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WEAR PERFORMANCE OF THREE CAD/CAM MONOLITHIC RESTORATIONS: TWO-BODY WEAR AND SURFACE ROUGHNESS

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ABSTRACT

Statement of the problem: The use of monolithic ceramic restorations is rapidly increasing. However, there is a rising concern about their wear performance against antagonist enamel.

Objective: The present study aimed at ranking and comparing the wear performance of three CAD/CAM monolithic ceramic materials and their effect on the wear and surface roughness of their antagonist enamel.

Materials and methods: Five cylindrical discs (n=5) were constructed from each of: BruxZir zirconia, IPS e.max CAD lithium disilicate based ceramic and Enamic hybrid ceramic representing three types of monolithic restorations (N=15). Ceramic samples were polished till obtaining convergent surface roughness values of the three materials. Enamel antagonists were prepared as sectioned buccal cusps of maxillary first premolars (N=15). Baseline surface roughness and weight values were obtained using optical surface profiler and sensitive balance, respectively, for all samples (ceramic discs and their antagonist cusps) prior to subjecting the samples to chewing simulation procedure test including the application of 5kg (49N) load for 120,000 cycle with vertical movement 1mm, horizontal movement 3mm and frequency 1.6Hz. Weight loss was calculated for all samples (ceramic discs and their antagonists) as an indication of wear. In addition, change in surface roughness was calculated using optical surface profiler. Obtained data were statistically analyzed.

Results: The statistically significant highest mean material's weight loss was recorded in Enamic group, whereas the statistically significant lowest mean weight loss was recorded in BruxZir group. The statistically significant greatest mean antagonist weight loss was recorded for e.max antagonist cusp, whereas the statistically significant lowest mean weight loss was recorded for Enamic antagonist cusp. Surface roughness increased after wear procedure in all samples.

Conclusions: Monolithic hybrid ceramic (Enamic) and zirconia (BruxZir) produce less wear in opposing teeth compared to lithium disilicate based ceramics (e.max CAD). However, hybrid ceramic is more affected by wear compared to zirconia.

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INTRODUCTION

In the last decade, rapid evolution of metal-free restorative esthetic materials coupled with the development of new manufacturing technologies opened new horizons in the field of prosthodontics. Continuing improvement and development of esthetic materials has led to the introduction of a wide range of metal free restorations with a large variety in chemical composition and microstructure. [1]

To optimize esthetics; high strength ceramic materials were used as frameworks substructure, that were subsequently veneered with high esthetic glass containing ceramics giving a superior quality esthetic outcome. However, this veneering layer and its bond to the high strength infra structure presented a major problem as its inferior mechanical properties compared to the high strength core material made chipping of this relatively weak layer a common failure type. In addition; the bond strength of this heterogenous structure (core/veneer bilayer) is usually questioned as it lacked the essential durability for a lifelong bond. [2]

The search was thus directed toward the development of restorative materials which combine the esthetic prerequisites in addition to the essential mechanical behavior for a durable restoration. The concept of monolithic, full contour restorations was thus introduced. These restorations are constructed from a single type of metal free restorative material, without the veneer layer. The fabrication of the structure in one block reduces breakage possibilities and avoids chipping.[3,4] Moreover, high strength, minimal occlusal adjustment, and accuracy are some of its advantages. [3-6]

The use of monolithic restorations was extended to include several types of ceramic materials that combined esthetic, biologic and mechanical properties. Zirconia, lithium disilicate and hybrid ceramics were among ceramic materials suggested for construction of monolithic restorations.

Lithium disilicate ceramics are characterized by high mechanical properties and superior esthetics. The smaller uniformly distributed crystals in this type of glass ceramic led to the possibility of producing anatomically shaped, monolithic restorations, with no veneering ceramic, reducing technical complications like chippings and fractures. Partially, pre-crystallized blocks are available for milling using CAD/CAM systems. These blocks contain both 40% lithium metasilicate (Li_2SiO_3) crystals and lithium disilicate ($Li_2Si_2O_5$) crystal nuclei.[7] In the initial condition, such machinable, bluish blocks show moderate hardness and strength (around 130MPa).[8] After milling, heat treatment (840ºC–850ºC for 10 min) determines full crystallization of the material: lithium metasilicates tend to evolve to form lithium disilicates (70%), [9] increasing the flexure strength up to 262±88MPa with a fracture toughness of 2.5MPa□m1/2. [10]

