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Comparison of Two Body Wear Resistance of Novel Strength-Gradient Monolithic Zirconia with Two Different CAD/CAM Materials

Zeynep Arıkan, Zeliha Şanıvar Abbasgholizadeh, Yılmaz Umut Aslan, Yasemin Özkan

Department of Prosthodontics, Faculty of Dentistry, Marmara University, Istanbul, Türkiye.

Correspondence Author: Zeynep Arıkan
E-mail: dtzeyneparikan@gmail.com
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ABSTRACT

Objective: Novel strength-gradient monolithic zirconia is a developed material recently introduced to the market and its mechanical properties should be investigated in vitro. The aim of the study is to compare the wear rates of three different CAD/CAM materials with a chewing simulator after one year of dynamic loading.

Methods: 7x7x3 mm discs were prepared from lithium disilicate, strength-gradient monolithic zirconia, and zirconia-reinforced lithium silicate glass ceramic. Both groups were divided into two subgroups (n=12) as glazed and mechanically polished.

The samples were scanned with a laser scanner device (SD Mechatronic Laser Scanner LAS-20, Westerham, Germany) to determine the amount of wear. The samples were placed in a chewing simulator (SD Mechatronic Chewing Simulator CS-4.2, Westerham, Germany) for 240 000 cycles which is equivalent to 1 year of clinical use. After the dynamic loading in the chewing simulator, the samples were scanned again in the laser scanner, and the data was obtained. Kruskal Wallis test was used to analyze the data.

Results: The amount of wear of each material was found to be statistically significant ($p<.05$). No significant differences between the polished and glazed groups of Zir and LD were found but glazed CD was significantly more wear-resistant than polished CD ($P<.05$).

Conclusions: Wear is a phenomenon that can be affected by different factors such as microstructure and surface finishing of the materials. Wear resistance should be taken into consideration when choosing a material.

Keywords: Strength-gradient monolithic zirconia, zirconia-reinforced lithium silicate, lithium disilicate, wear

1. INTRODUCTION

Due to their advantageous qualities, computer-aided design and computer-aided manufacturing (CAD-CAM) materials are being utilized more frequently (1,3), as the demand for monolithic restorations has been rising (4-7). Due to its high flexural strength, excellent mechanical properties, and enhanced translucency, lithium disilicate glass-ceramic has gained popularity for all-ceramic restorations (2,8,9). Full ceramic restorations eliminate the majority of the complications occurred in first-generation zirconia restorations such as chipping of veneering porcelain, delamination, and fracture (2,5,10). In addition, the need for excessive tooth preparation was also eliminated due to decreased thickness of monolithic restorations. Lithium disilicate being the superior restorative material in the dental market, forced manufacturers to develop aesthetically pleasing CAD/CAM monolithic materials with similar indications and properties. These materials are strength-gradient zirconia and zirconia-reinforced lithium silicate ceramic (5).

Zirconia-reinforced lithium silicate ceramic (ZLS) had 10% dissolved zirconia embedded in a silica-based glass matrix to combine beneficial characteristics of zirconia and glass ceramic (8,9,11,12). Although ZLS does not require heat treatment for the crystallization of the material, it has been reported that fired ZLS has stronger flexural strength than milled ZLS (3,12).

Conventional dental zirconia (3Y-TZP; 3mol% Yttria-stabilized Tetragonal Zirconia Polycrystal) is not particularly translucent or aesthetically pleasing (10). Strategies such as reducing the amount of aluminum oxide (Al_2O_3), increasing the yttria content, and controlling the sintering temperature have been developed to improve its translucency (13-18). Currently, 3Y-, 4Y, and 5Y-TZP (%mol yttria-stabilized zirconia) zirconia grades are available for monolithic restorations. In general,

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the cubic content and translucency increase with increasing yttria content. However, this also results in a decrease in strength and toughness (14). Strength-gradient zirconia has been introduced to the market to further enhance the aesthetic qualities of zirconia restorations by integrating the beneficial properties of several zirconia grades. In the base layer of the material, which functions as a strong framework for the cervical part of the restoration, a stronger 3Y-TZP or 4Y-TZP is used. The more translucent 5Y-TZP is placed in the top layers, coinciding with the restoration's incisal or occlusal part (15). Even though these strength-gradient zirconia blanks are currently on the market, there is relatively limited scientific information on these materials.

