Revista Odontológica Mexicana
Órgano Oficial de la Facultad
de Odontología UNAM

Original research

Analysis of the Superficial Morphology of Orthodontic Mini Implants Using Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy

Sayra Nayelli Velázquez-Serrano[1], Ricardo Medellín-Fuentes[2], Jesús Ángel Arenas-Alatorre[3], Ana Wintergerst[4], Jacqueline Adelina Rodríguez-Chávez[5], Abigailt Flores-Ledesma[6]

1. Posgrado de Ortodoncia División de Estudios de Posgrado e Investigación, Facultad de Odontología, Universidad Nacional Autónoma de México.
2. Coordinador de Posgrado de Ortodoncia División de Estudios de Posgrado e Investigación, Facultad de Odontología, Universidad Nacional Autónoma de México.
3. Laboratorio de Microscopia, Instituto de Física, Universidad Nacional Autónoma de México.
4. División de Estudios de Posgrado e Investigación, Facultad de Odontología, Universidad Nacional Autónoma de México.
5. Instituto de Investigación en Odontología. Departamento de Clínicas Odontológicas integrales. Universidad de Guadalajara.
6. Facultad de Estomatología de la Benemérita Universidad Autónoma de Puebla, México.

Corresponding Author:
Abigailt Flores-Ledesma
E-mail: abigailt.flores@correo.buap.mx
ORCID http://orcid.org/0000-0002-8136-4820

Date received: Abril 2022
Date accepted: June 2023

Cite as:
Velázquez-Serrano SN, Medellín Fuentes R, Arenas-Alatorre JA, Wintergerst A, Rodríguez-Chávez JA, Flores-Ledesma A. Analysis of the Superficial Morphology of Orthodontic Miniimplants Using Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy. [Análisis de la morfología superficial de miniimplantes ortodóncicos mediante microscopía electrónica de barrido y espectroscopía de rayos X de energía dispersiva]. *Rev Odont Mex*. 2023; *27*(2): 12-22. DOI: 10.22201/fo.1870199xp.2023.27.2.82499

Abstract

Introduction: Mini implants have simplified the biomechanic movements during an orthodontic treatment. The roughness, surface morphology, and individual characteristics relate to the pullout resistance and primary stability of mini-implants during dental movement. **Objective:** To evaluate the surface morphology and the chemical elemental composition of four brands of mini-implants using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). **Materials and methods**: Four mini-implants commercially available in México (n=5 of each): M.O.S.A.S. (Dewimed®), Implant QUICK (Borgatta), Vector TAS (Ormco™) and OrthoEasy (Forestadent®) were evaluated. Surface morphology was assessed by SEM (JEOL 5600LV, Japan) with secondary electrons in high vacuum mode (20 keV). EDS analyses were performed with 45 readings per group. **Results**: The analyzed brands presented homogenous polished zones, with few marks of the manufacturing processes. OrthoEasy shows the lowest conicity with 0.02°, followed by Implant QUICK and Vector TAS with 0.04°. The principal element in all brands was Titanium with 84.3-82.8%, the Aluminum content was between 11.3-12.8 %, and the Vanadium content was 4.3-4.4% (ANOVA, $p>0.05$). **Discussion**: The percentage of aluminum is higher than the 5.5-6.5% established in the ASTM F-136-08 standard. It is not a common element in the human body. **Conclusion**: The main differences in the mini-implant morphology are the thread and the form of the tip. The chemical elemental composition is homogeneous, but the aluminum content is higher than the specified by the ASTM F-136-08 standard.

Keywords: Mini implants, SEM, elemental chemical composition, surface morphology

INTRODUCTION

The use of mini-implants in orthodontics has simplified biomechanics. Mini implants or mini-implants are temporary devices that ease many orthodontic movements and avoid secondary or undesirable dental movements, usually produced during conventional orthodontic treatment. Since the introduction of mini-implants, the use of intraoral anchorage devices (lingual arch, transpalatine bar, Nance button) and extraoral devices (face mask or extraoral bow) has been less frequent. Mini implants are helpful when a dental anchorage is deficient in quality and quantity; these temporal anchoring aids reduce undesirable dental movements and allow stable osseous anchorage[1]. Their indications have increased: molar distalization or mesialization[2], intrusion or extrusion of anterior and posterior teeth[3] or to anchor molars or groups of teeth[4]. The mini-implant´s length and diameter are important considerations contingent on the zone where they will be placed: palate, jaw, retromolar, or interradicular area[5], so that mechanical retention is secured[6].

