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The Effect of Mechanical Cycling and Different Misfit Levels on Vicker's Microhardness of Retention Screws for Single Implant-Supported Prostheses

Wirley Gonçalves Assunção, DDS, MSc, PhD,[1] Juliana Ribeiro Pala Jorge, DDS, MSc, PhD,[2] Paulo Henrique Dos Santos, DDS, MSc, PhD,[3] Valentim Adelino Barão, DDS, MSc,[2] Érica Alves Gomes, DDS, MSc, PhD,[2] & Juliana Aparecida Delben, DDS, MSc[2]

[1]Associate Professor, Department of Dental Materials and Prosthodontics, Araçatuba Dental School, Univ Estadual Paulista (UNESP), Sao Paulo, Brazil
[2]Postgraduate Student, Department of Dental Materials and Prosthodontics, Araçatuba Dental School, Univ Estadual Paulista (UNESP), Sao Paulo, Brazil
[3]Assistant Professor, Department of Dental Materials and Prosthodontics, Araçatuba Dental School, Univ Estadual Paulista (UNESP), Sao Paulo, Brazil

Keywords
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Correspondence
Wirley Gonçalves Assunção, Department of Dental Materials and Prosthodontics, Araçatuba Dental School, Univ Estadual Paulista (UNESP), José Bonifácio, 1193, Araçatuba 16015-050, SP, Brazil. E-mail: wirley@foa.unesp.br

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Abstract

Purpose: The aim of this study was to evaluate the effect of mechanical cycling and different misfit levels on Vicker's microhardness of retention screws for single implant-supported prostheses.
Materials and Methods: Premachined UCLA abutments were cast with cobalt-chromium alloy to obtain 48 crowns divided into four groups (n = 12). The crowns presented no misfit in group A (control group) and unilateral misfits of 50 μm, 100 μm, and 200 μm in groups B, C, and D, respectively. The crowns were screwed to external hexagon implants with titanium retention screws (torque of 30 N/cm), and the sets were submitted to three different periods of mechanical cycling: 2×10^4, 5×10^4, and 1×10^6 cycles. Screw microhardness values were measured before and after each cycling period. Data were evaluated by two-way ANOVA and Tukey's test ($p < 0.05$).
Results: Mechanical cycling statistically reduced microhardness values of retention screws regardless of cycling periods and groups. In groups A, B, and C, initial microhardness values were statistically different from final microhardness values ($p < 0.05$). There was no statistically significant difference for initial screw microhardness values ($p > 0.05$) among the groups; however, when the groups were compared after mechanical cycling, a statistically significant difference was observed between groups B and D ($p < 0.05$).
Conclusions: Mechanical cycling reduced the Vicker's microhardness values of the retention screws of all groups. The crowns with the highest misfit level presented the highest Vicker's microhardness values.

Although mechanical problems can result from many factors, prosthesis misfit plays an important role in these complications.[1,2] The fit between prosthesis and implant may influence treatment outcomes, since irregular distribution of occlusal forces on the different components of the system can promote either screw loosening or component fracture.[3]

Metal fatigue is also known as a common cause of structural failure under repeated loading. Discontinuities in the structures or materials can cause stress concentrations. Moreover, porosities or inclusions can decrease fatigue resistance or even initiate material fatigue.[4] Retention screw fractures have been attributed to several factors, including screw alloy machining, alloy type, metal fatigue, micromovement during mastication, nonaxial loads, insertion torque, screw preload, and inadequate screw settling.[5,6]

Because of these factors, understanding the mechanical characteristics of these materials is necessary. Microhardness studies measure the material resistance against a penetration and indicate the material resistance in relation to the indentor.[7] There is a correlation between a material's microhardness and tensile strength. When exposed to mechanical cycling, a metallic material can suffer cyclic weakening or hardening (related to microhardness), or even remain stable; however, both events can usually occur in the same material, depending on the initial conditions and cyclic loading parameters.[8] Thus, microhardness is an important characteristic to predict clinical and long-term success of an implant-supported restoration.[7]

For testing metallic materials, mechanical cycling has also been accepted as an effective experimental model to reproduce the less favorable oral environment and has been used in several studies.[9–12] However, few studies associate the effect of mechanical cycling and microhardness of titanium materials. Therefore, the aim of this study was to evaluate the microhardness of retention screws for single implant-supported prostheses with different misfit levels submitted to mechanical cycling.

Materials and methods

Specimen preparation

Forty-eight metallic crowns were fabricated with 48 hexagonal UCLA abutments cast with cobalt-chromium alloy (Co-Cr) (EUCLA 406, SIN—Sistema de Implante, São Paulo, Brazil). Although this alloy is potentially corrosive, it is widely used in Brazil and other countries due to its low cost.

