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Marginal gap of zirconia and lithium disilicate frameworks produced by the CAD-CAM technique through a comparator microscope – in vitro analysis

Fenda marginal de estruturas de zircônia e dissilicato de lítio produzidas pela técnica CAD-CAM através de um microscópio comparador – análise in vitro

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ABSTRACT

Objective: The aim of this study was to evaluate the marginal gap of frameworks produced using the CAD-CAM system, from zirconia and lithium disilicate blocks, adapted to a tooth preparation and a gypsum die. **Material and Methods:** For this study, a human first molar tooth was used as a master model with a full crown preparation. It was molded 20 times to obtain the gypsum die and randomly divided into 2 groups (n=10) for the fabrication of zirconia and lithium disilicate frameworks. The frameworks were made using pre-sintered zirconia blocks and lithium disilicate blocks, both CAD-CAM systems. The marginal gap was measured in μm at four points (buccal, palatal, mesial, and distal) using a comparator microscope with 30x magnification, with the framework seated on the master model (tooth), and on the gypsum die. Marginal gap data (μm) were evaluated using two-way analysis of variance and Tukey's test with a significance level of 5%. **Results:** The results showed that there was no statistically significant interaction between the factors studied (p=0.223) or isolated factors (ceramic factor p=0.886 and die factor p=0.786). **Conclusion:** Both ceramics produced using the CAD-CAM technique did not exhibit statistical differences in marginal adaptation on the two types of substrates, both on tooth preparation and on the gypsum die.

KEYWORDS

CAD-CAM; Dental ceramics; Dental prosthesis; Lithium disilicate; Marginal adaptation; Zirconia.

RESUMO

Objetivo: O objetivo deste estudo foi avaliar o espaço marginal de estruturas produzidas usando o sistema CAD-CAM, a partir de blocos de zircônia e dissilicato de lítio, adaptadas a um preparo sobre dente e a um troquel de gesso. **Material e Métodos:** Para este estudo, um dente molar humano foi utilizado como modelo mestre com preparo para coroa total. Este foi moldado 20 vezes para obter o troquel de gesso e dividido aleatoriamente em 2 grupos (n=10) para a fabricação de estruturas de zircônia e dissilicato de lítio. As estruturas foram feitas usando blocos de zircônia pré-sinterizados e blocos de dissilicato de lítio, ambos sistemas para CAD-CAM. O espaço marginal foi medido em μm, em quatro pontos (bucal, palatal, mesial e distal), utilizando um microscópio comparador com ×30 de ampliação e com a estrutura assentada no modelo mestre (dente) e no troquel de gesso. Os dados de espaço marginal (μm) foram avaliados usando análise de variância bidirecional e teste de Tukey com um nível de significância de 5%. **Resultados:** Os resultados mostraram que não houve interação estatisticamente significativa entre os fatores estudados (p=0,223) ou isoladamente (fator cerâmica p=0,886 e fator troquel p=0,786). **Conclusão:** Ambas as cerâmicas produzidas usando a técnica CAD-CAM não apresentaram diferenças estatísticas em relação à adaptação marginal nos dois tipos de substratos, tanto na preparação dentária quanto no troquel de gesso.

PALAVRAS-CHAVE

CAD-CAM; Cerâmicas odontológicas; Prótese dentária; Dissilicato de lítio; Adaptação marginal; Zircônia.

INTRODUCTION

The growing demand for aesthetic dental procedures has driven the use of pure ceramics as biocompatible and functional alternatives to conventional restorative materials [1]. In addition to aesthetics, factors such as mechanical strength, color stability, and precision in marginal adaptation are essential for the success of these restorations [2]. Dental ceramics have a variety of shades similar to natural teeth, providing high aesthetics, as well as mechanical strength and durability [3].

The introduction of digital systems, such as scanners and milling machines, for the fabrication of prosthetic restorations from ceramic blocks has allowed the standardization of the work process and the use of materials with better performance and aesthetic quality [4-6]. Tetragonal zirconia partially stabilized with yttrium oxide (Y-TZP) has been incorporated into dentistry as a material for all-ceramic restorations using the CAD-CAM (Computer-Aided Design/Computer-Aided Manufacturing) system [7,8]. Zirconia has made a name for itself as a dental material due to its biocompatibility, hardness, mechanical strength, wear resistance, and excellent chemical and dimensional stability, enabling the fabrication of fixed partial prostheses with three or more elements, including posterior teeth and abutments on implants [9-13]. However, the opacity of this material, due to its high crystallinity and density, historically required the use of feldspathic ceramics to achieve the desired aesthetics [14,15]. Nevertheless, chipping and debonding of the veneering material were common failures [13]. Recently, translucent zirconia has been introduced to the market, enabling monolithic restorations with superior strength and aesthetics [16,17].

