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Digital Volumetric Analysis of CAD/CAM Ceramic Materials after Tooth Brushing

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ABSTRACT

***Objective*: The objective of this in vitro study was to evaluate the volumetric wear of three CAD/CAM (computer-aided design/computer-aided manufacturing) ceramic materials.**

***Materials and Methods*: The materials evaluated were CEREC Blocs (Dentsply Sirona), Initial LRF (GC) and Amber Mill (HASS Corp). All the samples (n=30) were subjected to simulated brushing (100,000 cycles). The wear was assessed by superimposing pre- and post-brushing scans obtained with an intraoral optical scanner (CEREC Primescan; Dentsply Sirona, Germany), which was then imported into the OraCheck 5.0 software (Dentsply Sirona, Germany).**

***Results*: The CAD/CAM ceramic materials tested showed no statistically significant differences in terms of the average volumetric wear (p-= 0.455).**

***Conclusion*: Therefore, it can be concluded that the ceramic materials have a good behavior under simulated brushing, without significant volumetric alterations.**

Keywords: CAD/CAM, ceramic, simulated brushing, volumetric analysis, wear test.

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I. Introduction

CAD/CAM (computer-aided design/computer-aided manufacturing) systems have developed rapidly over the past 35 years, with increasing clinical interest and a large number of new CAD/CAM materials being introduced into the market [1], [2]. CAD/CAM systems reduce clinical and laboratory time, are more accurate, and improve the performance of ceramic restorations by the fact that they can be designed and fabricated through digital flow [1], [3]. In addition, these materials by their fabrication based on new technologies are industrially produced with elevated pressure to form presintered structures achieving improved physical and mechanical properties [4].

The dental ceramics available for CAD/CAM systems according to their classification can be presented as: ceramics with glassy matrix and polycrystalline ceramics without glassy phase content [5], [6]. These types of materials differ considerably with respect to their chemical, mechanical and manufacturing properties [7]. Ceramics with a glassy matrix comprise three groups: feldspathic ceramics, which have the best esthetic characteristics, frequently used for the fabrication of veneers, inlays, onlays and crowns. However, their strength is not considered high enough for restorations in the posterior region, being considered brittle [3], [5], [8], [9]. The synthetic, high-strength ceramics with lithium disilicate crystal reinforcement, which makes them ideal for the fabrication of inlays, onlays, veneers and crowns with survival rates between 97% and 100%. Also on the market are polycrystalline ceramics that have a fine-grained crystalline structure that provides strength and toughness to fracture, but with lower translucency [8], [9].

Feldspathic ceramics are one of the oldest and one of the most common materials used in milling blocks (CEREC Blocs CB, Dentsply Sirona, York, Pennsylvania). They are fabricated blocks made of fine-grained powders that produce a relatively pore-free ceramic. Their fine particles (4 µm) provide improved polish ability, lower enamel wear and flexural strength of approximately 112 to 120 Mpa [10]. These blocks are composed of 64% silica and 23% aluminum oxide and can be monochromatic (C) and polychromatic (PC), with a variety of shades and sizes. They possess high translucency with mimetic effect and abrasion properties similar to those of enamel [3], [5]. In an effort to improve the flexural strength of feldspathic ceramics, leucite-reinforced ceramics were introduced, which possess high translucency, making them an ideal choice for highly esthetic cases. Initial LRF Block (LRF) (GC, Tokyo) is a leucite-reinforced feldspar ceramic block with a distribution and particle size of these crystals that favor esthetic appearance and with its homogeneously distributed dense ceramic particles, which provide flexural strength of close to 160 MPa. They have high translucency (HT), low translucency (LT) and 6 different shades [5], [8]. AMBER MILL (ABM) (Hass, Kangreung, Korea) is a lithium disilicate (DL) ceramic block composed of 40% metasilicate crystals and DL nuclei embedded in a glassy phase. These crystals allow for fast fabrication of the restorations. The material is wet milled in a pre-crystallized phase, then the crystallization process is carried out in a sintering furnace where it is possible to adjust the level of translucency of the material, the metasilicates are dissolved and the DL crystallizes, obtaining a material with 70% DL crystals in a glassy matrix with a flexural strength of between 350 MPa and 450 MPa [8], [11]-[13].