Initially zirconia lacked the essential translucency for constructing a monolithic restoration. Additive components and heat treatments were manipulated to produce an acceptable translucency to construct a full contour restoration. An example of these materials is Bruxzir. The translucency of BruxZir is achieved via the elimination of light-scattering alumina sintering aids and porosities, along with the utilization of a higher sintering temperature (1530˚C) and longer dwell time (6 hours). [11] The manufacturer of Bruxzir claims that the material is kinder to the opposing dentition and can be used as posterior restoration in bruxism cases. [12]

Vita Enamic belongs to a newly introduced class of dental materials called polymers-infiltrated-ceramic-network (PICN). [13,14] PICN consists of two interlocking phases, a porous sintered ceramic (75 vol%) and an infiltrating polymer (commonly methacrylates) (25 vol%). [13] These materials are characterized by associating the elastic modulus of composites, which is similar to that of dentin, with feldspathic ceramic, adding long-term esthetics. [14] It has been claimed that the existence of polymer in its composition could reduce brittle fracture in comparison to pure ceramic materials. [14]

An important consideration when restoring a component of a patient's dentition is the interaction between the restoring material and opposing teeth. It is critical that the restoring material is wear compatible with its opposing surface to prevent excessive wear of the material itself or damage to the opposing structure. [15] A major problem of using all ceramic restorations had been the increased concern about observed high wear of either opposing dental enamel or both enamel and ceramic itself [16-18] However, the responsible wear mechanism(s) are still unclear. [18]

Wear presents loss of material's surface, due to mechanical contact, chemical reactions or simultaneous effect of both. [19] The hardness and thickness of enamel, [19,20] the chewing behavior in combination with parafunctional habits and neuromuscular forces, [19,21] as well as the abrasive nature of food and the antagonist material all influence the clinical wear. [22]

Enamel wear caused by antagonistic enamel and ceramic crowns has been investigated in vivo [23-25] and in-vitro. [17-21] In-vivo quantification of enamel and material wear is difficult and time consuming, thus in vitro studies using chewing simulators are commonly used to conduct in-vitro tests attempting to simulate oral wear.

One of the primary challenges for using dental ceramics is their noticeable abrasive action when they are used on occlusal surfaces opposing natural enamel. [26] When compared to the mean annual occlusal wear of human tooth enamel (15-38 micron), dental ceramics are considered wear-resistant, they tend to cause damage to the opposing enamel and this damage varies according to the ceramic material used. [26] However, attempts to rank dental ceramics according to their wear behavior were difficult and conflicting.

While zirconia exhibited less enamel wear than did porcelain and lithium disilicate glass in one study, [27] lithium disilicate glass was not only resistant to wear, but was also wear friendly to enamel antagonist surfaces in another study. [28] In addition, a previous study using bovine enamel, reported no significant difference between the wear values for opposing enamel caused by lithium disilicate glass and bovine enamel. [29]

In another study, [30] monolithic zirconia showed low wear rate on enamel and in the material, itself. However, SEM examination of antagonist enamel showed that sliding of enamel on zirconia surface caused added cracks of the enamel. It should be noted that material behavior in previous studies are limited to the in-vitro experimental duration. Those behaviors can be diversely changed if tested materials were subjected to the wear procedure for a longer duration of time.

This in-vitro study was thus conducted to compare and rank enamel wear caused by monolithic ceramics (BruxZir zirconia, e.max CAD lithium disilicate glass ceramic and Enamic hybrid ceramic) in addition to wear of the materials' themselves. The null hypotheses tested were that no difference would be found in enamel wear and surface roughness against tested materials and that for each material, no difference would be found in material's wear and surface roughness against enamel.

MATERIALS AND METHODS

To conduct the present study, three types of ceramics representing monolithic restorations, namely zirconia (BruxZir, Glidewell Laboratories, USA), lithium disilicate (e.max CAD, Ivoclar, Vivadent) and hybrid ceramic; (Enamic, Vita Zahnfabrik, Bad Säckingen, Germany), were tested against natural teeth as antagonists.

Teeth selection:

Fifteen (N=15) human intact maxillary first premolars, extracted for periodontal reasons were collected. Selection criteria included similar crown sizes with well-developed cusps. Premolars with attrited and/or sharp cusps were discarded from the study. Each premolar was sectioned mesio-distaly using slow speed diamond disc (Diatech; Goltène AG, Switzerland) under copious water coolant to obtain crack free buccal cusp.