Lithium disilicate-reinforced ceramics stand out due to their excellent optical properties. This vitreous material offers options for both CAD-CAM systems and pressing techniques. Due to its favorable translucency and variety of colors, it is possible to make single-layer (monolithic) structures, which can subsequently be built up or simply glazed [18]. Clinical applications of the lithium disilicate-based system include inlay, onlay, overlay, laminate veneers, full crowns, and fixed partial prostheses of up to three elements in the anterior and premolar regions [14,18-20].

The marginal adaptation of ceramic restorations is one of the crucial factors for the clinical success and longevity of these rehabilitations [20,21]. Therefore, maladaptation that exceeds clinically acceptable limits (up to 120 μm) can result in biofilm accumulation, predisposing to periodontal disease, recurrent caries, and pulpal inflammation [22]. In addition, exposure of the luting agent to intraoral fluids can accelerate cement dissolution, leading to restoration failure [23,24]. Zirconia and lithium disilicate restorations seem to offer excellent marginal adaptation with reduced microgaps, thereby maintaining the health of periodontal structures and ensuring long-term clinical success [25-27]. To achieve this, obtaining the definitive mold, either physically or digitally, through conventional molding or digitalization is necessary to provide information for adequate marginal adaptation [28-33]. While both materials are classified as dental ceramics, there are differences between them, such as resistance, translucency, aesthetics, and hardness. The latter characteristic poses challenges in occlusal and proximal adjustments with diamond burs, potentially causing microcracks after the crystallization process [34,35].

Although the tips used in milling machines are specific to each material type, the hardness of zirconia and the size of the tip can result in restorations with fewer details when compared to lithium disilicate restorations [36]. Similarly, the number of milling machine axes can lead to marginal gaps with statistically significant differences [37,38].

Therefore, the objective of this study was to evaluate the marginal microgap of CAD-CAM infrastructures made with zirconia and lithium disilicate blocks when adapted to dental preparations and gypsum dies. The working hypothesis is that there are differences in the marginal microgap between the materials and their variables.

MATERIAL AND METHODS

This study was submitted to the Research Ethics Committee of São Leopoldo Mandic University, (Campinas, SP, Brazil) and registered under the number 2.270.526.

For this study, an extracted human left lower first molar [39] was selected according to the following inclusion criteria: absence of enamel or dentin fracture; dimensions and morphology of the crown consistent with the size of the preparation to be performed.

The element was included in a gypsum base (Durone, Dentsply, Pennsylvania, USA), leaving 1mm of the cervical area exposed for crown preparation, denominated master model (Figure 1). The crown preparation was performed manually, under visual inspection, in high rotation under abundant cooling, using spherical diamond burs #1012 and cylindrical #3216 (KG Sorensen, São Paulo, SP, BR), with the following settings: 1.2 mm circumferential reduction in chamfer, occlusal reduction of 2 mm, and convergence angle of the axial walls of 6°(degrees).

Twenty impressions of the master model were made with heavy-body and light-body polyvinyl siloxane (Futura AD, Nova DFL Produtos Odontológicos, Taquara, Rio de Janeiro) using the compression molding method in 1 step to obtain the gypsum casts, with the aid of an individual adapted tray. Then the molds was poured with Type IV gypsum (Durone, Dentsply, Pensilvânia, EUA) for die casting. The handling and proportioning of the materials used followed the guidelines of their respective manufacturers. As well as the master model, the casts were included in a gypsum base, leaving the cervical exposed for better visualization of the end of the preparation (Figure 2). The 20 gypsum casts obtained were divided into 2 groups with 10 samples each, according to the infrastructure ceramic:

Group 1 - zirconia-based frameworks;

Group 2 - lithium disilicate frameworks.