Dental ceramics have excellent esthetic properties and wear resistance [14]. However, they are subject to color changes, changes in micro hardness and changes in surface roughness due to endogenous and exogenous causes. There are extrinsic factors such as colored beverages, acidic solutions, high temperatures and tooth brushing, which are related to the degradation of ceramics. These conditions affect the structural composition and interfere with the surface properties of the material [15]. One of the factors that most contributes to surface wear is tooth brushing which, together with toothpaste, can produce a 3- or 4-body wear phenomenon in restorations [16]. Toothpastes are composed of abrasive components, which should be measured with the relative dentin abrasiveness (RDA). The American Dental Association recommends a maxi-mum dose of 250 RDA [17]. In addition, brushing can generate a removal of characterization, color change and an increase in surface roughness [16]. Roughness values higher than 0.2 µm are associated with an increase in bacterial retention and a decrease in gloss, indicating the deterioration of the material [14], [16]. Reference [18] reported that with a normal brush and common toothpaste there is wear of the surface characterization of feldspathic ceramic restorations over a period of 10 to 12 years.

The objective of this in vitro study was to evaluate the volumetric wear of three ceramic CAD/CAM materials after tooth brushing simulation using a three-body wear test. The null hypothesis of this in vitro study was that the ceramic CAD/CAM materials tested would not show significant differences in volumetric wear after simulated tooth brushing.

II. Materials and Methods

An in vitro comparative study was carried out, in which three types of ceramic CAD/CAM materials were evaluated. Ten blocks of each material were used: CEREC Blocs (Dentsply Sirona), Initial LRF (GC) and Amber Mill (HASS Corp). Information on the materials analyzed is presented in Table I.

A. *Specimen Preparation*

A scan of a printed model of an upper jaw with a preparation for a veneer on the up-per central incisor was made. The restoration was designed using CEREC 5.1.3 software. The design parameters were standardized for all specimens, with a minimum thickness of 1 mm. The information was then exported to the CAM software for materialization on a milling unit (MCXL, Dentsply Sirona, Germany). Ten samples were fabricated for each group (n=10). For the lithium disilicate ceramic group (Amber Mill) the samples underwent a crystallization process according to the manufacturer's instructions at 815 °C for 21 min. Subsequently all samples were subjected to a speculate polishing using a plush and polishing paste (AP Esthetic, Dusseldorf, Germany) for 60 seconds. They were washed with water and dried with compressed air for 20 seconds.

B. *Wear Test*

The brushing was simulated using an automatic brushing machine (MEV-3T XY; Odeme Dental Research, Luzerna, Brazil). The specimens were fixed in 18 mm×12 mm polyvinyl ride (PVC) holders with condensation silicone (Speedex; COL-119TENE). Hard bristle nylon brushes (Colgate Extra Clean; Colgate-Palmolive, Bogotá, Colombia) were used on each brush head. Each specimen was brushed in a direction perpendicular to the sliding surface with a load of 2N, an excursion amplitude of 15 mm and a frequency of 72 rpm/min (1.2 Hz) for a total of 100,000 cycles. A suspension containing 150g of fluoride paste (Colgate Total 12; Colgate-Palmolive, Colombia) with a Relative Dentin Abrasiveness (RDA) of 70/78 was injected with 1 L of distilled water. The solution was injected every 5000 cycles to keep the surface wet. The internal temperature of the machine was maintained at 36.5 °C. At the end of the brushing test, each sample was cleaned with tap water and dried with compressed air [5], [7].

C. *Volumetric Wear Assessment*

The volumetric wear of the materials was measured by superimposing pre- and post-brushing scans by means of an intraoral optical scanner (CEREC PrimeScan: Dentsply Sirona, Bensheim, Germany). The data acquired from the digitization of each specimen were imported in STL format into the Ora-Check 5.0 software (Dentsply Sirona, Germany), which allows 3D comparison between two or more digital scans, using the best-fit algorithm [19].

