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Different fabrication techniques of implant-supported prostheses: microhardness and fracture strength

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Aim: This study evaluated the mechanical behavior of implant-supported crowns obtained by different fabrication technique after thermomechanical cycling. **Methods:** Thirty-two external hexagon dental implants were divided into four groups (n=10): CC – conventional casting with torch; EI – electromagnetic induction casting; PL – plasma casting; and CAD-CAM – milling through computer-aided design and computer-aided manufacturing. Vickers microhardness of the specimens were made before and after the thermomechanical cycling, and then subjected to fracture load. Fracture pattern was evaluated. **Results:** No significant difference was observed comparing the microhardness before and after thermomechanical cycling. CAD-CAM group presented significant lower microhardness than the other groups. No significant statistical difference was showed on fracture load between the groups. The CAD-CAM and PL presented lower number of failure by plastic deformation. **Conclusion:** The manufacturing techniques affected the mechanical behavior and the failure pattern of implant-supported crowns tested.

Keywords: Dental implants. Prosthodontics. Computer-aided design. Flexural strength.

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Introduction

Metal-free restorations have been used to obtain improved aesthetics for dental prostheses. However, metal–ceramic restorations remain widely and the most used because of their excellent mechanical properties and clinical performance[1-2]. The framework and aesthetic veneer must have sufficient mechanical properties to support masticatory loading and possible injuries to the oral environment[3]. The framework of metal–ceramic prostheses can be fabricated using casting or milling process, and some key factors should be considered for the long-term success of metal–ceramic prostheses, such as alloy composition, casting technique, workability, surface roughness, framework shape, and microhardness[4-5].

Computer-aided design and computer-aided manufacturing (CAD-CAM) systems have been widely used for machining the framework of implant-supported prostheses. However, techniques using heating devices, such as torches, induction arcs, or electric arcs are still commonly used for manufacturing. The physical–chemical properties of the alloy can be altered according to the ability and knowledge of the operator, the equipment used, and the product quality, since the selected technique to obtain the framework should be considered[5-7].

Structural failures of implant-supported prosthesis may be related to the material hardness and also associated to material wear resistance in the oral environment. And, the hardness of material is an important variable to be analyze, due the possibility of evaluate the resistance of material to the localized plastic deformation. Therefore, the microhardness is an important method to predict the clinical success of the long-term treatments[8].

Structural failures described in the literature refer to plastic deformations, such as the displacement and damage of the components without a fragments rupture or fractures, such as the fragments rupture and detachment of the structure of prosthetic crowns. Both conditions compromise the mechanical functioning of the crown/screw/implant set and results in the failure of implant rehabilitation treatment[9-10]. The aim of this study was to evaluate the mechanical behavior (microhardness, fracture load and failure pattern) of implant-supported crowns obtained by different fabrication technique (conventional casting, electromagnetic induction casting, plasma casting or CAD-CAM) after thermomechanical cycling.

Materials and methods

Study Design

Fourty external hexagon dental implants (4.1-mm in diameter × 13-mm in length) (Pross; Dabi Atlante, Ribeirão Preto, SP, Brazil) were divided into four groups considering on manufacturing of the implant-supported crown (n=10): CC – conventional casting using torch; EI – electromagnetic induction casting; PL – plasma casting; and CAD-CAM – milling through computer-aided design and manufacturing. Vickers microhardness of the specimens were made before and after the thermomechanical cycling, and then they submitted to fracture load. Fracture pattern was also evaluated.

Specimen preparations

Dental implants were embedded in polyurethane (F16 FastCast Polyurethane, Axson, Cergy, France) using PVC tubes in a long axis assisted by a delineator (Bio-Art, São Carlos, SP, Brazil). A progressive waxing (Kota, São Paulo, SP, Brazil) was initially made on a 4.1-mm anti-rotational castable cylinder (Pross; Dabi Atlante, Ribeirão Preto, SP, Brazil) on the anatomy of the maxillary canine. Two-piece matrix was made in condensation silicone (Zetaplus, Zhermack, Badia Polesine, Rovigo, Italy) to standard the crown waxing maintaining the anatomical pattern.

Thirty waxes were obtained and randomly divided into three groups according to the manufacturing technique of the implant crowns (n=10): CC – conventional casting using torch; EI – electromagnetic induction casting; and PL – plasma casting. After casting in cobalt–chromium (Co–Cr) alloy (Fit Cast Cobalto; Talmax, Curitiba, PR, Brazil), the crowns were divested and sandblasted with 100-μm aluminum oxide particles (Polidental, Cotia, SP, Brazil), under 80psi (5.51 bars), and separated of the sprue using carborundum disks (Schelble, Petópolis, RJ, Brazil). For the CAD-CAM group, the crowns were made using scanning and milling techniques in the CAD-CAM system (Amangirgach, Koblach, Austria). A crown was waxed as priorly described and screwed to each implant (n=10), scanned, digitized (Ceramill Mind, Amann Girrbach, Koblach, Austria), and machined in pre-sintered Co–Cr alloy (Ceramill Sintron, Amann Girrbach, Koblach, Austria). All crowns were sintered under argon gas at 1300°C for six hours in a special furnace (Ceramill Argotherm, Amann Girrbach), following the manufacture instructions. The finishing and polishing were performed for all groups using specific burs and pastes for metals (Exa-Cerapol, Edenta, Au/SG, Switzerland)[11].