To obtain the frameworks, 10 blocks of pre-sintered zirconia (ICE Zirkon Transluzent Plus, Zirkonzahn®, Gais, Itália) and 10 blocks of lithium disilicate (Rosetta SM, OdontoMega, Ribeirão Preto, São Paulo, BR) in LT W2 shade were used and prepared in the CAD-CAM system from Zirkonzahn®. The master model and the gypsum dies were scanned (Scanner S600 ARTI, Zirkonzahn®, Gais, Itália), which features two high-resolution cameras, allowing a faster and more accurate scanning. The software used for digital design (CAD) was Zirkonzahn.Scan (Zirkonzahn®, Gais, Itália) and the files were sent to the milling software Zirkonzahn Fräsen (Zirkonzahn®, Gais, Itália) (Figure 3). The milling process was performed in the M1 5-Axis milling machine (Zirkonzahn®, Gais, Itália) and then

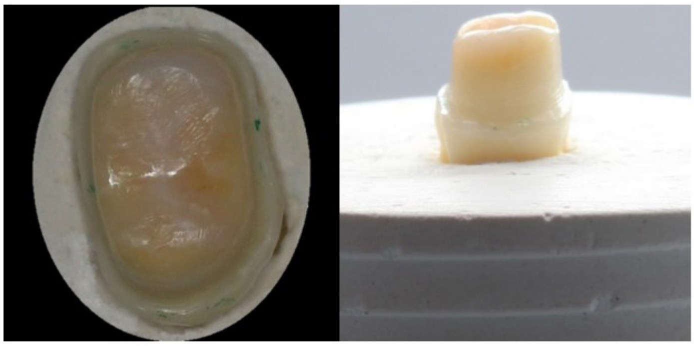

Figure 1 - Master model.

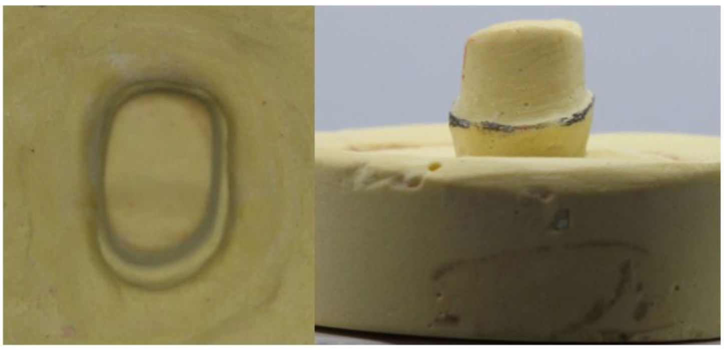

Figure 2 – Gypsum die.

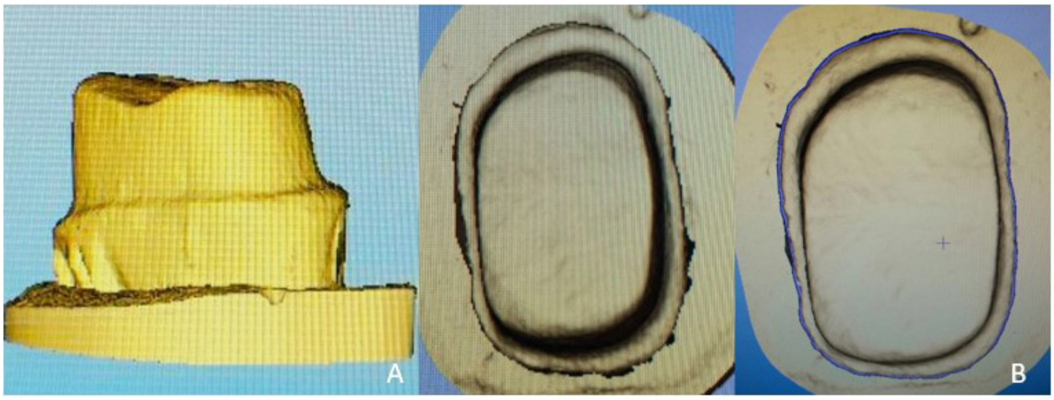

Figure 3 - Master model scan (A); margin delimitation with Zirkonzahn Fräsen software (B) (Zirkonzahn®, Gais, Italy).

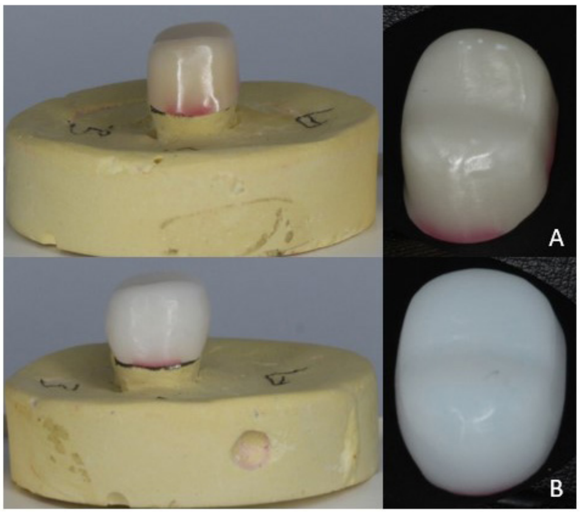

Figure 4 - Frameworks (A) Zirconia (B) lithium disilicate.

the blocks were sintered according to each of the manufacturer's recommendation using the Zirkonofen 600 oven (Zirkonzahn®, Gais, Itália) (Figure 4).

