Influence of the fabrication method on the fracture behavior of all-ceramic prosthesis

(Influência do método de fabricação no comportamento de fratura de próteses cerâmicas)

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Abstract

Different methods are available to produce all-ceramic dental prosthesis. Each processing step may introduce flaws to the material, which compromises its properties and reliability. The objective of this study was to evaluate the effect of fabrication method on the fracture behavior of prosthetic crowns produced with an alumina-based glass-infiltrated zirconia-reinforced ceramic. Two groups of all-ceramic crowns were produced according to the fabrication method of the infrastructure (IS) (n=30): IZC - IS produced by CAD-CAM; IZS - IS produced by slip-casting. The IS were veneered with porcelain and cemented to fiber-reinforced composite dies with resin cement. Crowns were loaded in compression to failure using a universal testing machine, at 1 mm/min crosshead speed and 37 ºC distilled water. Fractography was performed using stereomicroscope and SEM. Data were statistically analyzed with Student's t test (α=0.05) and Weibull analysis. There were no significant differences among the experimental groups for fracture load (p=0.481) and Weibull modulus. For both groups, the failure mode was catastrophic failure involving IS and porcelain. It was concluded that the fabrication methods evaluated resulted in all-ceramic crowns with similar fracture behavior and reliability.
Keywords: ceramics, mechanics, dental prosthesis.

Resumo

Diferentes métodos estão disponíveis para produzir próteses totalmente cerâmicas. Cada etapa do processamento pode introduzir falhas no material, comprometendo suas propriedades e confiabilidade. O objetivo desse estudo foi avaliar o efeito do método de fabricação no comportamento de fratura de coroas produzidas com uma cerâmica à base de alumina, infiltrada com vidro e reforçada com zircônia. Dois grupos de coroas totalmente cerâmicas foram produzidos de acordo com o método de fabricação da infraestrutura (IS) (n=30): IZC - IS produzida com a tecnologia CAD-CAM, e IZS - IS produzida com a técnica slip-casting. As IS foram recobertas com porcelana e cimentadas sobre um pilar utilizando cimento resinoso. As coroas foram submetidas a uma carga de compressão até a fratura utilizando uma máquina de ensaios universal, com velocidade de 1 mm/min, em água a 37 ºC. Análise fractográfica foi realizada em estereomicroscópio e MEV. Os dados foram analisados estatisticamente com teste t de Student (α=0,05) e análise de Weibull. Não houve diferença estatística entre os grupos experimentais para a carga de fratura (p=0,481) e módulo de Weibull. Para ambos os grupos, o modo de falha foi fratura catastrófica envolvendo IS e porcelana de recobrimento. Concluiu-se que os métodos de fabricação avaliados resultaram em coroas com comportamento de fratura e confiabilidade semelhantes.
***Palavras-chave**: cerâmicas, mecânica, prótese dentária.*

INTRODUCTION

Ceramics are widely used in Dentistry due to its aesthetics and biocompatibility. However, aesthetics ceramics (i.e. feldsphatic porcelain) are mainly constituted by a glassy phase, which results in low fracture toughness and may compromise their clinical performance. Therefore, aiming to obtain ceramics with improved mechanical behavior and expand their clinical indications, materials with high crystalline content were developed [1-3]. Crystal such as leucite, lithium disilicate, lithium silicate, alumina and zirconia were added as a reinforcing phase or to produce polycrystalline ceramics [4]. Not only the composition and the microstructure of ceramics were modified, different fabrication methods were also developed. The CAD-CAM (computer aided design-computer aided manufacturing) technology was introduced in Dentistry aiming to simplify the fabrication steps and produce restorations with a more homogeneous microstructure [5]. CAD-CAM technology may produce superior restorations than conventional techniques (i.e. layering, slip-casting, injection) by reducing the influence of the laboratory technician in the final result and by the use of prefabricated high-quality materials [5, 6].

Each processing step may introduce flaws to the material, which compromises its physical and mechanical properties and reliability. Thus, ceramics composition, microstructure and fabrication methods are directly related to the restoration

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clinical performance [2, 7]. Removing superficial flaws or reducing the size and number of such flaws may increase the fracture strength of ceramics. Studies suggested that the microstructure of ceramics produced using prefabricated CAD-CAM blocks is more homogeneous and present lower porosity than the microstructure produced by conventional techniques [8, 9]. Thus, restorations produced with ceramics with high crystalline content using the CAD-CAM technology may present improved mechanical behavior by reducing the amount of flaws that may lead to catastrophic failures. Yet, results found in the literature are controversial, with no consensus regarding the superiority of the CAD-CAM technology in comparison to conventional techniques [8-13]. Hence, this study aimed to evaluate the fracture behavior and reliability of all-ceramic crowns produced with two different methods (CAD-CAM and slip-casting). The study hypotheses are: 1) the fabrication method influences the fracture load and failure mode of prosthetic crowns; 2) prosthetic crowns produced with the CAD-CAM technique present higher reliability.