The obtained cusps were examined by a magnifying lens. Cusps with any sign of cracks were discarded from the study. An optical surface profiler (ZYGO Maxim-GP 200) was used to examine the surface roughness of the cusps to ensure similar baseline roughness values.

All cusps were then thoroughly cleaned with water to remove all attached debris and carefully dried with paper tissue.

Preparation of ceramic samples:

Fifteen standardized cylindrical disc samples (N=15) with 10mm diameter and 3mm thickness were constructed from the selected ceramic materials according to the following procedure:

Preparation of the mock-up acrylic resin disc:

To standardize the size and shape of all ceramic samples, a specially designed copper mold was used to construct an acrylic resin disc (Acrostone, Idustrial area El-Salam City, Egypt) of 10mm diameter and 3mm thickness. The polymer and monomer of the resin were mixed in a glass container according to the manufacturer's recommendations and then packed in the mold. Deficiencies were corrected by adding resin using bead brush technique. After complete curing, the disc was finished and smoothed. Dimensions of the disc were confirmed using digital caliper (Guilin measuring & cutting tool Co., Ltd China).

Preparation of Bruxzir zirconia discs:

Five cylindrical disc samples (n=5) were constructed using Bruxzir zirconia blocks (Glidewell Laboratories, USA). Using the mock-up acrylic resin disc as a pattern; 20% larger discs were milled using S1 VHF (vhf camfacture, Ammerbuch/ Germany) milling machine. Samples were then sintered at 1500^{o}C in Sintramat High Temperature furnace (Ivoclar Vivadent; Bufflo, NY, USA) with a heating rate of 8^{o}C/min and a holding time of 2 hours.

Preparation of e.max CAD discs:

Five cylindrical disc samples (n=5) of e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) were milled using CEREC inLab (Sirona, Bensheim, Germany) CAD/CAM machine. The acrylic mock-up disc was secured on the tray of the inEos scanner (inEos Scanner, Sirona, Bensheim, Germany) then scanned to obtain an optical impression. The ceramic discs were milled accordingly.

The bluish partially-crystallized milled discs were trimmed to remove excess materials at the site of connection with the ceramic block, then inserted into the Programat Furnace (P300, Ivoclar Vivadent AG, Lichenstien Germany) where crystallization process took place at 865^{o}C, according to manufacturer instructions.

Preparation of Enamic discs:

Five cylindrical disc samples (n=5) of Enamic (Vita Zahnfabrik, Bad Säckingen, Germany) were milled using CEREC inLab (Sirona, Bensheim, Germany) CAD/CAM machine using the previously constructed acrylic resin disc as a pattern.

Finishing of the ceramic samples:

After construction, all ceramic samples were polished using rubber disks (Shofu Dental; San Marcos, CA, USA) mounted in a slow speed handpiece. The initial baseline surface roughness of all samples was adjusted to obtain converging initial roughness values in all groups, following the recommendation of Amer et al [31]

Each ceramic sample was thoroughly cleaned with running water then dried with paper tissue. Surface roughness measurements was done using optical surface profilometer (ZYGO Maxim-GP 200), ensuring convergent values of all samples.

Wear simulation:

Quantification of wear process was done by calculating the amount of weight loss of samples (ceramic discs and natural cusps) after wear simulation procedure. [32-35] The weight of each sample was determined before and after wear to calculate the weight loss of each sample (mg). In addition, the surface roughness of the samples was characterized using 3D surface analyzer profiler before and after the two-body wear procedure.

Weighing of the samples before wear simulation procedure:

Each sample (cusps and ceramic discs) was individually weighed before initiation of the wear simulation procedure using electronic analytical balance (Sartorius, Biopharmaceutical and Laboratories, Germany) with an accuracy of 0.0001 gm. This electronic balance had a fully automated calibration technology and a micro weighing scale. To ensure accuracy, the balance was kept on a free-standing table, away from any vibration and each sample was weighed with the glass doors of the balance closed to avoid the effect of air drafts. The weight of each sample was recorded in mg.

Determination of surface roughness

Baseline surface roughness was determined before wear procedure for all samples (cusps and ceramic discs). Samples were photographed using USB Digital microscope with a built-in camera (Scope Capture Digital Microscope, Guangdong, China) connected with an IBM compatible personal computer using a fixed magnification of 120X. The images were recorded with a resolution of 1280 × 1024 pixels per image. Digital microscope images were cropped to 350 x 400 pixels using Microsoft office picture manager to specify and standardize the area of roughness measurement.