The gap were measured by passively placing the frameworks on the master model and the gypsum die on half of each side of the samples, that is, in the middle of the buccal, lingual, mesial, and distal faces (Figure 5), from the margin to the cervical end of the preparation. The measurement points were marked with colored graphite for better visualization under the microscope. The measurements were performed with a comparator microscope (Olympus Corporation - USA) at ×30 magnification, and the measurement system was the OLYMPUS MMDC 201. Each face was measured in triplicate, obtaining, thus, the average.

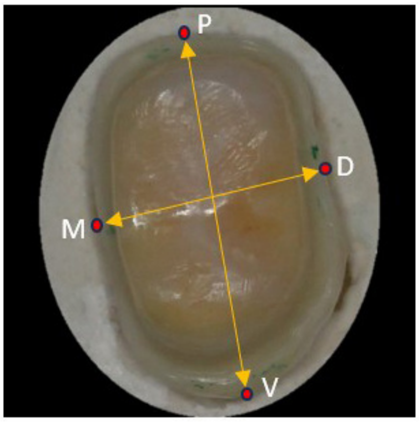

Figure 5 - The measurement points.

Statistical analysis

Prior to the analyses, the marginal gap data (μm) were evaluated as for their normality by the Shapiro-Wilk test (p=0,071). They were then submitted to ANOVA two-way analysis of variance. The study factors were the ceramics (lithium disilicate and zirconia) and the different dies (tooth and gypsum). Statistical calculations were conducted using a 5% significance level (α = 0.05) in SigmaPlot

Table I - Mean values of marginal gap ±standard deviation (µm)

	Master model	Gypsum die	Overall average
Lithium disilicate	54 ±19	74 ±47	64 ±37
Zirconia	68 ±63	55 ±19	61 ±43

14.0 software (Systat Software Inc., San Jose, California, USA).

RESULTS

Table I shows the mean values and the standard deviation of the marginal gap of the different ceramics in relation to the different dies.

The two-factor analysis of the variance showed no statistically significant interaction between the studied factors ($p=0.223$), as there was no statistically significant result for the isolated factors - ceramic factor ($p=0.886$) and die factor ($p=0.786$).

DISCUSSION

In the present study, the results demonstrated that there was no difference in adaptation between zirconia and lithium disilicate using the CAD-CAM technique, nor between the evaluation of the adaptation of the master model (tooth) and the gypsum die; therefore, the experimental hypothesis was rejected.

The standardization of processes and the use of the CAD-CAM system for the manufacture of both types of ceramics resulted in similar gaps, especially in the gypsum die, which presented average values of 74 μm ± 47 for lithium disilicate and 55 μm ± 19 for zirconia. Other studies that evaluated gaps using CAD-CAM technology obtained results without statistical differences between materials, as shown in the present study [1,27].

The milling machine used in this study had a 5-axis system (Zirkonzhan M1). The number of axes on the milling machine can compensate for differences in the fit of ceramic restorations. This observation aligns with the results of our study, emphasizing the importance of the milling machine's axis count in ceramic restoration precision and indicating that a higher axis count correlates with increased accuracy. Studies have demonstrated that a 5-axis milling machine produced better fits than the results from a 3-axis milling machine, regardless of the type of ceramic [27,37,38]. However, a study comparing 3-axis and 5-axis milling machines highlighted that the 3-axis milling machine produced crowns with smaller marginal discrepancies. This finding suggests that, despite the significance of the axis count, other factors, such as the diameter of the milling tool tips, play a crucial role in the precision of marginal adaptation. According to the authors, the difference may be because the 3-axis milling machine used a 1 mm diameter diamond bur to cut the internal surface of the crown, while the 5-axis milling machine uses burs with diameters of 3 mm, 2 mm, and 1 mm in sequence to cut the surface of the crown notch, contributing to the discrepancy in the margin [35]. In addition to these results, a study observed that zirconia restorations exhibited the least occlusal contact fidelity during milling and post-processing, along with the lowest need for occlusal adjustment, advocating for reduced occlusal compensation [36]. Collectively, these studies offer a comprehensive perspective on the impact of various variables on the quality of ceramic restorations produced by CAD-CAM milling machines. Furthermore, the effect of the CAD-CAM technique used to produce the structure in this study resulted in acceptable marginal gaps that were smaller than the value established in the literature (120 μ) [40,41]. An important factor to be considered after milling is the sintering of these ceramics. This must be controlled for each type of ceramic, as this process provides the mechanical resistance and translucency of each material [39,42]. In this study, zirconia was sintered for 2 hours (8 °C/min), until a final temperature of 1500°C, and lithium disilicate for 10 minutes (95°C/min), reaching a final temperature of 850°C. Studies demonstrate that sintering can significantly interfere with the marginal and internal adaptation of ceramic crowns [18,39,42]. Therefore, it is extremely important to follow the protocols recommended by manufacturers, especially the time x temperature relationship to achieve the potential of glass ceramics [42].