Twelve abutments were used as received from the manufacturer, while 36 abutments were prepared in a machine (GIN-Chan Machinery Co., Ltd, Taipei, Taiwan) to create unilateral angular misfits of 50 μm, 100 μm, and 200 μm with an accuracy of 8 μm (0.05 ± 0.008 mm, 0.10 ± 0.008 mm, 0.20 ± 0.008 mm). The plastic sleeves of the abutments were sectioned and coated with autopolymerizing acrylic resin (Duralay; Reliance Dental Mfg. Company, Worth, IL) in a conical shape (8 mm high, 8 mm wide)[11] with a slice of 30° in the occlusal surface opposite to the misfit. The metallic sphere for loading was positioned on this slice during the mechanical cycling test.

All crowns were fabricated according to a silicone matrix (Zetalabor, Zhermack, Badia Polesina, Italy) to standardize the dimensions. The patterns were invested with phosphate investment (Flash, CNG Soluções Protéticas Ltda, São Paulo, Brazil) and cast with Co-Cr alloy (StarLoy C, DeguDent GmbH, Wolfgang, Germany).

The 48 crowns were distributed into four groups (n = 12), according to the level of misfit to the implant:

Group A: crowns with no misfit.
Group B: crowns with 50-μm angular unilateral misfit.
Group C: crowns with 100-μm angular unilateral misfit.
Group D: crowns with 200-μm angular unilateral misfit.

Forty-eight external hexagon implants (3.75 mm diameter, 15.0 mm length) (Revolution SUR 4015, SIN—Sistema de Implante) were embedded with autopolymerizing acrylic resin (Jet, Artigos Odontológicos Clássico Ltd, São Paulo, Brazil) in a metallic matrix to standardize the positioning with 30° of inclination in relation to the vertical axis. This procedure allowed oblique loading with the misfit opposite to the loading surface. The implants were randomly divided into four groups (A, B, C, D) and attached to the crowns with Ti retention screws (PTQ 2008, SIN—Sistema de Implante) using an analog torque gauge (BTG36CN-S, Tohnichi Mfg. Co. Ltd, Tokyo, Japan) with a torque of 30 ± 0.5 N/cm (Fig 1).

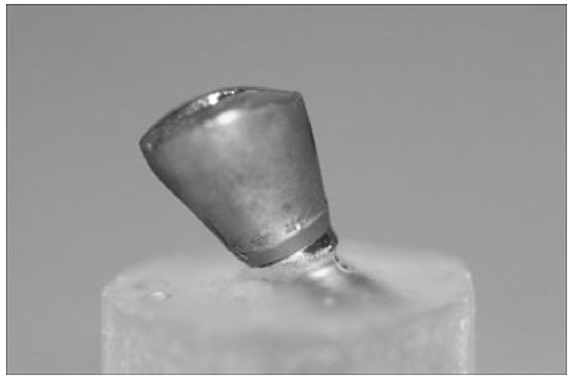

Figure 1 Specimen containing the implant in the acrylic resin cylinder and the screwed metallic crown for mechanical cycling application.

Mechanical cycling test

The specimens were submitted to mechanical cycling in an electromechanical mastication fatigue test machine (MSFM—ELQUIP, Equipamentos para Pesquisa Odontologica, Sao Carlos, Brazil) calibrated to operate in three periods: 2×10^4, 5×10^4, and 1×10^6 cycles. A dynamic load of 130 N at 2 Hz was calibrated with a load cell (MS 50, Líder Balanças, Araçatuba, Brazil) and applied to each replica immersed in distilled water under constant circulation at 37 ± 2°C.

Microhardness tests

Screw microhardness measurements were obtained after each cycling period (2×10^4, 5×10^4, 1×10^6 cycles) beginning with zero. All retention screws were replaced after each cycling period to evaluate and compare the influence of cycling period and misfit on screw microhardness. Therefore, 12 retention screws were used for each group in each cycling period, totaling 144 retention screws.

The microhardness values obtained before the mechanical cycling characterized the control values for each group in each mechanical cycling period. After each cycling period, the screws were removed and then submitted to a new microhardness test at room temperature (22 ± 2°C). The load used was 500 gf for 15 seconds, and microhardness values were expressed in Vicker's hardness units (VHN).[5,13,14] Vicker's microhardness values were calculated using the following formula:

$$\mathrm{VHN} = \frac{2\mathrm{P}\sin(136^\circ/2)}{\mathrm{d}^2}$$

where P = applied load and d = length of the indentation's diagonals. Microhardness tests were accomplished on the lateral region of the screw head (Fig 2), and the test was repeated four times in four randomly distributed points in each screw. The mean of these four repetitions corresponded to the Vicker's microhardness value of the screw.