The cropped images were analyzed using WSxM software (Ver 5 develop 4.1, Nanotec, Electronica, SL). WSxM software was used to calculate average of heights (Ra) expressed in µm, which can be assumed as a reliable index of surface roughness. [36] Subsequently, a 3D image of the surface profile of the specimens was created using A digital image analysis system (Image J 1.43U, National Institute of Health, USA). The unworn surface served as a reference. With this method, a 3-dimensional geometry of the worn surface was generated.

Two-body wear procedure:

The 2-body wear testing was performed using ROBOTA chewing simulator integrated with thermo-cyclic protocol operated on servo-motor (model ach-09075dc-t, AdTech technology co., Germany). ROBOTA chewing simulator is composed of four chambers moving in a vertical and horizontal movements simulating mandibular movements simultaneously in a thermodynamic condition. Each of the chambers consists of an upper Jackob's chuck to which the tooth antagonist was tightened with a screw and a lower Teflon housing sample holder in which the ceramic disc was embedded.

The chewing simulation test included the application of 5kg (49N) load for 120,000 cycle with vertical movement 1mm, horizontal movement 3mm and frequency 1.6Hz. The load application was associated with thermocycling procedure including the immersion in cold/hot water bath with temperature variation 5^{o}C/55^{o}C and dwell time 60 seconds.

After completion of the wear testing procedure all samples were thoroughly washed then dried with paper tissue. Each sample (cusp and ceramic disc) was weighed again using the electronic analytical balance to obtain the amount of weight loss due to wear.

Moreover, the surface roughness of the samples was evaluated after conducting the wear simulation procedure following the same procedure used for obtaining the baseline roughness and using the same devices at the wear scar.

Statistical analysis

Obtained data was statistically analyzed using (SPSS 16.0 (Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA) for Windows. Data were explored for normality using Kolmogorov-Smirnov test of normality. The results of Kolmogorov-Smirnov test indicated that most of data were normally distributed (parametric data), so one way analysis of variance ANOVA test was used to compare between materials and antagonist cusps, followed by Tukey's post hoc test when the difference was found to be significant. Paired t test was used to compare mean roughness values before and after chewing simulation. The significance level was set at $p \leq 0.05$

RESULTS

Weight loss in mg

a) Weight loss of material:

The greatest mean material's weight loss was recorded in Enamic group, whereas the lowest mean weight loss was recorded in BruxZir group. ANOVA test revealed that the difference between materials was statistically significant (p=0.002). Tukey's post hoc test revealed a significant difference between each 2 groups. (Table 1)

b) Weight loss of antagonist cusp

The greatest mean antagonist weight loss was recorded for e.max antagonist cusp, whereas the lowest mean weight loss was recorded for Enamic antagonist cusp. ANOVA test revealed that the difference was statistically significant (p=0.022). Tukey's post hoc test revealed no significant difference between Bruxzir antagonist cusp and Enamic antagonist cusp. (Table 2)

TABLE (1) Weight loss (mg) of material and significance of the difference between groups using ANOVA test

Material	Mean	Std Dev	Max	Min	F	P value
BruxZir	0.53^{c}	0.17	0.70	0.30	7.831	0.002*
E. maxCAD	0.73^{b}	0.25	1.20	0.30		
Enamic	0.90^{a}	0.20	1.10	0.70		

Significance level p<0.05, *significant

Tukey's post hoc test: means with different superscript letters are significantly different

TABLE (2) Weight loss (mg) of antagonist cusps and significance of the difference using ANOVA test

Antagonist Cusp	Mean	Std Dev	Max	Min	F	P value
Bruxzir	1.67^{b}	0.57	2.30	1.20	4.399	0.022*
e.max	2.13^{a}	0.25	2.40	1.90		
Enamic	1.57^{b}	0.47	2.10	1.20		

Significance level p<0.05, *significant

Tukey's post hoc test: means with different superscript letters are significantly different

II-Surface Roughness (Ra) in μm

a) *Surface roughness (Ra) of material (μm)*

The mean surface roughness increased after wear in all materials. T test revealed that the increase in surface roughness was statistically significant in all groups (p<0.0001, p=0.0024, p=0.011, for Bruxzir, e. max CAD and Enamic respectively).