The phenomenon of wear is a physiological process; any restoration material could influence the wear rate of the opposing teeth (4). Surface pretreatment is an important parameter affecting the wear resistance of a material (2,19). Typically, pretreatment consists of polishing and/or glazing to obtain a homogenous surface for both oral health and aesthetics (20). Polishing has become even more crucial as a result of the development of CAD/CAM technology, which has made it possible to provide restorations in just one appointment (5).

The aim of this study is to examine the in vitro two-body wear resistance of ceramic materials (strength-gradient zirconia, lithium-disilicate, zirconia-reinforced lithium silicate ceramic) after two different surface pretreatment procedures. The first hypothesis was that the wear resistance of the established materials would not be different when opposing monolithic zirconia; the second hypothesis was that different pretreatments would not influence the wear resistance of the materials.

2. METHODS

Three monolithic ceramics were examined: strength-gradient monolithic zirconia ([Zir], IPS e.max ZirCAD Prime, Ivoclar, Schaan, Liechtenstein), a lithium-disilicate ([LD], IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), and a zirconia-reinforced lithium silicate glass ceramic ([ZLS], Celtra Duo, Dentsply Sirona, Bensheim, Germany) listed in Table 1. For each material, a total of 24 disk-shaped samples (n = 24, N = 72) were manufactured.

Table 1. *Materials used in study*

Material	Classification	Composition	Manufacturer
IPS e.max CAD	Lithium disilicate ceramic	57%-80% SiO_2, 11%-19% Li_2O, 0%-13% K_2O, 0%-11% P_2O_5, 0%-8% ZrO_2, 0%-8% ZnO, 0%-5% Al_2O_3, 0%-5% MgO	Ivoclar Vivadent AG
IPS e.max ZirCAD Prime	Strenght-Gradient Monolithic Zirconia	Tetragonal polycrystalline zirconia with 3mol, 4mol, 5mol-%yttria	Ivoclar Vivadent AG
Celtra Duo	Zirconia-reinforced lithium silicate ceramic	Lithium silicate with 10% $Zr0_2$	Dentsply Sirona

2.1. Specimen Preparation

LD and CD blocks were cut into disks (7x7x3 mm) with a precision saw (IsoMet 1000; Buehler, IL, USA), polished with silicon abrasive papers (400-, 600-, 800-, 1200-grit papers; 3M, MN, USA) by a mechanical polishing machine (Presi Minitech, Eybens, France) at a constant speed of 300 rpm under water irrigation. LD samples were then crystallized (850◦C for 10 min at a heating rate of 30◦C/min) following the manufacturer's instructions in a ceramic oven (Programat P310; Ivoclar Vivadent, Schaan, Liechtenstein). The zirconia specimens were milled from disks and were sintered in a furnace (Mihm-Vogt HT, Mihm-Vogt & Co KB, Stutensee, Germany) for 2 hours at 1550 ^{0}C.

Specimens were then subdivided into two groups (n = 12 per subgroup) undergoing different pretreatments: 1) polishing (P), 2) glazing (G). LD and ZLS specimens were polished with a three-step polishing system (DIAPOL® RA, EVE Ernst Vetter GmbH, Keltern, Germany), and IPS e.max ZirCAD Prime specimens were polished with a two-step polishing system (DIACERA RA, EVE Ernst Vetter GmbH, Keltern, Germany). DIAPOL® RA and DIACERA RA polishing kits (EVE Ernst Vetter GmbH, Keltern, Germany) were used at a constant of 10 000 rpm for 30 seconds. The same operator carried out all the manual finishing and polishing procedures. The manufacturer's recommended glazing material was used on each ceramic and samples were fired in a ceramic oven (Programat P310, Ivoclar Vivadent, Schaan, Liechtenstein; Multimat Cube, Dentsply Sirona, Bensheim, Germany) respectively.