Vickers microhardness

The Vickers microhardness (HV) of the Co–Cr alloys obtained using different techniques (castings or milling) was measured with a load of 19.614 N for 20 s (HMV-2 Microhardness tester; Shimadzu, Kyoto, Japan)[12]. Five measurements were performed for each specimen, before and after thermomechanical cycling.

Thermomechanical cycling

The accelerated aging was performed using thermomechanical cycling in a pneumatic mastigation simulator (Biopdi, São Carlos, SP, Brazil). Six specimens were simultaneously submitted to the thermomechanical cycling, with a loading of 120N applied through a metallic tip with a flat surface, during 1×10^6 mechanical cycles with a frequency of 3 Hz with temperatures ranging of 5°C to 55°C in distilled water with a dwell time of 40 s in each bath.

Fracture load

The specimens were submitted to fracture loading in a universal testing machine (Biopdi, São Carlos, SP, Brazil). Each specimen (implant/screw/crown) was positioned in a 30° metal device (ISO 14801) and compressive load was applied with crosshead speed of 1mm/min until specimen failure. The loading point was located 11.5mm from the surface of the implant platform. During the test, the load was applied on the specimens until plastic deformations occurred in some components of the set (implant/screw/crown).

Statistical analysis

The analyses were performed using statistical software (20.0 SPSS Statistics, IBM, Chicago, IL, USA). Linear mixed-effects model and Bonferroni complementary test were performed to analyze microhardness data ($p<0.05$). Data of fracture load were submitted to one-way ANOVA followed by Tukey's post-hoc test ($p<0.05$).

Results

The results of microhardness are presented in the Table 1. In intra-groups comparation (before and after thermomechanical cycling), the statistical analysis showed no significant difference ($p>0.05$). Therefore, the thermomechanical cycling presented no effect in the microhardness. In relation to different manufacturing technique, CAD-CAM group presented significant lower microhardness than the other groups ($p<0.05$). In addition, the EI group after thermomechanical cycling presented higher microhardness values compared with CC and PL ($p<0.05$).

Table 1. Comparison of Vickers microhardness (HV) before and after thermomechanical cycling.

Comparison	Thermomechanical cyclic loading	Mean difference	p-valor	Confidence Interval	
				Upper Limit	Lower Limit
GC × GI	before	154.025	0.001	57.376	250.674
	after	117.212	0.000	63.541	170.884
GC × GP	before	-29.000	1.000	-125.649	67.649
	after	-61.650	0.018	-115.321	-7.979
GC × GCAD	before	10.350	1.000	-86.299	106.999
	after	9.975	1.000	-43.696	63.646
GI × GP	before	39.350	1.000	-57.299	135.999
	after	71.625	0.004	17.954	125.296
GI × GCAD	before	183.025	0.000	86.376	279.674
	after	178.863	0.000	125.191	232.534
GP × GCAD	before	143.675	0.001	47.026	240.324
	after	107.237	0.000	53.566	160.909

The results of fracture load are shown in Table 2. The statistical analysis showed no significant statistical difference on fracture load between the groups ($p>0.05$). After compression resistance test, the qualitative evaluation using micro CT images showed differences in the failure mode. In both CC and EI groups, six specimens failed with plastic deformation and two with fracture; whereas in the PL group, two specimens failed with plastic deformation and six with fracture. The CAD-CAM group presented one specimen with plastic deformation and seven with fracture.

Table 2. Mean and standard deviation of compression strength (N).

Groups	Compression Strength
GC	884.00 (70.11) a
GI	865.53 (157.32) a
GP	930.32 (136.94) a
GCAD	912.22 (78.78) a

Values with the same letters in the same column present no statistically significant difference at 5% significance level.

Specimens with plastic deformation showed failure due to misfit to crown/screw/implant sets during loading and, consequently, displacement of the prosthetic screw. The plastic deformation of the prosthetic screw and coronal third of the implant, including the platform, was observed in all groups (Fig. 1).