Comparing surface roughness of all materials after chewing simulation revealed that the highest mean surface roughness was recorded in Enamic and e.max CAD, with no significant between both groups (P=0.553).

Comparing the percent change of surface roughness in all materials after wear revealed the highest mean percent increase was recorded for e. max CAD, while the lowest percent increase was recorded for Enamic, with a significant between both groups (p<0.0001), (Table 3)

b) *Surface roughness (Ra) of antagonist cusp (μm)*

The mean surface roughness increased after wear in all antagonist cusps. T test revealed that this increase was not statistically significant (p=0.222, p=0.1141 for BruxZir and e.max CAD antagonists respectively), while for Enamic antagonist the difference was statistically significant p=0.004).

Comparing all cusps after wear revealed that the highest mean surface roughness was recorded in BruxZir antagonist cusp, with a significant between it and the other 2 groups (p<0.0001).

Comparing the percent change of all cusps after wear revealed the highest mean percent increase in surface roughness was recorded in Enamic antagonist cusps, while the lowest percent increase was in BruxZir antagonist cusp, with a significant difference (p<0.0001), (Table 4).

TABLE (3) Surface roughness (Ra) of material (μm) before and after wear and significance of the difference using ANOVA test

	Before wear		**After wear**		**Percent change after wear**	**Significance of increase**	
Material	Mean	Std Dev	Mean	Std Dev		t value	P^2 value
Bruxzir	0.250	0.003	0.258	0.001	$3.18^{b}\pm1.05$	8	<0.0001*
E.max CAD	0.250	0.004	0.260	0.008	$3.92^{a}\pm0.95$	3.53	0.0024*
Enamic	0.256	0.002	0.260	0.001	$0.79^{c}\pm0.34$	2.83	0.011*
F value			0.606		78.011	-----	
P^1 value			0.553^{ns}		<0.0001*		

P1=Significance of the difference between materials after wear and significance of difference between increase surface roughness in different materials

P2=Significance of Difference between after and before for each material

Significance level p<0.05, *significant

Tukey's post hoc test: means with different superscript letters within the same column are significantly different

TABLE (4) Surface roughness (Ra) of antagonistic cusps (μm) before and after wear and significance of the difference using ANOVA test

	Before wear		**After wear**		**Percent change after wear**	**Significance of increase**	
Antagonist cusp	Mean	Std Dev	Mean	Std Dev		t value	P^{2} value
Bruxzir	0.263	0.004	0.265^{a}	0.003	$0.73^{c}\pm0.22$	1.2649	0.222^{ns}
E.max CAD	0.252	0.007	0.256^{b}	0.003	$1.94^{b}\pm0.56$	1.6609	0.1141^{ns}
Enamic	0.248	0.005	0.256^{b}	0.003	$2.98^{a}\pm0.97$	4.339	0.004*
F value			30		29.2	-----	
P^{1} value			<0.0001*		<0.0001*		

P1=Significance of the difference between materials before wear, after wear and significance of difference between increase in different cusps

P2=Significance of Difference between after and before for each cusp

Significance level p<0.05, *significant

Tukey's post hoc test: means with different superscript letters within the same column are significantly different

DISCUSSION

"Wear" is defined as the loss of a substance due to continual use. In dentistry; it occurs when two articulating surfaces undergo slipping and sliding frictional movements against one another while a load is applied causing progressive loss of substance through mechanical action. (37)

Dental materials should ideally present wear behavior similar to that of enamel so as not to cause abrasive damage to antagonistic teeth (19) thus avoiding occlusal disturbances resulting from major differences in wear behavior. (38) Excessive wear of teeth, restorations or the entire dentition may be associated with supra eruption of opposing teeth, periodontal breakdown, traumatic occlusion, loss of vertical dimension and even temporomandibular joint dysfunction. (39)

Clinical in-vivo tests are essential for estimating the complex wear performance of dental materials. However, such in vivo evaluations are often restricted by high costs and high variability among patients because individual chewing forces or ambient conditions cannot be sufficiently controlled. (40) In contrast, in vitro studies may not only allow the investigation of single parameters of the wear process but also a comparative evaluation of different materials under standardized conditions is possible.