Seventy-two monolithic zirconia (GC Initial Monolithic Zirconia, GC, Leuven, Belgium) antagonists which are in a form of a rounded triangular prism with a round tip of 3 mm in diameter were designed (SolidWorks 3D CAD, SolidWorks Corporation, Waltham, MA, USA), milled (inLab MC X5, Dentsply Sirona, Bensheim, Germany), and sintered (Mihm-Vogt HT, Mihm-Vogt & Co KB, Stutensee, Germany) for 2 hours at 1550 ^{0}C. The antagonists were then polished in a mechanical polishing machine with silicon carbide abrasive papers (400-, 600-, 800-, 1200-grit papers; 3M, MN, USA) and DIACERA RA polishing kit (EVE Ernst Vetter GmbH, Keltern, Germany) respectively.

The specimens and the antagonists were placed in metal holders with an auto-polymerizing acrylic resin (Imicryl, Konya, Turkey) and stored in distilled water at 37 ^{0}C for 24 hours before testing.

2.2. Wear Evaluation

A dual-axis computer-controlled chewing simulator (CS-4.2, SD Mechatronik GmbH, Westerham, Germany) was used for the two-body wear simulation. The specimens were fixed to the lower rotating component of the machine, whereas the antagonists were fastened to the upper stationary part. The equivalent of 1 year in vivo which is a total number of 240 000 cycles was applied with a vertical load of 50 N, and a lateral movement of 0.6 mm with a frequency of 1.6 Hz. The wear procedure was performed in distilled water simultaneously thermocycling between 5 ^{0}C and 55 0C. The parameters used for the chewing simulation are presented in Table 2.

Table 2. *Settings of Parameters for the Wear Resistance Protocol*

Parameter	Value
Number of cycles	240 000
Load	50 N
Lateral movement	-0.6 mm
Descendent speed	30 mm/s
Lifting speed	55 mm/s
Feed speed	30 mm/s
Return speed	55 mm/s
Temperature	5 ^{0}-55 ^{0}C
Frequency	1,6 Hz

Each specimen was scanned with a three-dimensional (3D) laser scanner (LAS-20, SD Mechatronik GmbH, Westerham, Germany), antagonists were wetted with scan powder (Matte Spray, Creamagna Chemicals, İstanbul, Turkey) and scanned with a dental lab scanner (inEos X5, Dentsply Sirona, Bensheim, Germany) before and after undergoing the chewing test to acquire standard tessellation language (STL) files. Data were superimposed (Fig 1) to calculate the volumetric loss (mm^3) and wear depth (mm) of each specimen and the volumetric loss (mm^3) of their antagonists using a surface analysis program (Geomagic Control of 3D Systems, SD Mechatronik, Westerham, Germany).

2.3. Statistical Analysis

IBM Statistical Package for Social Sciences V23 software (IBM Corp, New York, USA) was used to complete the statistical analysis. Data's normality was determined by the Kolmogorov-Smirnov test. The correlation between volume loss (mm^3) and wear depth (mm) was analyzed by Kendall's Tau-b test. The wear data were evaluated using the Kruskal-Wallis and Mann-Whitney U test, with the statistical significance set at $p < .05$.

3. RESULTS

Table 3 shows every material and antagonist's mean values, standard deviations, and statistical results. Kruskal-Wallis confirmed statistically significant differences in volume loss and wear depths among all materials ($p < .05$) (Fig 2). The lowest mean volume loss (0.020±0.018 mm^3) was found for Z, followed by LD (0.060±0.036 mm^3). CD showed the highest mean volume loss of 0.066±0.041 mm^3. Kendall's Tau-b correlation test indicated a 90% positive correlation between volume loss and wear depth ($p < .01$). No significant difference was found between the antagonists' volume loss and wear depths ($p > .05$). No significant differences between the polished and glazed groups of Zir and LD were found however, glazed CD was significantly more wear-resistant than polished CD ($p < .05$).