Mini implants are exposed to a high humidity environment, as well as chemical and thermal changes; therefore, they could undergo corrosion[7,8]. Additionally, the liberation of ions can induce physiological adverse effects such as carcinogenicity and hypersensitivity[9]. Dental alloys should not present toxicity and must be biocompatible, with adequate mechanical properties capable of resisting stress and tension. Dental mini-implants are thus usually made of grade 5 Titanium or stainless steel[10]. Ti6Al4V is the most common alloy used for mini-implants, it has a biphasic microstructure, an α, and a β phase that should be equilibrated[11,12].

Mini implants are available in different lengths, diameters, and tips. These characteristics improve mechanical retention avoiding premature displacement since they will be in the oral cavity approximately for 4.6 to 11 months[2]. After this period, they need to be easily removed so there should be no osteointegration contrary to what is needed for rehabilitation implants. Considering the wide variety of characteristics and prices of mini implants available on the market, it makes it difficult for the clinician to choose the most appropriate mini implants for each case, thus this study aimed to describe morphological characteristics such as taper, threads, flank thread depth, tip and the chemical elementary composition through scanning electron microscopy (SEM) and energy dispersion spectroscopy (EDS) of four brands of dental mini implants commercially available in Mexico.

MATERIALS AND METHODS

Four types of mini-implants were evaluated: M.O.S.A.S. Schrauben (Dewimed®), QUICK Implant (Borgatta), Vector TAS (Ormco™), and OrthoEasy (Forestadent®). Manufacturer characteristics are specified in Table 1. Five samples of each brand (n=5) were ultrasonically cleaned (Branson 2510R MTH 2001, USA) for 15 minutes at room temperature and 40Hz, and immersed in acetone, since it is recommended for cleaning stainless steel products as it is non-reactive and serves as a cleaning and degreasing agent[13]. Afterwards, the mini-implants were sterilized in an autoclave (Cristófoli Vitale 21, Brazil) at 134°C for 20 minutes, the mini implants were immediately taken into SEM observation, to avoid contamination. No pilot test was performed since the cleaning method is a standardized and methodic procedure[14].

The microstructure of the mini-implants' surface was assessed by SEM (JEOL, JSM 5600-LV, Japan) performed in high vacuum mode with a secondary electrons signal at 20 kV, with 18x and 100x. The samples were placed on double carbon tape for SEM observations. Three micrographs of each sample were taken to obtain the total surface area of the mini-implant (18x magnification). The micrographs were analyzed with ImageJ 1.45 Software (National Institutes of Health, Bethesda, MD). The scale bar in each image was used to calibrate the software and obtain measurements: maximum and minimum diameter of the thread, taper, pitch, flank, thread angles, number of threads, inter-thread distance, thread depth, crest, and tip as shown in Figure 1. The elemental chemical analysis was carried out in triplicate on three areas: head, neck, and thread. Nine EDS were made for each sample, to complete a total of 45 EDS per group. The atomic percentages of each element (Ti, Al, V) were semi-quantified. Data was analyzed in SPSS version 20 (Statistical Package for the Social Sciences; SPSS, Version 20, Chicago, IL). Normal distribution was determined with Shapiro Wilks tests (p>0.05), thus parametric analysis was performed with ANOVA, (CI=0.05).

Table 1. Manufacture specifications of the four brands of mini implants.

Name	Manufacture	Length (mm)	Diameter (mm)	Neck (mm)	Tip
M.O.S.A.S. Schrauben	Dewimed®, Germany	8.0	1.6	2.5	Self-cutting and self-drilling
QUICK Implant	Borgatta, China	7.0	1.6	2.0	Self-cutting
Vector TAS	Ormco™, USA	8.0	1.4	1.0	Self-cutting and self-drilling
OrthoEasy	Forestadent®, Germany	8.0	1.7	2.0	Self-cutting and self-drilling