TABLE I: Technical Characteristics of the CAD/CAM Materials Evaluated in This Study

Material	Code	Classification	Manufacturer	Composition	Lot Number
CEREC Blocs	CB	Feldspathic ceramic	Dentsply Sirona	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, TiO_2, pigments	98850
Initial LRF	LRF	Leucite reinforced glass ceramic	GC	Not available in detail	1901151
Amber Mill	ABM	Lithium disilicate ceramic	HASS Corp	SiO_2, Li_2O, P_2O_5, Al_2O_3, other oxides and dyes	EBE05NF0901

D. Statistical Analysis

Data records for each group of samples were compiled in an Excel (version 16, Microsoft, Redmond, WA, USA) file and imported into the SPSS program (IBM SPSS Statistics version 26 in Spanish). For the hypothesis testing of the research, the assumptions of normality (Shapiro-Wilk) and homoscedasticity (Levene) were verified. Once the normality of the data was determined, an ANOVA test with a 95% confidence interval was used.

III. Results

A. Wear Test

The results of the volumetric wear comparison of the CAD/CAM ceramic materials are shown in Table II. Fig. 1 show the differences obtained in the average volumetric wear for each CAD/CAM ceramic material. LRF presented highest average volumetric change (0.229 mm^3) followed by ABM (0.189 mm^3), with the lowest being CB (0.161 mm^3). Fig. 2 shows graphs of measurements made with Oracheck 5.0 software.

TABLE II: Means and Standard Deviations (SDs) of Volumetric Losses of Materials after Wear Test

Material	N	Mean	Standard Deviation	Min	Max
Amber	10	0,19	0,09	0,09	0,32
Cerec	10	0,16	0,13	0,00	0,40
Initial	10	0,23	0,13	0,02	0,43
Total	30	0,19	0,12	0,00	0,43

measurement results in mm3 for each treatment

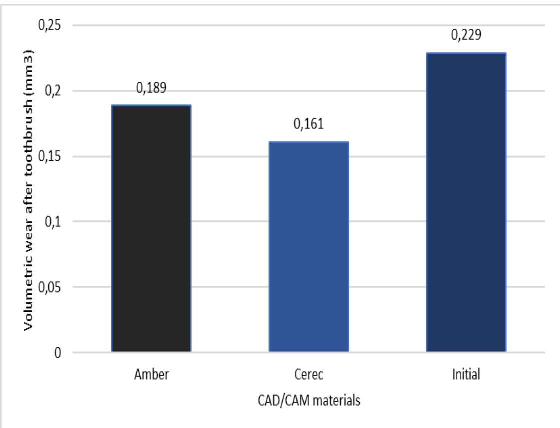

Fig. 1. Graph of average volumetric wear for each material.

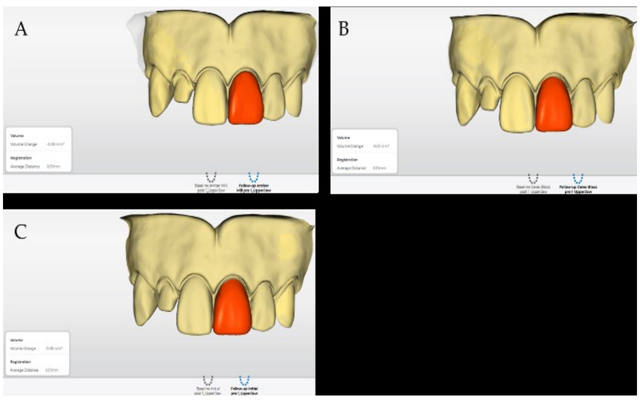

Fig. 2. Result of the initial scan and post-wear scan overlay in the Oracheck software 5.0: (A) Amber Mill (ABM); (B) CEREC Blocs (CB); (C) Initial LRF (LRF).

Table III shows the results of the normality and homoscedasticity tests. For the normality test, it was concluded that the data came from a population with a normal distribution (p-value = 0.412 > 5%) and according to the result of the homoscedasticity test, it was concluded that the data came from populations with equal variances (p-value = 0.281 > 5%).