Table 3. *Mean values (and Standard Deviations) for Volume Loss and Wear Depth*

Material	Volume Loss (mm^3)	Wear Depth (mm)	Antagonist Wear (mm^3)
ZirP	0.016 ± 0.012^a	0.003 ± 0.002^x	0.002^y
ZirG	0.025 ± 0.022^a	0.003 ± 0.002^x	0.003^y
LDP	0.072 ± 0.042^b	0.048 ± 0.029^y	0.002^y
LDG	0.049 ± 0.026^b	0.032 ± 0.024^y	0.003^y
CDP	0.082 ± 0.031^c	0.050 ± 0.025^z	0.002^y
CDG	0.050 ± 0.045^d	0.028 ± 0.029$^\alpha$	0.002^y

[a] *Same letters indicate no statistically significant differences for the same column (p = .05).*

4. DISCUSSION

This study examined the wear resistance of CAD/CAM ceramic materials and zirconia antagonists. The effect of the material in terms of wear resistance was significant, therefore the first null hypothesis was rejected. The second null hypothesis was that surface pretreatment did not affect the materials' wear resistance. This hypothesis was partially accepted, except for CD group.

It is crucial for a restorative material to have similar mechanical properties to the enamel. An acceptable wear pattern of restorative materials should represent the physiological wear of natural teeth (3). Over the decade, many studies have compared the wear of lithium disilicate to the gold alloy which is known for its similar wear behavior to that of enamel (21). The wear resistance of lithium disilicate has also been compared with zirconia in the literature (3,22-25). Therefore, in this study the wear resistance of novel strength-gradient monolithic zirconia and zirconia-reinforced lithium silicate materials have been compared to lithium disilicate. In the present study, LD was more wear-resistant than CD with its antagonist as zirconia. Ozkir et al (22) and Matzinger et al (24) both found LD to be more wear-resistant which is consistent with the results of the present study. On the contrary, other studies have reported similar wear behaviors between LD and ZLS (1,4,5,26). Differences in results may be due to the mechanical differences between polished ZLS and glazed ZLS.

Lithium disilicate is a material that needs to be crystallized which increases the production time and cost of a restoration. In opposition to this, ZLS-based Celtra Duo was developed and advertised in the market as a material that does not need crystallization and can be mechanically polished and adhesively luted just after occlusal adjustment in the same session. Due to this benefit, CD is particularly well suited for the chairside fabrication of indirect restorations. However, Celtra Duo benefits from a glaze firing cycle because it enhances its aesthetics and increases its flexural strength from 210 MPa to 370 MPa (3). In two studies that investigated the wear resistance of CD both after grinding and after an additional glaze firing cycle for six months in vivo, glazed CD exhibited a wear resistance similar to LD and gold alloy whereas the wear resistance of ground CD was found to be statistically different from LD and gold (3,21). The present study also found that glazed CD was significantly more wear-resistant than polished CD. These findings suggest that the glaze firing cycle results in increased wear resistance of ZLS-based materials.

The majority of the studies that have examined the wear resistance of monolithic zirconia used 3Y-TZP. Few studies have investigated the wear behavior of 4Y-TZP and 5Y-TZP, however, there is limited information on the wear properties of strength-gradient zirconia in the literature. Regardless of their yttria content, fracture toughness, or strength, different generations of zirconia gave rise to minimal and comparable wear behaviors (10,27,28). Similarly, Zir exhibited significantly higher wear resistance as compared to other ceramic materials which complies with previous studies that reported consistent results on the high wear resistance of zirconia (2,10,29-31). Zir's strong wear resistance, similar to that of 3Y-TZP, suggests that microstructural differences between zirconia generations are likely to have little impact on wear behavior (32). However, differences in material properties, such as hardness, modulus of elasticity, or flexural strength play a role in the wear behavior of CAD/CAM materials (24).