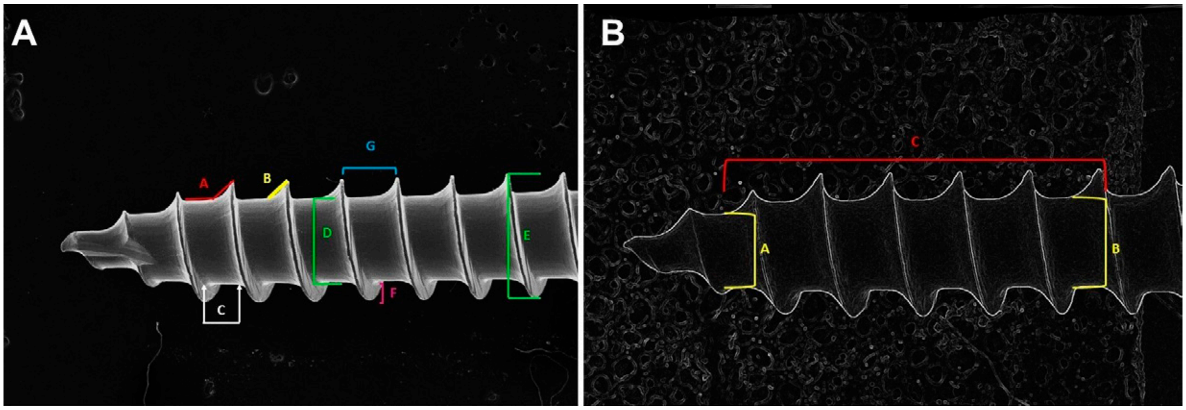

Figure 1. A-Morphologic characteristics evaluated: A. Thread angle, B. Flank width, C. Pitch width, D. Internal diameter, E. External diameter, F. Depth of the thread, G. Inter thread distance. 18x magnification, scale bar represents 1mm. B-The taper of the mini implants was obtained by the following formula: (B-A)/(2xC). 18x magnification, scale bar represents 1mm.

RESULTS

The semiquantitative analysis of the elemental chemical composition is presented in Table 2, the main element in all mini-implants was titanium (82.8-84.3%) followed by aluminum (11.3-12.8%) and vanadium (4.3-4.4%) corresponding to the three elements of the Ti6Al4V alloy, however, no statistically significant differences were found for these elements among the brands (ANOVA, p> 0.05).

The morphology of the total length of the mini-implants is shown in Figure 2. The heads of the M.O.S.A.S. Schrauben, QUICK Implant, and Vector TAS have fewer retention zones since the head area is more rounded. QUICK Implant mini-implants show a cylindrical tip while M.O.S.A.S. Schrauben, Vector TAS, and OrthoEasy mini implants present a tapered tip corresponding to a self-cutting tip (Figure 3). All brands displayed a smooth homogenous surface over the thread and the transmucosal area, with some marks of the manufacturing processes such as pores and milling scratches (Figure 3). The mini-implants' descriptive morphological characteristics such as the maximum and minimum diameter of the thread, taper, pitch width, flank width, thread angle, number of threads, inter-thread distance, thread depth, crest, and tip are presented in Table 3.

Table 2. Mean and SD of element percentage of titanium, aluminum, and vanadium obtained by EDS.

Name	Titanium	Aluminum	Vanadium
M.O.S.A.S. Schrauben	84.3 ± 2.6[a]	11.3 ± 2.8[a]	4.4 ± 0.4[a]
QUICK Implant	83.4 ± 3.3[a]	12.2 ± 3.4[a]	4.4 ± 0.4[a]
Vector TAS	83.3 ± 2.4[a]	12.4 ± 2.5[a]	4.3 ± 0.4[a]
OrthoEasy	82.8 ± 6.8[a]	12.8 ± 7.2[a]	4.4 ± 0.5[a]

No significant statistical significance was found when comparing by element, n=45. ANOVA p>0.05, Lowercase letters are used to compare means in the same column; means sharing a superscript letter are not significantly different.

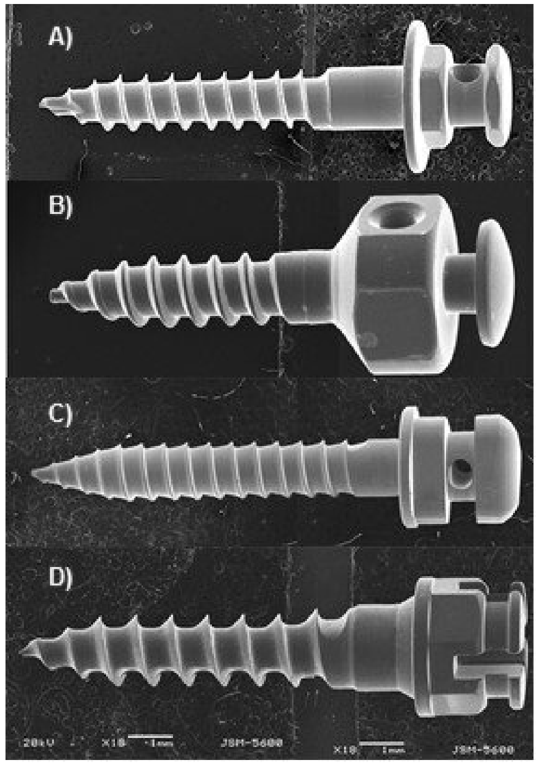

Figure 2. Total length of the mini implants. A. M.O.S.A.S. Schrauben, B. QUICK Implant, C. Vector TAS, and D. OrthoEasy. Images were taken at 18x magnification, scale bar = 1mm.