MATERIALS AND METHODS

All-ceramic prosthetic crowns produced with an alumina-based glass-infiltrated zirconia-reinforced ceramic (In-Ceram Zirconia, Vita Zahnfabrik, Germany) were evaluated in this study. Two groups of all-ceramic crowns were produced according to the fabrication method of the infrastructure (IS) (n=30): IZC - IS produced by CAD-CAM; IZS - IS produced by slip-casting. The crowns were designed based on a composite die (glass fiber-reinforced epoxy resin, NEMA G10) simulating a prepared first lower premolar, with 4.5 mm height, 6° axial taper, and a 120° chamfer [14]. Impression of the composite die was taken using the simultaneous impression technique (Express Material de Moldagem de Silicone por Adição, *pasta pesada* and *pasta fluida*, 3M Dental Care, Brazil). The models were produced according to the IS fabrication method.

For IZC group, IS were produced using Cerec InLab MC XL CAD-CAM system (Sirona Dental, USA). A special type IV plaster (Tuff Rock Formula 44) was used to produce the model. The model received a layer of metallic spray and was scanned using InEos Blue scanner (Sirona Dental). The IS was designed in the CAD-CAM software and the ceramic blocks were milled. IS were glass-infiltrated (Zirconia Glass Powder, Vita Zahnfabrik) according to the manufacturer's recommendations using a special furnace (In Fire HTC Speed). The excess glass was removed from the infiltrated IS with burs and abrasive points. For IZS group, two layers of a spacer (Vita In-Ceram Varnish, Vita Zahnfabrik) were applied on the composite die. A silicon mold (CEHA White ECS Duplicating Silicone - Components 1 and 2 - C, Hafner, Germany) was used to duplicate the die into plaster models (Vita In-Ceram Special Plaster, Vita Zahnfabrik). A ceramic slurry was prepared by mixing 38 g of powder (Vita In-Ceram Zirconia Powder, Vita Zahnfabrik) with 5 mL of liquid (Vita In-Ceram Alumina/Zirconia, Vita Zahnfabrik) and one drop of additive (Vita In-Ceram Zirconia Additive). The slurry was applied on the models. After the plaster had absorbed the moisture, the green body was removed from the model. This structure was sintered in the InCeramat 3 furnace (Vita Zahnfabrik) according to the manufacturer's instructions. Same glass infiltration and finishing procedures described for IZC were performed for IZS. All IS were veneered with VM7 porcelain (R2.5 shade) by a dental laboratory technician. A mixture of porcelain powder and distilled water was applied to the IS. Excess humidity was removed with absorbing paper and the crown was placed in the Vita Vacumat 40 furnace (Vita Zahnfabrik) for sintering, according to manufacturer's instructions. Then, a second layer of porcelain was applied and sintered to obtain the final premolar configuration (1.2 mm uniform thickness). Finally, crowns were subjected to a glaze firing.

Before cementation, crowns were sonically cleaned in distilled water bath for 5 min. Cementation surface of composite dies were first etched with 10% hydrofluoric acid for 1 min, washed in water for 30 s and air-dried [15]. A silane bonding agent (Silano Agente de União, Angelus, Brazil) was applied and left to evaporate for 1 min. Next, the ED Primer A+B adhesive (Kuraray, Japan) was applied. Cement pastes (Panavia F, Kuraray) were mixed for 20 s and applied to the internal surface of the crowns, which were placed onto the dies. A static load of 20 N was applied to the occlusal surface of the crown for 5 min using a cementation device. Excess cement was removed, Oxiguard was applied at the crown margin and removed after 3 min. Each crown surface was light cured for 20 s (Kondortech Equipamentos Odontológicos, Brazil) from each side. No treatment was performed in the inner surface of the crowns. The crowns were stored in 37 °C distilled water for 24 h prior to the mechanical test.

The fracture load test was performed using a universal testing machine (Emic DL 2000, Brazil). The compressive load was applied with a stainless-steel piston (2 mm diameter flat contact with the ceramic surface) in the center of the occlusal surface, parallel to the long axis of the crown, until failure. The test was performed in 37 °C distilled water and at crosshead speed of 1 mm/min. A polyester strip was placed between the crown and the piston to provide a uniform stress distribution. Fracture surfaces of all crowns were examined using a stereomicroscope (Leica MZ 125, Leica Microsystems, Germany). Two crowns from each group were analyzed using scanning electron microscopy (SEM) for a more careful analysis of the fractographic features and the flaw origin. Fracture load data were statistically analyzed using student t test (α=0.05) and Weibull analysis.