The surface finish of zirconia, achieved by mechanically polishing or glazing, is an important determinant of its and antagonists' wear properties (33). It has been stated that when the antagonist comes to contact with the restoration, the friction causes the 20 to 50 µm superficial glaze layer to wear revealing the underlying ceramic. If the underlying ceramic is not mechanically polished, its surface roughness is more likely to be higher which increases the wear on both the material and the antagonist (2,19,33,34). The present study showed no significant differences between the wear of glazed Zir and polished Zir. Many studies comparing the wear behavior of glazed and polished zirconia detected higher volume loss and wear depth on glazed specimens (2,19,33-36) however Çakmak et al (1) stated that glazing or polishing did not affect the wear resistance of the material or its antagonist. Similar to the present study, Çakmak et al (1) tested the materials for approximately 1 year in vitro. On the other hand, studies that found significant results tested their materials for longer periods of time up to 5 years in vitro (2,19,34). Determining which pretreatment yields the optimal results is difficult to say because different test parameters and periods of time, chewing simulators, and tested materials give different results.

Intraoral tribology has a complex mechanism that is challenging to mimic hence the in vitro methods for the evaluation of wear have greatly differed from one another. In vitro evaluation of wear is directly dependent on the testing conditions such as load, frequency, lubricant, antagonist, and time. It has been stated that cycle numbers under 5000 were insufficient to measure the wear of zirconia (37), therefore in the present study, the equivalent of 1 year of mastication which is 240 000 cycles were performed. The adjustment of the chewing simulator directly affects the observed wear rate. Heintze (38) stated that vertical biting force ranges between 20 to 120 N, and was affected by different factors such as the region of the mastication in the oral cavity, the hardness of the food, and the age of the patient. In order to match physiological parameters and achieve a clinically accepted intraoral simulation, the occlusal load was selected as 50 N applied with a frequency of 1.1 Hz with a lateral movement of 0.6 mm. During the chewing movement, the temperature fluctuates intraorally hence thermocycling with temperature differences between 5 and 55^{0}C was applied simultaneously by using distilled water as a lubricant (22). Distilled water also acted as an agent to remove debris, decreasing the friction in the medium (22).

There is no set method for the use of antagonist material in wear test mechanism protocols in the literature (24). Numerous research has imitated clinical conditions for the relationship between the natural tooth and its antagonist using steatite (10,25,39), aluminum oxide (22), stainless steel (2), zirconia (3,29,40), or human enamel (1,41,42). Due to variations in enamel thickness, mineralization, cusp anatomy, and morphology, human enamel is prone to inhomogeneities. Moreover, extensive preparation and alteration are required in order to standardize enamel, which further reduces the validity of the test results (43). Therefore, as proposed in the literature (38), monolithic zirconia cusps that were 3 mm in diameter (3) were used in the present study to accurately assess the wear of CAD/CAM restorative materials in standardized experimental conditions. Throughout the whole test period, they kept their shape, which minimized the impact of any changes to the antagonist surface on specimen wear (44), and no difference was found between the volume loss and wear depths of the antagonists (3,21,45) ($p>0.05$).

The present study evaluated the wear properties of novel strength-gradient monolithic zirconia and zirconia-reinforced lithium silicate in comparison to lithium disilicate. One of the limitations of this study is that the control group was identified as lithium disilicate as opposed to enamel. In addition, monolithic zirconia was used as an antagonist material in this study. In order to make a better deduction about the wear resistance and abrasiveness of these materials, enamel and other various restorative materials are needed in comparison to the materials and also as antagonists. Lastly, 240 000 masticatory cycles were performed which was equivalent to 1 year in vivo. Further research may be conducted investigating the effect of prolonged times of mastication to the wear resistance of these materials.

5. CONCLUSION

The current technique showed that when subjected to simulated chewing cycles, various materials exhibit statistically significant wear resistance characteristics.

Strength-gradient zirconia is a new material in the market. Further research that investigates the wear resistance and wear pattern of strength-gradient zirconia for extended time periods both in vitro and in vivo is needed.

Even though Celtra Duo can be mechanically polished and cemented right after milling, it is advised to be subjected to a glaze firing cycle to slightly increase its mechanical and esthetic properties, and wear resistance.

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