DISCUSSION

Since one of the main advantages of mini-implants is their easy placement and secure osseous anchorage without undesirable dental movements (they are temporary devices) osteointegration is therefore not needed but it is necessary to have good mechanical retention. Mini implants are made of medical grade Ti6Al4V alloy, that provides excellent mechanical resistance and a great molding capability, mainly because its biphasic microstructure is composed of an α phase (rich in Al) and a β phase (rich in V)[15]. Aluminum has great solubility in titanium, improving corrosion and oxidation resistance. The α phase presents low plasticity and displays mechanical and anisotropic properties, whereas the β phase shows high ductility and provides stabilizers to reduce the temperature needed for metal transformation from α to β, making it possible to carry out thermal treatment to increase its resistance, and improving plastic deformation[16]. Young's modulus of the α-Ti and α+β-Ti alloys is 100-110GPa and it is about 60-80 GPa for β-Ti alloys, making a more ductile alloy[11,12]; both phases must be in equilibrium to secure the best mechanical properties.

Ti6Al4V alloy is considered the gold standard for medical use, making it suitable for dental use[11,12,17]. One of the major concerns related to vanadium is its release because it deposits in the liver, kidney, and lungs[18]. This release could occur when the increase of chloride in human serum produces a corrosive environment for metallic alloys since the pH decreases to 5.2 after the implantation associated with the inflammatory process; pH recovers to 7.4 at 14 days[19]. New β-Ti alloys have been developed[11,20] to avoid this vanadium release, where a passivation film of titanium oxide is formed on the surface of the mini implants reacting with bone ions

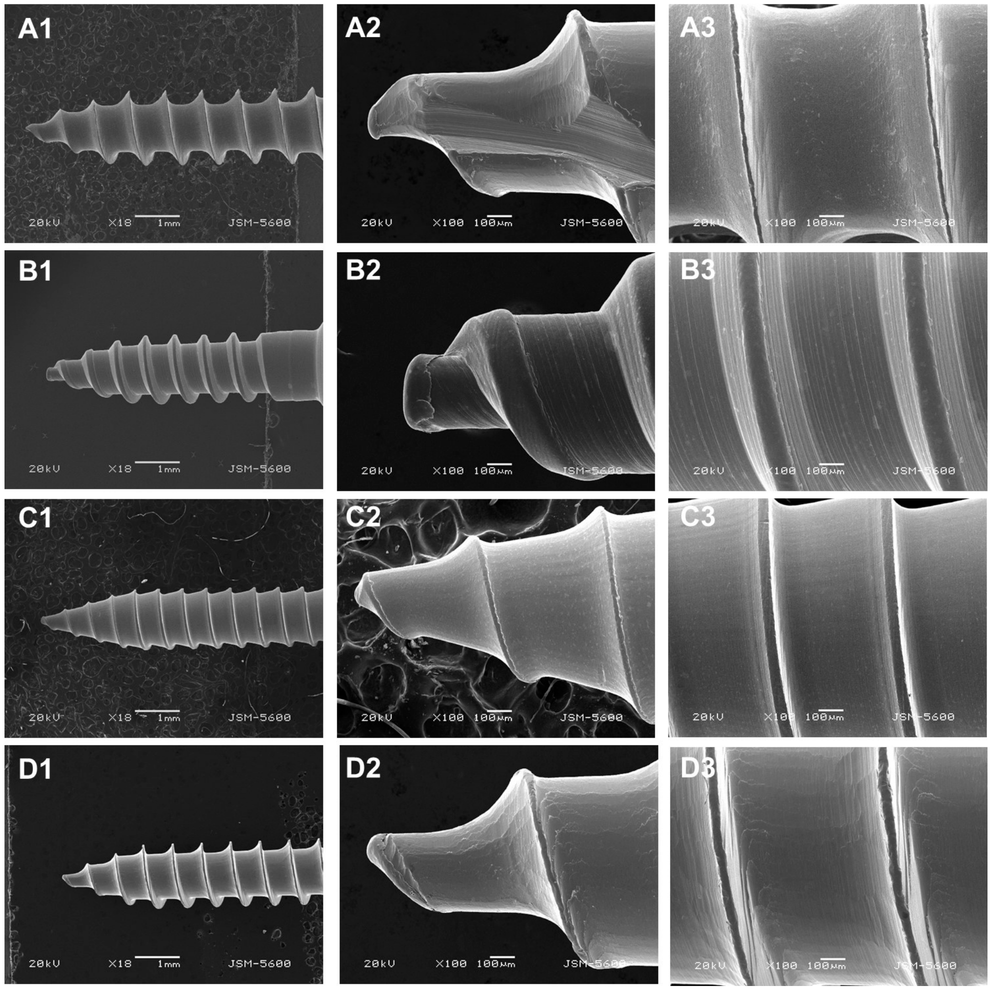

Figure 3. SEM images of the mini implants. A. M.O.S.A.S. Schrauben, B. QUICK Implant, C. Vector TAS, and D. OrthoEasy. Column 1- show images of the mini implants´s threads. Images were taken at 18 x magnification. Scale bar = 1mm. Column 2- Tip region, 100x magnification; scale bar =100 μm. Column 3- Interthread area, images taken at 100x. Scale bar =100 μm.