To closely mimic in-vivo wear testing; a variety of in vitro wear testing systems have been introduced to model in vivo wear through different testing parameters. Clinical measurement of the in vivo forces of mastication indicated that the normal range of forces for a single molar lies between 20 and 140 N. In addition to the initial impact when opposing teeth first contact, there is a sliding phase of mastication that has been measured between 0.9 and 2.86 mm. (41) Thus, a chewing force of 50 N, applied with a frequency of ~ 1–1.6 Hz, presents the average mastication load (19) and is commonly used for oral simulation. (19, 42) In the present study, a chewing force of 49N at 1.6Hz frequency was used to test the two-body wear performance of the tested materials.

During mastication, wear occurs by three-body abrasion when food particles are interposed between teeth and two-body abrasion after the food has been cleared and during parafunctional habits such as bruxism. This tooth contact is lubricated by saliva except in cases of severe xerostomia and hyposalivation. [(43)]

To simulate the two-body wear that occurs in the occlusal contact area, several types of devices were used ranging from simple pin-on-disc tests to sophisticated chewing simulators. [(44,45)] No matter how sophisticated the device is; the basic idea included the tested material opposed by an antagonist. Previous studies used different types of antagonists as metal, hydroxyapatite, bovine enamel, or human enamel, depending on the methodology employed. [(46)]

In the present study, enamel antagonists were used in an attempt to simulate clinical situations. Enamel antagonists were used to conduct several similar in-vitro studies. [(30, 31, 41, 47)] However, using enamel antagonist was sometimes criticized due to morphological and structural differences among enamel samples which makes standardization difficult.[(30)] To decrease the amount of in-homogeneity; standardization of enamel samples through grinding and polishing was sometimes suggested. [(19, 46)] The standardization procedure included grinding the cusp tip to achieve the desired shape. [(48)]

Buccal cusps of upper first premolars that did not show signs of abrasion on their tip were used to conduct this study as the 'antagonist' samples, with no standardized polishing or grinding procedure. Studies which used standardized enamel antagonists have reported that standardization of enamel did not reduce variability among wear results. [(46, 49)] Enamel hardness decreases on moving closer to the dentin-enamel junction, and it is hardest at the enamel surface. [(50)] Therefore, removing the hard enamel surface during standardization will affect the wear properties and will not simulate the clinical situations.

In the present study, the wear behavior of three types of monolithic CAD/CAM ceramics was tested against enamel antagonists. The three materials selected were: a recently introduced monolithic zirconia, Bruxzir, claimed to be kinder on opposing dentition such that it can be used for bruxism patients, a lithium disilicate based glass ceramic; e.max CAD, and a hybrid ceramic; Enamic. All tested materials received a polishing procedure which aimed at reaching similar degree of baseline surface roughness. To ensure standardization, baseline roughness measurements for all samples were obtained prior to conducting wear test to ensure that all samples have convergent baseline surface roughness values (tables 3 and 4). This procedure was suggested in a study conducted by Amer et al [(31)] who recommended standardization of the initial Ra values of all samples, regardless of the finishing method used, instead of standardization of polishing procedure, time and pressure.

Polished ceramic surfaces have been reported to be equal or surpass the smoothness accomplished with surface glazing. [(51)] It was reported that the formed glaze layer is usually worn out within the first six months after the insertion of the restoration, [(17)] uncovering the restoration's deeper layer. The antagonist hitting the rough surface might lead to increased contact wear if a longer simulation program would have been conducted. [(52)]

Wear was quantified in the present study based on the amount of weight loss. It was calculated based on the difference between the initial weight (before chewing simulation procedure) and the final weight (after chewing simulation procedure), for each sample. [(32-35)] Different methods were employed for in-vitro quantification of wear among different studies making comparison difficult. Calculations of volume loss and height loss were among the widely-used methods. [(41, 46, 47)] However, Heintze et al [(53)]

tested different methods used for the quantification of the in vitro wear of dental materials and found that all measuring principles were suitable for the quantification of the wear generated on flat samples.