RESULTS

There were no statistical differences between the mean fracture load values for the experimental groups (p=0.481), Similar Weibull modulus (m) and characteristic fracture load (P_0) were also observed between groups as the confidence intervals overlapped (Table I and Fig. 1). All crowns showed

Table I - Mean (P), standard deviation (SD), Weibull modulus (m), characteristic fracture load (P_0) values, and respective confidence intervals (CI) of the experimental groups. Fracture load for a 5% probability of failure ($P_{5\%}$).
[Tabela I - Média (P), desvio-padrão (SD), módulo de Weibull (m), carga de fratura característica (P_0) e respectivos intervalos de confiança (CI) dos grupos experimentais. Carga de fratura para uma probabilidade de falha de 5% ($P_{5\%}$).]

Group	P (N)	SD (N)	m	95% CI_m	P_0 (N)	95% CI_{P0} (N)	$P_{5\%}$ (N)
IZS	1,400[a]	274	6[a]	4-7	1516[a]	1393-1646	897
IZC	1,353[a]	212	7[a]	5-10	1442[a]	1345-1533	970

Note: values followed by the same letters in the column are not statistically different ($p>0.05$).

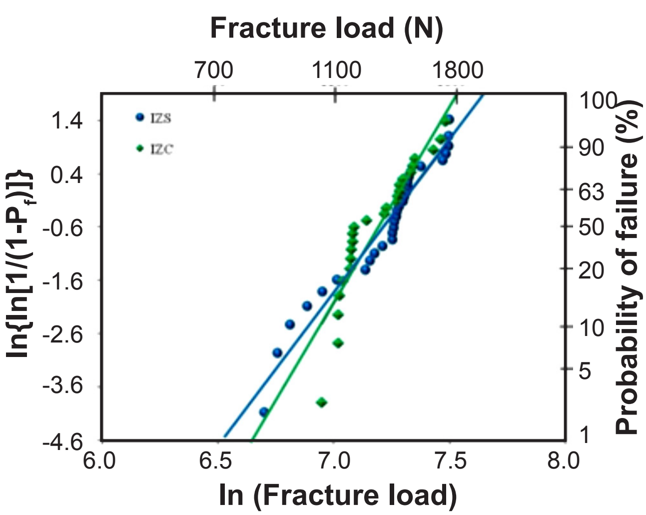

Figure 1: Weibull graph of fracture load data of the experimental groups.
[Figura 1: Gráfico de Weibull com os dados de carga de fratura para os grupos experimentais.]

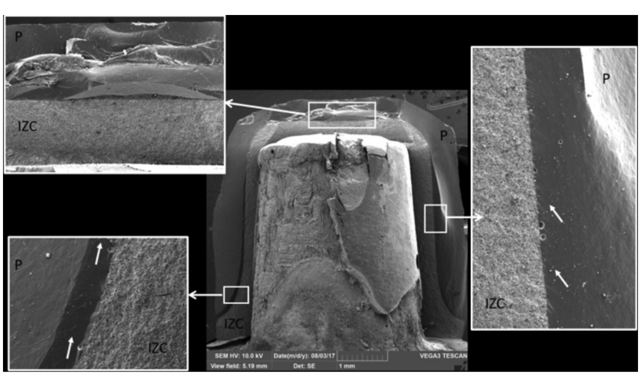

Figure 2: Failure analysis of a crown from group IZC. Wake hackles in the porcelain (P) layer point (white arrows) to the flaw origin in the damage contact area of the occlusal surface.
[Figura 2: Análise de falha de uma coroa do grupo IZC. Wake hackles na camada de porcelana (P) apontam (flechas brancas) para a origem da falha na zona de dano de contato da superfície oclusal.]

catastrophic failure involving IS and porcelain layer. SEM analysis suggested that failure origin was located at the occlusal surface, in the contact damage area. SEM images of a crown from IZC and IZS groups are presented in Figs. 2 and 3, respectively.