The materials used in the master model (tooth, metal or resin) and in the production of dies (gypsum or resin) can contribute to the marginal gap values. In the present study, the master model was obtained from the preparation of an extracted human tooth and after molding, a type IV gypsum was used to create the die. These factors did not affect the gap, as there was no difference in the values between the master model (tooth) and the gypsum die. Even taking into account the dimensional changes that gypsum can undergo, the study demonstrates that, if the processes are carried out properly, favorable results can be achieved. Studies that used the metal master model and type IV gypsum models concluded that the different materials did not influence the accuracy of the marginal adaptation [43,44]. Furthermore, a comparative study of accuracy between conventional printing and digital printing concluded that gypsum models still had more details in grooves and fissures compared to CAD-CAM models [45].

The dimensional accuracy of an impression is decisive in the adaptation of a fixed prosthetic work; therefore, the choice of technique and impression material can contribute to marginal discrepancies [29,30]. Some studies show superior accuracy in the 2-step technique (double mixing) [29,30], while others prefer the 1-step technique [31]. In this study, the double-mix (one-step) molding technique was applied, based on studies that demonstrated superiority in terms of marginal adaptation [31]. It should be considered that this study was conducted in vitro, and clinical factors such as gingival retraction, bleeding, and saliva were not considered. With the advancement of digital dentistry, digital impressions made with intraoral scanners have presented models with greater precision than conventional impression techniques [32]. Furthermore, the procedure is faster and shortens the operative time, in addition to being more comfortable for the patient [33].

Both ceramics produced by CAD-CAM technology exhibited similar results in terms of marginal adaptation on the tooth preparation and gypsum die. Thus, the ceramics did not present statistical differences as materials for the infrastructure (disilicate vs. zirconia). In addition, the adaptation of the margin was within acceptable values. Most of the literature considers acceptable values of up to 120μm, a value initially determined for metallic structures [43]. Regarding zirconia, a systematic review concluded that marginal integrity presented high success values for different observation periods [26], and another study presented satisfactory results in relation to marginal adaptation in its in vivo study, reaching a survival rate of 100% for crowns made of monolithic zirconia, monitored for 2 years [15]. These results highlight the increasing accuracy of these systems, with some studies indicating statistical differences between ceramics [44].

Other variables, such as scanner, software, and operator, did not influence the results of this study. However, the importance of technology, its development, and understanding, in addition to fundamental knowledge in prosthetics and dental materials, cannot be underestimated. According to previous research, these variables significantly affect the results obtained through intraoral scanning [46].

Since this study was conducted in vitro, the mentioned variables, which could influence the clinical outcome of the restorations, were considered limitations. Therefore, controlled in vivo studies are needed to evaluate scanning accuracy in conjunction with clinical factors and the application of current technologies.

CONCLUSION

According to the results, it can be concluded that both ceramics produced through CAD-CAM technique showed no statistical differences regarding marginal adaptation on the two types of substrates, both on the tooth preparation and on the gypsum die, and that the gap values are acceptable.

Author's Contributions

ECRA: Conceptualization, Resources, Writing – Review & Editing. VCF: Conceptualization, Resources, Methodology, Data Curation, Formal Analysis, Writing – Original Draft Preparation. KANO: Supervision, Methodology, Validation. WCB: Supervision, Methodology, Formal Analysis, and Writing – Review & Editing.

Conflict of Interest

The authors have no conflicts of interest to declare.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

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Regulatory Statement

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