Results

The means of the Vicker's microhardness values measured before and after the cycling periods are shown in Table 1. Two-way ANOVA for the means obtained after mechanical cycling

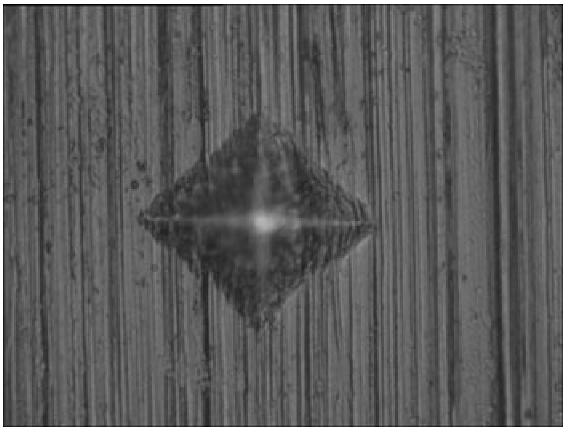

Figure 2 Vicker's microhardness obtained on the lateral region of the screw head.

Table 2 Two-way ANOVA for the Vicker's microhardness means after mechanical cycling for the groups

Source of variation	df	SS	MS	F	*p*
Cycling periods	1	1804.8339844	1804.8339844	25.8612	0.00003*
Groups	3	625.3196615	208.4398872	2.9867	0.03469*
Interaction	3	382.7988281	127.5996094	1.8284	0.14642
Residue	88	6141.4531250	69.7892401		
Total	95	8954.4055990			

*$p < 0.05$ denotes statistically significant difference.

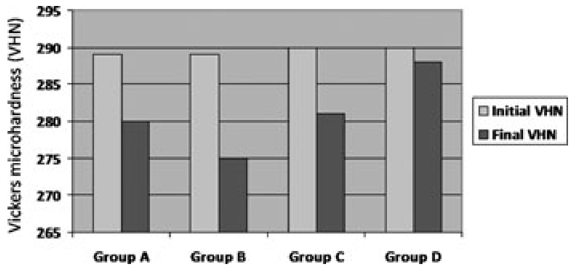

Figure 3 Initial and final Vicker's microhardness means for all groups regardless of cycling periods.

Table 3 Tukey's test for Vicker's microhardness means (VHN) regardless of the cycling period and groups

Period	Means
Initial	290.07a
Final	281.39b

Means followed by different letters are different at 5% significance level.

revealed statistically significant differences among the cycling periods and among the groups (Table 2). Mechanical cycling statistically reduced the microhardness values of the retention screws, regardless of cycling period and group (Table 3). Considering the groups' microhardness means, regardless of cycling period, mechanical cycling decreased the microhardness values of the retention screw in all groups (Fig 3). In groups A, B, and C, the initial microhardness values were statistically different from the final microhardness values ($p < 0.05$) (Table 4). There was no statistically significant difference in screw microhardness values obtained before mechanical cycling among the groups ($p > 0.05$) (Table 4); however, when the groups were compared after mechanical cycling, a statistically significant difference between groups B and D was observed ($p < 0.05$) (Table 4).

Discussion

Unfavorable anatomic conditions in the bone region for implant placement frequently require changes in surgical planning, and the long axis of the implant may be altered during its insertion. Thus, after prosthetic rehabilitation, the abutment/implant system can receive eccentric masticatory loads,[15] which may contribute to either screw fracture or implant loss.[1,4,16] The present in vitro study aimed to simulate this clinical condition through a dynamic-loading fatigue test.[3,9-13] Cyclic loading, also called mechanical loading, is defined as a load applied on a surface in different numbers of cycles and frequency.[9] In dentistry, cyclic loading is used as an in vitro test to simulate the occlusal forces on natural or artificial crowns. Several authors have successfully used this type of test to simulate masticatory forces.[9-11]

A certain level of misfit in the prosthetic crown can generate mechanical complications[17] and affect the longevity of an implant-supported prosthesis.[2] For this reason, the present study evaluated different levels of misfit of implant-supported crowns (0, 50, 100, and 200 μm). This level of prosthesis misfit is related to a significant increase of load inside the implant system.[18] Metallic materials, when exposed to cyclic loading, can fail by fatigue even if the applied load is inferior to their strength resistance limit. Alterations in the material