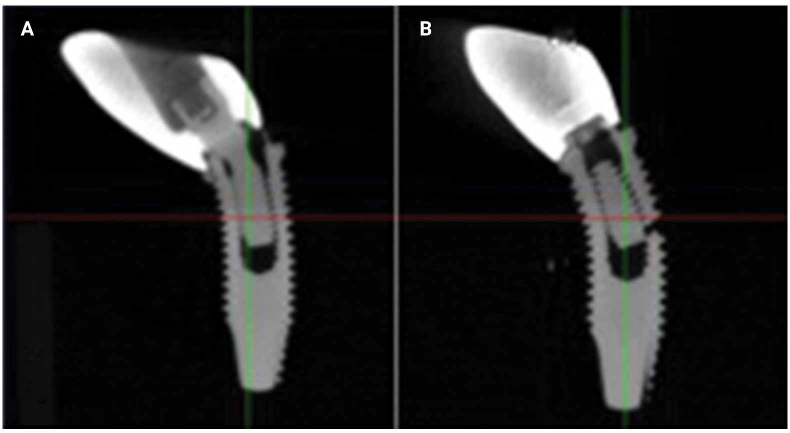

Figure 1. Micro-CT images representing the failure mode: (A) plastic deformation, and (B) plastic deformation and fracture.

Discussion

The manufacturing methods affected the Vickers microhardness results in the present study. The CAD-CAM group presented the lowest values, which were closest to those reported in the literature for Co–Cr alloy[13]. A previous study[4] reported that casting procedures change the surface composition, but after polishing as-cast surface, the alloy composition is similar those obtained by the manufacturer previously the manipulation. The different microhardness found for the CAD-CAM group can be justified by the cast surfaces of the EI, CC, and PL groups that, probably presents a different surface composition and have a additional surface layer obtained because of the reaction between investment and alloy. Although, casted crowns were polished for evaluating the microhardness, the depth of this surface layer remained unknown, and the composition of casted crowns can be different from CAD-CAM crowns. In addition, it is important to consider the difference of the microstructure of Co–Cr alloys obtained by casting and CAD/CAM. The microstructure of the cast Co–Cr alloys contain large grains, whereas Co–Cr alloys produced by CAD/CAM present finer grains, thereby improving the mechanical properties[14]. Nevertheless, thermomechanical cycling did not affect the microhardness results.

In the present study, specimens failures were not found during and after thermomechanical cycling. However, the plastic deformation failure of the specimen or implant fracture occurred when higher load was applied on the compressive strength test. The mean of values obtained for the compressive strength test (CC=884.00N, EI=865.53N, PL=930.32N, and CAD-CAM=912.22N) was within the acceptable limits of the masticatory load to the anterior region. The physiologic forces in this region ranged between 132–231N and the magnitude of masticatory load in patients with parafunctional habits presented a mean of 812.2N[15-16].

Some studies have indicated that the frequency of mechanical complications (component fractures and screw loosening) is greater in hexagonal external connection than in internal connection[9,17-18]. It is believed that this phenomenon occurs because static and dynamic masticatory loads incident on specimens (crown/screw/implant) are distributed along the prosthetic screw surface, which can lead to loosening or fracture.

In the present study, the oblique load applied on specimens during the compressive loading test caused the prosthetic screw to exert a force against the lateral wall of the implant opposite to the loading point, leading to fracture because of excessive stress on the site. This characteristic of the stress concentration in the region contralateral to the load point is significantly increased when an angular load is applied, which ca be explained by the rigidity and flexion of the sample[19]. Therefore, additional care should be taken during oral rehabilitation with external hexagonal connection, particularly in cases where intermediate abutments is not used. However, when there is a prosthetic abutment against high masticatory forces, the implant seems to be protected, but with failures in the abutment (abutment body or retaining-screw) and no implant fracture[20-22], as related in this current study. Thus, the use of intermediate abutment would be a favorable option because the clinician can reverse the situation using specific drills depending on the type of failure present in these abutments and replacing only the abutment and the crown, without damaging to the implant and, consequently, the osseointegration previously achieved.

Fracture load showed similar results among milled and casted crowns. However, a higher number of implant fracture was observed in the CAD-CAM group compared with the casting groups, which presented higher number of plastic deformations. We believe that these results were observed because of a difference in the alloy composition and surface oxidation due to different casting processes[23]. When the casting process ocurr in an open environment, the base alloys expose metals to deleterious gases and elements, such as nitrogen and oxygen, which can be absorbed during the heat produced, and negatively influencing the final cast, increasing the porosity of the alloy[24], and inducing elastic instability[25]. Thus, the CAD/CAM system may allow a greater appartness of the metallic alloy from the external environment protecting the material of the gas interaction, and probably offering a better prognosis of the proposed rehabilitation treatment.

Overall, the manufacturing techniques affected the mechanical behavior of implant-supported crowns being that the CAD-CAM system presented lowest micro-hardness. The fracture load was similar, while the failure pattern was different between the manufacturing techniques tested.

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