonance frequency analysis: a study in human cadavers. *J Oral Maxillofac Surg*. 2010;68:2682–2689.
14. Dalessandri D, Salgarello S, Dalessandri M, Lazzaroni E, Piancino M, Paganelli C, Maiorana C, Santoro F. Determinants for success rates of temporary anchorage devices in orthodontics: a meta-analysis (n>50). *Eur J Orthod*. 2014; 36:303–313.
15. Uesugi S, Kokai S, Kanno Z, Ono T. Prognosis of primary and secondary insertions of orthodontic miniscrews: what we have learned from 500 implants. *Am J Orthod Dentofacial Orthop*. 2017;152:224–231.
16. Uesugi S, Kokai S, Kanno Z, Ono T. Stability of secondarily inserted orthodontic miniscrews after failure of the primary insertion for maxillary anchorage: maxillary buccal area vs midpalatal suture area. *Am J Orthod Dentofacial Orthop*. 2018;153:54–60.
17. Elshebiny T, Palomo JM, Baumgaertel S. Anatomic assessment of the mandibular buccal shelf for miniscrew insertion in white patients. *Am J Orthod Dentofacial Orthop*. 2018; 153:505–511.
18. Cheng SJ, Tseng JY, 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.
19. Yun S-D, Choi S-H, Cha J-Y, et al. Effects of recycling on the biomechanical characteristics of retrieved orthodontic miniscrews. *Korean J Orthod*. 2017;47:238.
20. Estelita S, Janson G, Chiqueto K, Ferreira, E. Effect of recycling protocol on mechanical strength of used mini-implants. *Int J Dent*. 2014;2014:424923.
21. Watanabe T, Miyazawa K, Fujiwara T, Kawaguchi M, Tabuchi M, Gotob, S. Insertion torque and Periotest values are important factors predicting outcome after orthodontic

miniscrew placement. *Am J Orthod Dentofacial Orthop*. 2017;152:483–488.
22. Son S, Motoyoshi M, Uchida Y, Shimizu N. Comparative study of the primary stability of self-drilling and self-tapping orthodontic miniscrews. *Am J Orthod Dentofacial Orthop*. 2014;145:480–485.
23. Akyalcin S, McIver HP, English JD, Ontiveros JD, Gallerano RL. Effects of repeated sterilization cycles on primary stability of orthodontic mini-screws. *Angle Orthod*. 2013;84: 67479.
24. Mattos CT, Ruellas AC, Sant'Anna EF. Effect of autoclaving on the fracture torque of mini-implants used for orthodontic anchorage. *J Orthod*. 2011;38:15–20.
25. Nienkemper M, Wilmes B, Panayotidis A, et al. Measurement of mini-implant stability using resonance frequency analysis. *Angle Orthod*. 2013;83:230–238.
26. Su YY, Wilmes B, Honscheid R, Drescher D. Application of a wireless resonance frequency transducer to assess primary stability of orthodontic mini-implants: an in vitro study in pig ilia. *Int J Oral Maxillofac Implants*. 2009;24:647–654.
27. Nienkemper M, Santel N, Hönscheid R, Drescher D. Orthodontic mini-implant stability at different insertion depths. *J Orofac Orthop*. 2016;77:296–303.
28. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications. *Periodontol 2000*. 2008;47:51–66.
29. Turkyilmaz I, Sennerby L, Yilmaz B, Bilecenoglu B, Ozbek EN. Influence of defect depth on resonance frequency analysis and insertion torque values for implants placed in fresh extraction sockets: a human cadaver study. *Clin Implant Dent Relat Res*. 2009;11:52–58.
30. Hosein Y, Dixon J, Rizkall A, Tassi A. A novel technique for measurement of orthodontic mini-implant stability using the Osstell ISQ device. *Angle Orthod*. 2019;89:284–291.