Regarding the material loss after chewing simulation; Enamic samples showed the statistically significant highest material loss while BruxZir showed the statistically significant lowest material loss, table (1), suggesting that zirconia was the most resistant material to wear degradation. This result is in accordance with other studies, (27, 47,54,55) in which zirconia proved to be resistant to loss by wear when it was compared to different restorative materials. Moreover, polished zirconia-based ceramics showed no material loss after chewing simulation against enamel and steatite in other studies. (19, 30) Ceramics with higher crystal content as zirconia show greater wear resistance compared to ceramics with less crystalline content. (56-58)

On the other hand, regarding the antagonist cusp weight loss after chewing simulation, the least mean weight loss was recorded in antagonists cusps of Enamic and BruxZir with no statistically significant difference between the two materials, table (2). Antagonist cusps of e.max CAD recorded statistically significant higher weight loss values. Smoothly polished zirconia caused also less wear in antagonist enamel compared to lithium disilicate glass ceramics in other investigations. (19, 27, 48, 54)

When ceramic slides against ceramic or enamel, wear does not occur by plastic deformation, as with metals, but by fracture. (59) The microfracture mechanism is the dominant mechanism responsible for the surface breakdown of ceramics after being subjected to wear simulation procedures. (60) Fracturing of ceramic's surface roughens the surface and releases wear fragments, accelerating the wear of opposing enamel. (59) In glass ceramics, as e.max CAD used in the present study, lower strength matrix is worn-out by fracture prior to the high strength crystals which will then act as asperities causing further wear of the antagonist enamel. (61) These asperities will themselves fracture after further conduction of the wear test as they are also brittle causing the process to be repeated thus resulting in material loss. (61) Meanwhile, glass particles that detach during the wear process behave as an abrasive medium and lead to a 3-body wear mechanism. (62) However, polycrystalline ceramics as zirconia, are less susceptible to fracture due to their high mechanical properties thus produce less wear of opposing enamel, (41) in accordance of the results of the present study, table (2).

Hence, the possible explanation of superior wear of BruxZir compared to e.max CAD is that zirconia is less susceptible to the microfracture mechanism than glass ceramic because of the much higher fracture resistance of zirconia. The fracture toughness of the material is a key to the prevention of cracking. (63) Consequently, under the same condition of wear process, the microcrack is probably more difficult to propagate through the crystalline structure of zirconia compared to e.max CAD. (48)

In addition; grain size and porosity are two important microstructural parameters which may affect the mechanical and tribological performance of the ceramic. (64) A decrease in the ceramic's grain size causes an increase in its wear resistance. (65, 66) On investigating the grain size of different ceramic materials; Amer et al (31) found that Y-TZP had the smallest grain size among the tested ceramics (0.4 μm compared to 2 μm for lithium disilicate). He et al (66) reported that Y-TZP exhibits a Hall-Petch type of wear resistance relationship at grain sizes of ≤0.7 μm. Decreasing the zirconia grain size to 0.7 μm or smaller will make the material much more wear resistant by increasing the energy needed to remove the grain from the matrix of the ceramic. Based on this finding, the manufacturers of Bruxzir zirconia claims that this type of zirconia is wear resistant and kinder to the opposing dentition as it has a smaller grain size that it can be used as a restoration for bruxism patients. (12)

On the other hand, the statistically significant highest material weight loss was recorded by Enamic samples indicating that it was the most affected material with the wear procedure conducted. The same result was obtained by Dupriez et al(55) and Zhi et al. (67) Furthermore, Mörmann et al (68) stated that wear performance of Enamic combines the wear characteristics of ceramic and composites as it contains 25% polymer and 75% ceramic matrix. (69, 70) The ceramic matrix is mainly leucite-based silicate glass while the polymer component is composed of PMMA. (14)

Researches investigating the wear of resin based restorations suggested lower wear resistance of these materials when compared to ceramics. (67,71, 72) Thus, the polymer matrix within the hybrid ceramic wore before the ceramic contents leading to increased weight loss of this group.

The high resilience of Enamic compared to ceramics also affects the response of the material to repetitive loading during chewing simulation. (73) Cyclic stresses fatigue failure or creep rupture cause spallation process in the surface of resilient materials. (55) Because the modulus of crystals is much higher than that of the matrix, subsurface microcracks preferentially form along the crystal boundaries and coalesce into a crack network. (74) In addition, the presence of water is known to enhance the failure due to a chemical reaction between water molecules and ionic-covalent bonds of the material. Hydrolysis of silane in water during thermocycling procedure associated with chewing simulation might have caused low bonding at the crystal boundary favoring the release of polymer matrix. (55)

Enamel wear caused by restorative materials is also a multifactorial condition. Over the previous decades, many studies have attempted to determine which factors affect the wear of human enamel caused by these materials. (60,75) Surface roughness, hardness, and fracture toughness of opposing restorative materials are some of the contributing factors that determine enamel wear caused by ceramics. (60)