Through the ANOVA test, it was determined that the CAD/CAM ceramic materials tested did not present statistically significant differences in terms of the average volumetric wear (p-value = 0.455 > 5%). Table IV shows the results of the comparison of the average volumetric change between the three materials.

TABLE III: Results of Assumptions Verification

Test	Statistic	Degrees of freedom	p-Value
Normality (Shapiro-Wilk)	0,965	30	0,412
Homoskedasticity (Levene)	1,331	(2;27)	0,281

Note: significance level at 5%

TABLE IV: Result of the Comparison in the Average Volumetric Change (mm^3) between Materials

	Sum of squares	gl	Root mean square	F	Sig.
Between groups	0,023	2	0,012	0,811	0,455
Within groups	0,389	27	0,014		
Total	0,412	29			

Note: significance level at 5%, ANOVA test.

IV. Discussion

This in vitro study was aimed at investigating the volumetric wear of CAD/CAM ceramic material surfaces after simulated tooth brushing. The results showed that there are no statistically significant differences between the samples. Because of this, the null hypothesis of the study was accepted. For the CAD/CAM Cerec Blocs (CB) and Initial LRF (LRF) ceramics, no glazing and firing steps were required, while the Amber Mill (ABM) samples underwent a crystallization process.

Several methods have been described for in vitro wear analysis: the measurement of surface roughness, volume loss after the wear test, and the weight of the samples subjected to the wear test. In this study, the volume loss of each ceramic material was analyzed by means of an intraoral scanner, which is a fast, easy-to-use tool with acceptable reliability of the results. The scanner was used for data acquisition before and after tooth brushing simulation and subsequently analyzed in OraCheck software to deter-mine the volumetric wear of each ceramic material [20].

There are different in vitro aging protocols proposed to simulate the oral cavity conditions to which restorative materials are subjected. The most common are: thermo cycling, immersion in liquids and simulation of dental brushing. Under clinical conditions, thermal, chemical, and mechanical factors affect the quality, esthetics and longevity of ceramic restorations [14]. The complex interaction of food, beverages, saliva, and fluoride interaction of toothpaste with tooth brushing has previously demonstrated changes in the surface of ceramic materials in terms of volume, gloss, characterization, and hardness, resulting in low durability

[16], [21], [22]. Therefore, tests such as tooth-brushing simulation can help to gain insight into the clinical performance of these materials [14], [23].

The effect of toothpaste abrasiveness on restorative materials has been well documented. Tooth brushing with low RDA toothpaste can produce wear in the color characterization on the surface of a metal-ceramic restoration within 10 to 12 years [16]. One study proved that the wear was produced only by the effect of toothpaste and there was no relation with toothbrush [17]. This was confirmed by another study in which the authors suggested that the use of very abrasive toothpaste is re-sponsible for the surface wear [23]. The paste used in the present study has low abrasiveness of 70 RDA. Many researchers have related the optical properties to surface roughness. In addition, it is attributed that the smooth surface of materials is directly proportional to surface light reflection and scattering, which improves the optical properties [23]. Surface roughness (Ra) values greater than 0.2 µm have been reported to be related to increased bacterial retention [14]. In addition, studies have reported that the human tongue is capable of clinically perceiving a surface roughness of 0.25 to 0.50 µm, reducing patient comfort [17], [22].

The present study determined an average Ra value of 0.19 ± 0.09 mm^3 for ABM, 0.16 ± 0.13 mm^3 for CB and 0.23 ± 0.13 mm^3 for LRF. These values are below the clinical limit mentioned above. Therefore, they are not considered clinically significant. Reference [24] in their study showed that the super surface roughness (Ra) values of the same ceramics tested in this study did not present significant differences between them, in addition to presenting high gloss retention after testing.