Table 3. Descriptive linear, angular, and morphologic characteristics of each group.

	M.O.S.A.S. Schrauben	QUICK Implant	Vector TAS	OrthoEasy
Maximum diameter of the thread (mm)	1.33	1.18	1.15	1.22
Minimum diameter of the thread (mm)	0.83	0.67	0.65	0.65
Taper (conicity)	0.04	0.06	0.04	0.02
Pitch width (mm)	0.40	0.36	0.38	0.55
Flank width (mm)	0.31	0.25	0.11	0.39
Thread angle (°)	136	124	155	135
Number of threads	10	7	13	8
Interthread distance (mm)	0.66	0.67	0.55	0.8
Threads depth (mm)	0.27	0.20	0.11	0.32
Crest	Sharp	Rounded	Sharp	Sharp
Tip	Tapered	Cylindrical	Tapered	Tapered

like $(Ca)^{2+}$ and $(PO_4)^{3-}$[16,17]. In the current study, the vanadium content (3.5-4.5%) coincides with that reported in ASTM F-136-08[21] and with that reported by Patil *et al*.[22]. The percentage of aluminum (11.27-12.8%) in the evaluated mini-implants is higher than the 5.5-6.5% established in ASTM F-136-08[21]. Aluminum is not a common element in the human body; it has been found to have undesirable effects on the human body such as cytotoxicity or apoptosis[23] and has been associated with Alzheimer´s disease[24]. It is present in beverages, food, and cosmetics and has been detected in mucosal cells in patients with mini implants[25]; but no studies on cytotoxicity associated with its use in mini-implants have been performed. As mentioned above and previously reported there were no differences in the Ti, Al, and V content in the different brands[26], indicating that there is an excellent quality control in the manufacture of these devices.

Characteristics such as width, active tip, exterior and internal diameter coil, number of threads, width of the flank, and the taper are related to retention and insertion[27,28]. Nevertheless, some authors mention that the location and angle placement and age could also affect biocompatibility, retention, and resistance[12]. Another factor for stability, the passivation film on the mini-implant surface[16], is influenced by the inflammatory response after its placement and helps to improve the corrosion resistance produced by an electrolytic solution such as saliva[22,26]. Mini implants have shown surface degradation, plastic deformation, and some ruptures after clinical use[29] but no corrosion has been observed after 230 days in the oral cavity[30]. Therefore, it is important that the transmucosal part is fully polished to avoid inflammation caused by the retention of plaque[31], as it was previously mentioned the heads of the M.O.S.A.S. Schrauben, QUICK Implant, and Vector TAS have less plaque retention zones since the head area is more rounded. It has been reported that dry sterilization might have a negative effect on the mechanical properties of mini implants[32], especially on their fracture torque; however, other studies have shown that steam sterilization does not have any effect on the mechanical properties of the mini-implants such as insertion torque or the resistance to fracture[32–34].

Chang *et al*.[27] carried out a finite element study on the influence of the design of the mini-implants, finding that mini implants with more thread depth and a smaller taper produce more displacement. The tapers they studied were 0.03, 0.05, 0.07, and 0.11°, and found that the mini-implant's pullout resistance decreases as the taper decreases. In the current study, OrthoEasy shows the lowest conicity with 0.02°, followed by QUICK Implant and Vector TAS with 0.04°. A smaller conicity will avoid fracture in the placement area by reducing stress since they have less contact with the bone, a conical thread diminishes the unwanted destruction of the bone, favoring its primary stability; the taper of the mini-implants guarantees osseous condensation avoiding destruction of the cortical bone caused by an eccentric insertion[35]. It has been suggested that mini-implants should be preferably conical in an apical direction[36] since the extraction force will increase if the mini implant is more cylindrical[37].

In the current study, the mini-implants present different designs and surface morphology. The form and width of the mini-implants are fundamental for its fixation; more threads represent more resistance to displacement and more primary stability; in this sense, M.O.S.A.S. Schrauben, Implant QUICK, and OrthoEasy could bring more primary stability than Vector TAS, because the thread depth is above 0.20 mm. The pullout resistance is affected with a thread depth between 0.32 and 0.40 mm and produces a high stress in the neck zone[27]. The best pullout resistance is obtained with depths of 0.16 and 0.32 mm[27]; we found values in the range of 0.11 to 0.32 mm which indicates good resistance.

Mini implants with a wide diameter are used to obtain more contact with the bone but can cause micro fractures of the bone and inside the threads, as well as obstruction of blood irrigation that could induce osseous necrosis[38]. On the other hand, a mini-implant with an internal diameter that is too small can fracture due to friction with the bone, especially cortical bone. The thread design can influence resistance; a reversed thread produces more stability and resistance in comparison with rounded and trapezoidal threads. The morphology of the surface and roughness can provide more stability inside the oral cavity [39].