Being brittle, enamel wears by microfracture of the organic phase matrix followed by fracture of hydroxyapatite crystals. (46) However, the wear pattern consists of chips, not scratches as ceramics. The chipping occurs because enamel is stressed transversally to its prismatic orientation. (76)

Surface roughness is one of the factors that increase coefficient of friction and wear of the opposing surfaces. It can also be considered as a result of the wear process. In the present study, all samples (cusps and ceramic discs) were finished until roughness was adjusted to 0.250±0.02um so that a comparison of the surface roughness after chewing simulation could be processed. It was previously reported that patients can identify differences at surface roughness of 0.5 µm or more. (77)

Furthermore, weight loss of antagonist cusps occurring after wear procedure applied in the present study, (table 2), can be also attributed to the increased surface roughness which occurred in all tested materials after chewing simulation, (table 3). The coefficient of friction, which increases by surface roughness, has been reported to result in greater wear of the antagonist. (78) An in vitro study by Kadokawa et al (79) showed that the wear rate of enamel when opposed to a smooth porcelain surface was significantly lower than when opposed to a rough porcelain surface.

However, some authors questioned the use of roughness parameter to evaluate surface degradation resulting from wear processes as degradation is a time dependent phenomenon, thus values may change according to the parameters of chewing simulation procedure and the stage of measuring, making comparison among studies difficult. (80,81)

In the present study, weight loss of cusps opposing

Bruxzir and Enamic was lower than that opposing e.max CAD, with no significant difference between the two antagonist cusps. This can be attributed to the fine crystalline structure of the former, hence, the zirconia surface remains smoother because fewer microfractures occur during abrasive wear, and the presence of the 25% polymer matrix in the later, as previously indicated.

As e.max CAD recorded the statistically highest percent change in roughness after the wear procedure applied, its opposing cusp recorded the highest weight loss among tested cusps. While BruxZir recorded lower percent change in roughness; lower amount of weight loss was recorded for its antagonist cusps. These results coincide with those obtained by Sripetchdanond and Leevailoj, [48] indicating that when the roughness of the restorative material is increased due to the formation of asperities as a result of wear, opposing cusps are adversely affected. This relationship was previously verified in other studies. [54, 77, 82] The physical and micro-structural characteristics, chemical degradation, and surface roughness of ceramics affect wear between ceramics and enamel. [59] Higher enamel wear caused by glass ceramic might also arise from the formation of wear debris. Glass particles that detach during the wear process might behave as an abrasive medium and lead to a 3-body wear mechanism. [62]

Furthermore, Enamic samples yielded the statistically significant lowest percent change of surface roughness values, table (3). This result does not necessarily indicate that no surface degradation had occurred in Enamic samples after wear procedure as they recorded the significantly highest material loss after chewing simulation. Zhi et al [67] reported the formation of a smooth surface layer on Enamic after chewing simulation. Provided that all samples were subjected to the same wear procedure, surface roughness of Enamic samples might have undergone successive stages of increased and decreased roughness. A lower surface roughness of samples does not necessarily represent lower surface degradation, but it can represent a gradual and uniform loss of reinforcing crystal alternating with loss of polymer matrix. This assumption is reinforced by the results of the antagonist cusp weight loss, table (2) coupled with roughness values, table (4) where the significantly highest percent change of roughness and the least amount of weight loss were obtained for cusps opposing Enamic samples. Hence, while Enamic did not cause weight loss of its antagonist cusp, it has caused increased roughness of its surface. Confirmation of this assumption could have been possible if the number of chewing simulation cycles had been increased. Meanwhile the significantly highest percent change in surface roughness recorded by Enamic antagonist cusps, table (4), resulted in the significantly highest weight loss recorded by Enamic samples, table (1).

Although simulation of the clinical situation was followed during the course of the present study; in vitro studies need to be reinforced with clinical studies. However, in-vitro studies are useful in ranking restorative materials under standardized conditions. As results from different studies depend on the experimental conditions created to simulate clinical wear, it would have added to the depth of information obtained from the present study if measurements were conducted at different stages of wear simulation.

CONCLUSIONS

Within the limitations of the present study the following can be concluded:

Monolithic hybrid ceramic (Enamic) and zirconia (BruxZir) produce less wear in opposing teeth compared to lithium disilicate based ceramics (e.max CAD). However, hybrid ceramic show material loss due to wear. Surface roughness of the restorative material can be correlated to its wear behavior, yet further investigation is required.

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