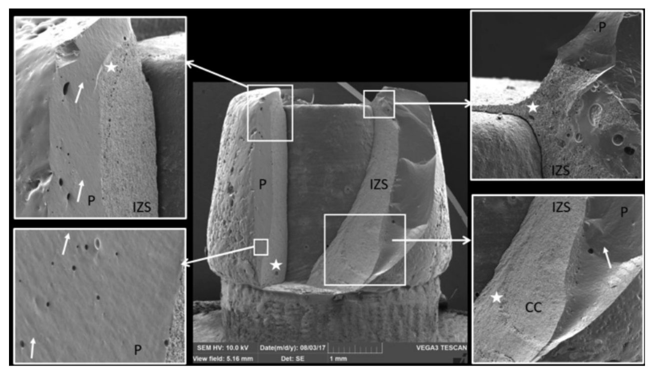

Figure 3: Failure analysis of a crown from group IZS. Wake hackles in the porcelain (P) layer point (white arrows) to the flaw origin in the damage contact area of the occlusal surface. Porosity can be observed in the IS microstructure (white stars). A compression curl (CC) was located in the right side of the crown.
[Figura 3: Análise de falha de uma coroa do grupo IZS. Wake hackles na camada de porcelana (P) apontam (flechas brancas) para a origem da falha na zona de dano de contato da superfície oclusal. Pode-se observar porosidade na microestrutura da IS (estrelas brancas). Uma curva de compressão (CC) foi localizada no lado direito da coroa.]

DISCUSSION

This study proposed to investigate *in vitro* the fracture behavior of all-ceramic crowns produced with different fabrication methods, using a test that aimed to simulate the conditions found in the oral cavity. Thus, we chose crown-shaped specimens with a simple and reproducible geometry, respecting all the fabrication steps of the methods evaluated. In addition, a multilayer specimen can reproduce all failure modes resulting from the complex geometry constituted by veneering ceramic (porcelain), infrastructure ceramic, luting agent, and abutment [16]. All manufacturer's instructions were followed and there was no internal adjustment of infrastructure prior to cementation as flaws can be introduced during the fabrication steps and the clinical adjustment of ceramic restorations [7]. The fabrication method had no influence on the fracture behavior of prosthetic crowns, rejecting the first study hypothesis. Chemical composition, atomic structure, fabrication process, and microstructure have a strong relationship with mechanical and physical properties of the materials [1, 2, 8-10, 17]. The present study assessed two ceramics with the same chemical composition and atomic structure, but produced with different methods. The similarity of fracture load values between the groups suggested that both techniques were able to create a homogeneous and similar microstructure. A previous study also found similar fracture load values and failure modes among crowns produced with CAD-CAM system and the slip-casting technique [11]. Yet, a study showed that specimens produced with the slip-casting technique resulted in higher flexural strength than CAD-CAM, but similar fracture toughness values were found for both fabrication methods. The study observed that, even though the ceramic microstructure was similar, porosity observed for the CAD-CAM group was higher [8]. In the present study, during the fractographic analysis, higher porosity was observed for crowns produced with the slip-casting technique (Fig. 3).

The second hypothesis of the study was rejected as similar reliability of the prosthetic crowns was obtained for both methods. This result suggested that the fabrication method did not alter the flaw population of the material. Yet, a more homogeneous microstructure was observed for CAD-CAM crowns during the fractographic analysis. The Weibull analysis also estimated the fracture load for a 5% probability of failure ($\sigma_{5\%}$) of 897 N for the crowns of group IZS and of 970 N for group IZC. Considering that the mean masticatory load in the posterior region is approximately 220 N, a low probability of failure is suggested for crowns with zirconia-based infrastructures [18]. Catastrophic failure was observed for all crowns tested involving porcelain and infrastructure ceramic. Therefore, the fabrication method had no influence on the fracture mode of crowns. Fractography analysis suggested that failure initiated in the occlusal region, in the contact area between porcelain and the loading piston. Clinically, the failure modes observed for all-ceramic single crowns with alumina- and zirconia-based infrastructure are chipping of the veneering ceramic and catastrophic fracture, with origin at the intaglio surface between infrastructure ceramic and cement layer or at the external surface, due to contact damage [19-21]. Fracture load tests are often used to assess *in vitro* the fracture behavior of ceramic restorations. However, fast fracture tests show limitations as they may fail to reproduce the loading conditions found in the oral cavity [18, 22]. On the other hand, these tests are useful to provide an initial characterization of the restorations mechanical behavior and plan further improvements in the configuration and fabrication process. In order to more closely simulate the oral conditions, a glass fiber-reinforced epoxy resin material with similar elastic properties and bond strength to dentin was chosen as the abutment [15, 22]. Cementation was performed using a MDP-based resin cement, which can chemically react with metal oxides present in zirconia-based ceramic [3, 23].

CONCLUSIONS

The fabrication method had no influence on fracture load and failure mode of zirconia-based ceramic prosthetic crowns. Crowns produced by CAD-CAM and slip-casting presented similar reliability.

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