The distance between the threads must be sufficient, to avoid bone fractures, because in that case mechanical retention could be lost; the distance of the threads between 0.5mm and 0.75mm is sufficient for stability[40,41]. In this study, M.O.S.A.S. Schrauben, QUICK Implant, and Vector TAS show an inter-thread distance of 0.66, 0.67, and 0.55 mm, but in the OrthoEasy mini implants, the distance was 0.8 mm and that could reduce the mechanical retention. However, the pitch width measured in the four mini-implants was similar between 0.36-0.55 mm.

A trapezoidal thread related to the reduced thread angles and flank width requires more insertion force and torque causing higher tissue compression and increasing the risk of bone fracture[29]. It was observed that the thread angles of the M.O.S.A.S. Schrauben and OrthoEasy were similar with 136° and 135° and flank widths of 0.31 and 0.39 mm respectively, while the Vector TAS show 155° and 0.11mm, but QUICK Implant showed the smallest angle with 124° that according to Marigo *et al*.[29] could increase the probability of bone fracture, but it is equilibrated with a narrow flank width of 0.25 mm.

There are two placement techniques, the first one where a previous perforation is needed for the insertion of the mini-implant, and the second one where the mini-implants can be inserted without a previous perforation (self-cutting). All the mini-implants evaluated in the current study are reported by the manufacturer as self-cutting, but the QUICK Implant mini implant has a flatter tip, that could make the insertion more difficult. The self-cutting mini-implants have less mobility and have more contact between the bone and the mini implant in comparison with those that need previous perforations[42].

Primary stability of the implant depends mainly on the mini implants' characteristics and is less affected by the placement technique of the operator or the insertion area, while the secondary stability is given by the cortical bone; the thicker the cortical bone the higher the secondary stability, independently of the length, diameter, and taper of the miniimplants[37,43]. New studies with finite elements or photoelastic analysis should be made to evaluate the stress areas related to the mini implants and bone, that could lead to clinical investigation.

CONCLUSIONS

The analyzed Ti6Al4Va mini-implants present slight differences in the superficial and morphologic analysis in different zones of the mini implants. Their composition and characteristics fulfill the manufacturer's reports. We propose further studies to analyze corrosion, ion release, and the effect of morphologic characteristics on stress and torque.

BIBLIOGRAPHIC REFERENCES

1. Lim HM, Park YC, Lee KJ, Kim KH, Choi YJ. Stability of dental, alveolar, and skeletal changes after miniscrew-assisted rapid palatal expansion. *Korean J Orthod*. 2017; 47(5): 313-322. DOI: 10.4041/kjod.2017.47.5.313