Table 1 Means (standard deviation) of Vicker's microhardness values (VHN) before and after mechanical cycling

	Group A		Group B		Group C		Group D	
Cycling period	Before	After	Before	After	Before	After	Before	After
2×10^4	302.7 (5.89)	302 (5.46)	305.9 (3.31)	297.3 (5.64)	305.6 (2.97)	301.1 (4.4)	310.1 (4.52)	299.3 (3.62)
5×10^4	299.4 (3.56)	289.6 (10.4)	299.1 (5.30)	291.7 (11.43)	292.7 (9.03)	285.1 (7.11)	290.6 (8.06)	283.7 (8.14)
1×10^6	289.3 (3.56)	280.2 (10.4)	289.3 (5.3)	275.4 (11.43)	290.8 (9.03)	281.8 (7.11)	290.7 (8.06)	288 (8.14)

Table 4 Tukey's test for Vicker's microhardness means (VHN) obtained before and after mechanical cycling for all groups

	Groups			
Mechanical cycling	A	B	C	D
Before	289.33a A	289.35a A	290.81a A	290.77a A
After	280.27b AB	275.54b B	281.81b AB	288.08a A

Groups with different lowercase letters in the same column are significantly different at 5% significance level. Groups with different uppercase letters in the same row are significantly different at 5% significance level.

properties caused by fatigue process can usually promote cyclic deformation as a result of the interaction between movements and loads.

The most important alterations are related to the material mechanical properties and can be evaluated by continuous measurements during cyclic loading in tests controlled by deformation.[7,8] Therefore, either microhardness weakening or hardening can be observed in the material.

Those observations are in accordance with the results of the present study, where lower Vicker's microhardness values were found (281 VHN) for all retention screws after the mechanical cycling test. This can be explained by material fatigue, since failures are caused by different agents as discontinuities on the material that cause stress concentrations. Overstress can be related to porosities or inclusions in the material and may reduce fatigue resistance or even induce fatigue.[5,19] Implant-supported restorations are prone to complex stresses during mastication, and reduction or elimination of those defects could minimize fatigue failure.

When different angular unilateral misfits were compared, a statistically significant difference was found between the VHN values of groups B (275 VHN) and D (288 VHN). According to Taylor,[1] misfit of an implant-supported crown could jeopardize clinical success, resulting in retention screw loosening or even screw fracture. Considering that the screws from group D (highest misfit) presented the highest microhardness values, it is possible to conclude that these screws suffered the lowest cyclic weakening; however, due to this high level of misfit, it can be suggested that a microhardness decrease could have occurred in other regions of the retention screw, such as the screw neck, but these regions were not analyzed in the present study.

Metallic materials, when exposed to cyclic loading, could fail by fatigue even if the loads applied are lower than their resistance limit.[7] The parameter used in this study for stress simulation was mechanical cycling until 1×10^6 cycles. According to some authors,[9,20] this period would be equivalent to 5 years of intraoral clinical use of the implant-supported restoration.

A retentive screw should present sufficient resistance (strength) to not fail under normal masticatory function.[5] However, no data in the literature determines the amount of Ti retention screw resistance to avoid mechanical failure.

In addition, to the authors' knowledge, no study states that screw microhardness values should remain stable during screw life. Al Jabbari et al[14] analyzed the mechanical behavior of retrieved prosthetic retention screws after long-term use in vivo. They observed that different retention screws from the same and different manufacturers exhibited different macro- and microstructures, alloy constituents, and microhardness, and these differences influenced the preload and the load fracture value of the retention screw. Therefore, changes in retention screw microhardness during a prosthesis' lifetime may increase the risk of treatment failure (i.e., screw loosening or fracture).

Although this was an in vitro study, it can be suggested that the decrease of microhardness values after mechanical cycling, causing a cyclic weakening, would be favorable to stress dissipation at the screw head; however, it is not possible to affirm that this decrease would jeopardize the long-term clinical success of the restoration in vivo. Moreover, the clinician should be very careful when attaching a screwed crown on an implant, because a great misfit could bring unfavorable long-term consequences to the prosthesis/implant system, regardless of the screw alloy. According to these factors, additional studies to evaluate longer periods of cycling, different retention screw alloys, different prosthetic crown veneering materials, and different implant systems from several manufactures are necessary.

Conclusion

According to the results and within the limitations of the present study, it was concluded that

(1) Mechanical cycling reduced the Vicker's microhardness values of the retention screws of all studied groups, and
(2) the highest degree of misfit resulted in the lowest amount of decrease in screw microhardness.

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