Reference [25] also support the present results with their investigations on the surface roughness (Ra) of different dental materials. The authors found no significant differences in lithium disilicate ceramics before and after tooth brushing simulation. This could potentially be explained by its high strength and hardness of 590 VHN (Vickers Hardness). On the other hand, [17] found that Ra values increased slightly over time. In their study they showed that it took 12 years of tooth brushing simulation to obtain noticeable changes of extrinsic stains in the IPS E-max Press (lithium disilicate pressable) ceramic. In another study [15], authors analyzed the surface roughness (Ra) of 2 groups of lithium disilicate ceramics: one group with glaze application and sintering and another with surface polishing with abrasive discs. The results gave values of Ra of 0.38 ±0.01 µm and 0.10 ±0.00 µm, respectively. These results demonstrate that mechanical polishing can provide lower Ra values for CAD/CAM lithium disilicate restorations with optimal properties capable of reducing microbial adhesion and mechanical retention of extrinsic substances. This allows the clinician to perform adjustments in the chair without additional laboratory processing [15]. Reference [6] reported that there was no significant difference between lithium disilicate and zirconium-reinforced ceramics in terms of wear potential. They also informed that lithium disilicate ceramics wore the antagonist enamel more than the other ceramic systems [6], [25]. In relation to our study, the lithium disilicate ceramics obtained surface roughness values very similar to the other ceramics studied without statistically significant differences, however, the feldspathic ceramics showed the lowest volumetric change, as shown in Fig. 1. Reference [26] reported higher sur-face roughness in the ceramic and higher wear on the antagonist enamel compared to the zirconium and composite resins. In contrast, [27] reported that pre-lithium disilicate ceramics showed a wear rate similar to that of gold and enamel [27]. The inconsistency in the results of these studies may be due to the different test methods applied. Surface wear of ceramics has been attributed to glass particles that are detached and act similarly to abrasives and lead to a three-body wear process [28].

In a study by [29], 3 restorative materials were compared: composite resin, polymer-infiltrated ceramic, and feldspathic ceramic. The results showed that feldspathic ceramic had higher gloss retention and lower surface wear after brushing. The feldspathic ceramic is a ceramic with higher hardness, the abrasive silica particles in the toothpaste, together with the brush, could have actuated as a long-term polishing procedure [29]. Reference [30] also indicated in their study that after tooth brushing simulation, feldspathic ceramic reinforced with leucite showed low values of surface roughness, considering it a stable material in the oral cavity. In another research, [14], showed in their study that after tooth brushing simulation performed on leucite-reinforced vitreous ceramic, polymer-infiltrated vitreous ceramic, and composite resins, only the first two presented acceptable gloss values. This may be due to the fact that these materials have a higher vitreous content and consequently, a higher refractive index. Although the results of the studies are not conclusive, it can be evidenced that the materials with vitreous matrix have the lowest values of surface roughness and that being materials with higher hardness they are less prone to wear [14]. In such a way, ceramic materials are able to maintain their physical properties such as surface roughness, gloss and volumetric change with minor alterations against extrinsic factors, such as tooth brushing, over time.

While it is true that the literature reports contradictory information related to the number of cycles necessary to simulate tooth brushing abrasion, in this study 100,000 cycles were performed to simulate 10 years of tooth brushing. Based on previous studies showing that the average force applied in tooth brushing is 2-3 N, the brushes used in this study were applied to ceramic surfaces with a force of 2 N and a frequency of 72 rpm/min [31].

This in vitro study presents some limitations such as: the movements of the toothbrush, the composition of the mixture used that did not contain saliva or artificial saliva, and the difficulty in dissimulating the dynamic oral environment, such as pH fluctuation, masticator forces, and the presence of bacteria [16], [17]. In addition, variables such as, the difference in the force people apply when brushing their teeth, the abrasiveness of toothpastes, the type of toothbrush bristles and the regularity with which people brush their teeth have not been included. Further studies are needed to mimic the actual situation of a ceramic restoration in the oral cavity to provide more feasible information under clinical conditions.

V. Conclusion

Based on the results of this in vitro study, the following conclusions were obtained:

- The tooth brushing simulation showed no statistically significant differences in average volumetric wear among the ceramic materials.
- After brushing, all materials presented clinically acceptable roughness values be-low 0.2 µm.
- Mechanical polishing can provide low surface roughness values with optimal properties capable of reducing microbial adhesion and mechanical retention of extrinsic substances, favoring working time for the clinician.
- Vitreous ceramics have excellent strength and hardness values, which favor better gloss durability, lower surface roughness, and thus less wear to external factors.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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