2. Mohamed RN, Basha S, Al-Thomali Y. Maxillary molar distalization with miniscrew-supported appliances in Class II malocclusion: A systematic review. *Angle Orthod*. 2018, 88(4): 494-502. DOI: 10.2319/091717-624.1
3. Baumgaertel S, Smuthkochorn S, Palomo JM. Intrusion method for a single overerupted maxillary molar using only palatal mini-implants and partial fixed appliances. *Am J Orthod Dentofacial Orthop*. 2016; 149(3): 411-415. DOI: 10.1016/j.ajodo.2015.10.016
4. Antelo OM, Meira TM, Oliveira DD, Pithon MM, Tanaka OM. Long-term stability of a Class III malocclusion with severe anterior open bite and bilateral posterior crossbite in a hyperdivergent patient. *Am J Orthod Dentofacial Orthop*. 2020; 157(3): 408-421. DOI: 10.1016/j.ajodo.2018.10.029
5. 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): 745-751. DOI: 10.2319/011117-34.1
6. Albogha MH, Takahashi I. Generic finite element models of orthodontic mini-implants: Are they reliable? *J Biomech*. 2015; 48(14): 3751-3756. DOI: 10.1016/j.jbiomech.2015.08.015
7. Tamilselvi S, Raman V, Rajendran N. Corrosion behaviour of Ti-6Al-7Nb and Ti-6Al-4V ELI alloys in the simulated body fluid solution by electrochemical impedance spectroscopy. *Electrochim Acta*. 2006; 52(3): 839-846. DOI: 10.1016/j.electacta.2006.06.018
8. Yoneyama Y, Matsuno T, Hashimoto Y, Satoh T. In vitro evaluation of H_2O_2 hydrothermal treatment of aged titanium surface to enhance biofunctional activity. *Dent Mater J*. 2013; 32(1): 115-121. DOI: 10.4012/dmj.2012-087
9. Camero S, Talavera I, González G, Réquiz R, Rosales A, Suárez M, *et al.* Estudio de la corrosión de una aleación Ti6Al4V utilizada como biomaterial. *Rev Fac Ing UCV*. 2008; 23(3): 27-34. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0798-40652008000300003&lng=es&nrm=iso&tlng=es
10. Bollero P, Di Fazio V, Pavoni C, Cordaro M, Cozza P, Lione R. Titanium alloy vs. stainless steel miniscrews: An in vivo split-mouth study. *Eur Rev Med Pharmacol Sci*. 2018; 22(8): 2191-2198. DOI: 10.26355/eurrev_201804_14803
11. Niinomi M, Liu Y, Nakai M, Liu H, Li H. Biomedical titanium alloys with Young's moduli close to that of cortical bone. *Regen Biomater*. 2016; 3(3): 173-185. DOI: 10.1093/rb/rbw016
12. Sivamurthy G, Sundari S. Stress distribution patterns at mini-implant site during retraction and intrusion — a three-dimensional finite element study. *Prog Orthod*. 2016; 17: 4. DOI: 10.1186/s40510-016-0117-1
13. Schuster JM, Schvezov CE, Rosenberger MR. Influence of experimental variables on the measure of contact angle in metals using the sessile drop method. *Procedia Materials Science*. 2015; 8: 742-751. DOI: 10.1016/j.mspro.2015.04.131
14. Parirokh M, Asgary S, Eghbal MJ. An energy-dispersive X-ray analysis and SEM study of debris remaining on endodontic instruments after ultrasonic cleaning and autoclave sterilization. *Aust Endod J*. 2005; 31(2): 53-58. DOI: 10.1111/j.1747-4477.2005.tb00222.x
15. Rack HJ, Qazi JI. Titanium alloys for biomedical applications. *Mater Sci Eng C*. 2006; 26(8): 1269-1277. DOI: 10.1016/j.msec.2005.08.032
16. Huo WT, Zhao LZ, Zhang W, Lu JW, Zhao YQ, Zhang YS. In vitro corrosion behavior and biocompatibility of nanostructured Ti6Al4V. *Mater Sci Eng C*. 2018; 92: 268-279. DOI: 10.1016/j.msec.2018.06.061
17. Zhang LC, Chen LY. A review on biomedical titanium alloys: Recent progress and prospect. *Adv Eng Mater*. 2019; 21(4): 1-29. DOI: 10.1002/adem.201801215
18. Morais LS, Serra GG, Muller CA, Andrade LR, Palermo EFA, Elias CN, *et al.* Titanium alloy mini-implants for orthodontic anchorage: Immediate loading and metal ion release. *Acta Biomater*. 2007; 3(3): 331-339. DOI: 10.1016/j.actbio.2006.10.010

19. Hanawa T. Metal ion release from metal implants. *Mater Sci Eng C*. 2004; 24(6-8): 745-752. DOI: 10.1016/j.msec.2004.08.018
20. Al-Mobarak NA, Al-Swayih A, Al-Rashoud FA. Corrosion behavior of Ti-6Al-7Nb alloy in biological solution for dentistry applications. *Int J Electrochem Sci.* 2011; 6(6): 2031-2042. DOI: 10.1016/S1452-3981(23)18165-X
21. ASTM International. *F136 Standard specification for wrought Titanium-6Aluminum-4Vanadium ELI (extra low interstitial) alloy for surgical implant applications (UNS R56401).* [Internet]. https://compass.astm.org/document/?contentCode=ASTM%7CF0136-13R21E01%7Cen-US&proxycl=https%3A%2F%2Fsecure.astm.org&fromLogin=true
22. Patil P, Kharbanda OP, Duggal R, Das TK, Kalyanasundaram D. Surface deterioration and elemental composition of retrieved orthodontic miniscrews. *Am J Orthod Dentofacial Orthop.* 2015; 147(4 Suppl): S88-S100. DOI: 10.1016/j.ajodo.2014.10.034
23. Yu L, Wu J, Zhai Q, Tian F, Zhao J, Zhang H, *et al.* Metabolomic analysis reveals the mechanism of aluminum cytotoxicity in HT-29 cells. *PeerJ*. 2019; 7: e7524 DOI: 10.7717/peerj.7524
24. Klotz K, Weistenhöfer W, Neff F, Hartwig A, Van Thriel C, Drexler H. The health effects of aluminum exposure. *Dtsch Arztebl Int*. 2017; 114(39): 653-659. DOI: 10.3238/arztebl.2017.0653
25. Martín-Cameán A, Jos A, Puerto M, Calleja A, Iglesias-Linares A, Solano E, *et al.* In vivo determination of aluminum, cobalt, chromium, copper, nickel, titanium, and vanadium in oral mucosa cells from orthodontic patients with mini-implants by Inductively coupled plasma-mass spectrometry (ICP-MS). *J Trace Elem Med Biol*. 2015; 32: 13-20. DOI: 10.1016/j.jtemb.2015.05.001
26. Silverstein J, Barreto O, França R. Miniscrews for orthodontic anchorage: nanoscale chemical surface analyses. *Eur J Orthod*. 2016; 38(2): 146-153. DOI: 10.1093/ejo/cjv007
27. Chang JZC, Chen YJ, Tung YY, Chiang YY, Lai EHH, 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): 279-288. DOI: 10.1016/j.ajodo.2011.09.008
28. Duaibis R, Kusnoto B, Natarajan R, Zhao L, Evans C. Factors affecting stresses in cortical bone around miniscrew implants: A three-dimensional finite element study. *Angle Orthod*. 2012; 82(5): 875-880. DOI: 10.2319/111011-696.1
29. Marigo G, Elias CN, Marigo M. Surface analysis of 2 orthodontic mini-implants after clinical use. *Am J Orthod Dentofacial Orthop*. 2016; 150(1): 89-97. DOI: 10.1016/j.ajodo.2015.12.012
30. Caetano PL, Bahia MS, da Fonseca e Silva E, Vitral RWF, Campos MJS. Corrosion resistance and surface characterization of miniscrews removed from orthodontic patients. *Rev Port Estomatol Med Dent Cir Maxilofac*. 2019; 60(1): 1-7. https://pdfs.semanticscholar.org/d0ca/b53ee094e555b42039d7c81a9b60e2dc62b9.pdf
31. *Squeff LR, Simonson MBA, Elias CN, Nojima LI. Caracterização de mini-implantes utilizados na ancoragem ortodôntica [Characterization of the mini-implants used to orthodontic anchorage]. Rev Dent Press Ortodon Ortop Facial. 2008; 13(5): 49-56. DOI: 10.1590/S1415-54192008000500006*
32. Alavi S, Asadi F, Raji SAH, Samie S. Effect of steam and dry heat sterilization on the insertion and fracture torque of orthodontic miniscrews. *Dent Res J (Isfahan)*. 2020; 17(3): 219-224. https://journals.lww.com/derj/_layouts/15/oaks.journals/downloadpdf.aspx?an=01439444-202017030-00009
33. 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(1): 15-20. DOI: 10.1179/14653121141200
34. Kitahara-Céia FMF, Assad-Loss TF, Mucha JN, Elias CN. Morphological evaluation of the active tip of six types of orthodontic mini-implants. *Dental Press J Orthod*. 2013; 18(2): 36-41. DOI: 10.1590/s2176-94512013000200012
35. AlSamak S, Bitsanis E, Makou M, Eliades G. Morphological and structural characteristics of orthodontic mini-implants. *J Orofac Orthop*. 2012; 73(1): 58-71. DOI: 10.1007/s00056-011-0061-0

36. Hergel CA, Acar YB, Ateş M, Küçükkeleş N. In-vitro evaluation of the effects of insertion and sterilization procedures on the mechanical and surface characteristics of mini screws. *Eur Oral Res*. 2019; 53(1): 25-31. DOI: 10.26650/eor.20197993
37. Pan CY, Chou ST, Tseng YC, Yang YH, Wu CY, Lan TH, *et al*. Influence of different implant materials on the primary stability of orthodontic mini-implants. *Kaohsiung J Med Sci*. 2012; 28(12): 673-678. DOI: 10.1016/j.kjms.2012.04.037
38. Brown RN, Sexton BE, Chu TMG, Katona TR, Stewart KT, Kyung HM, *et al*. Comparison of stainless steel and titanium alloy orthodontic miniscrew implants: A mechanical and histologic analysis. *Am J Orthod Dentofacial Orthop*. 2014; 145(4): 496-504. DOI: 10.1016/j.ajodo.2013.12.022
39. Yao CCJ, Chang HH, Chang JZC, Lai HH, Lu SC, Chen YJ. Revisiting the stability of mini-implants used for orthodontic anchorage. *J Formos Med Assoc*. 2015; 114(11): 1122-1128. DOI: 10.1016/j.jfma.2014.08.001
40. Eliades T, Zinelis S, Papadopoulos MA, Eliades G. Characterization of retrieved orthodontic miniscrew implants. *Am J Orthod Dentofacial Orthop*. 2009; 135(1): 10.e1-10.e7 DOI: 10.1016/j.ajodo.2008.06.019
41. 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(5): 821-827. DOI: 10.2319/103009-607.1
42. 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(2): 190-194. DOI: 10.1016/j.ajodo.2004.01.030
43. Han CM, Watanabe K, Tsatalis AE, Lee D, Zheng F, Kyung HM, *et al*. Evaluations of miniscrew type-dependent mechanical stability. *Clin Biomech*. 2019; 69: 21-27. DOI: 10.1016/j.clinbiomech.2019.06.016