Two-Body Wear Resistance of Three Different Lithium Disilicate, and One Zirconia Reinforced Lithium Silicate CAD/CAM Materials

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Abstract

This in vitro study performed a two-body wear test on four different chair-side CAD/CAM ceramic materials. The study aimed to compare wear resistance between three lithium disilicate and one zirconia reinforced lithium silicate CAD/CAM material, in terms of the volume loss. Six flat square specimens (8 x8 x4 mm^3) were prepared from each IPS emax CAD (EM), n!ce (NI), Amber Mill (AM), and Celtra Duo (CD) CAD/CAM blocks. Only EM and AM specimens were crystallized using a furnace following the manufacturers' instructions. Spherical steatite ceramic with a diameter of 6 mm was used as an antagonist. The specimens and antagonists were embedded in the wear simulation holder using auto-polymerized acrylic resin to secure the specimen and stored in deionized water at 37°C for 7 days before wear testing. The simulated two-body wear was performed using a chewing simulator (120,000 cycles, 50 N, 1.34 Hz, sliding movement 0.5 mm). The volume loss of the specimen was measured after 120,000 cycles using a contact profilometer. The height loss of the antagonist opponent was measured using a stereomicroscope and the volumetric loss was calculated. Data were analyzed with one-way ANOVA, followed by Tukey or Games-Howell post-hoc analysis ($\alpha = 0.05$). The highest specimen volume loss was EM (0.51±0.10 mm^3), followed by CD (0.48±0.06 mm^3), NI (0.27±0.03 mm^3), and AM (0.10±0.02 mm^3), respectively. The result of statistical analysis in volume loss showed significant differences among materials ($p < 0.001$). Post hoc analysis revealed that EM demonstrated a significantly greater volume loss than AM and NI ($p < 0.05$) but showed comparable to CD ($p > 0.05$). For the steatite antagonist, the steatites opposed to NI demonstrated the least antagonist volume loss compared to the others ($p < 0.05$). The wear behaviors and wear resistance of glass-ceramics were influenced by their mechanical properties and microstructure, such as crystal size and crystal volume fraction. New lithium-based glass-ceramic materials, especially n!ce, showed better wear resistance and caused less abrasion to antagonists when compared with IPS emax CAD.

Keywords: *two-body wear test, wear resistance, CAD/CAM, chewing simulator, ceramics*

1. Introduction

Computer-aided design and Computer-aided manufacturing (CAD/CAM) technology have grown in popularity in recent years as a result of well-designed and user-friendly devices. The fast fabrication process facilitates single-visit restoration delivered. Furthermore, the materials could be used as a monolithic restoration due to the enhanced restorative strength. However, it is unavoidable that the prosthetic surfaces have to be subjected to a wear mechanism during mastication.

The common mechanism of wear in the oral cavity is abrasive wear which can be classified into two types: two- and three-body wear (Tsujimoto et al., 2018). Two-body wear usually occurs at the occlusal contact area. The antagonists directly occlude on each other, so-called attrition. Three-body wear usually presents a non-contact area with the presence of third body particles between the occluding surfaces, for example, toothbrushing with toothpaste and chewing food. When glass-ceramics were used to restore a tooth structure, it is undeniable that glass-ceramic material must consecutively occlude with an antagonist resulting in microcrack and exfoliation of ceramic particles from its surface. This ceramic particle could act as an abrasive particle which could increase the progressive wear on the ceramic surface. The combined effect of a rougher ceramic surface and the presence of hard three-body particles causes a significant increase in dental wear (Branco et al., 2020). As a result of wear, a rough surface is created and might attribute to unpleasant appearance, patient discomfort, plaque accumulation, increase wear to the opposing antagonist, and chipping

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or fracture of the restoration. Therefore, the wear properties and abrasiveness of the materials are essential properties to be concerned.

The wear properties of lithium disilicate glass-ceramics have been studied on IPS emax CAD in several studies (Matzinger et al., 2019; Preis et al., 2013; Wille et al., 2021) since it has been commercially available in the market for many years. Previous studies on the wear resistance of the IPS emax CAD revealed that it showed a significant number of worn surfaces. This could be owing to the shape, size, and distribution of the crystallinity in its structure (Dupriez et al., 2015; Tribst et al., 2019; Wille et al., 2021). Furthermore, the patent of lithium disilicate expired, several new lithium silicate glass-ceramics have been introduced in the market, for instance, Amber Mill (Hass, Gangneung, Korea), n!ce (Straumann, Freiburg, Germany), and Celtra Duo (Sirona Densply, Milford, DE, USA). In comparison to IPS emax CAD, the microstructure of the new CAD/CAM glass-ceramic material has been modified to a smaller homogenous crystal (Lubauer et al., 2021). Manufacturers attempt to decrease particle size in order to improve mechanical properties and generate new materials that can be used instantly without the firing process. Amber Mill is a partially crystallized lithium disilicate product that has an amber-colored appearance. A single block can be developed in four translucencies (HT, MT, LT, MO) by different heat treatment temperatures. n!ce is a fully-crystallized lithium aluminosilicate reinforced with lithium disilicate which has 5-10% higher alumina content than the IPS emax CAD. Celtra Duo is a fully crystallized zirconia reinforced lithium silicate glass-ceramic containing 10% zirconium oxide dissolved in a glassy matrix and the small crystalline of lithium silicate. Both n!ce and Celtra Duo allow chair-side fabrication without crystallization after milling.

There are a few studies about wear properties on these recent CAD/CAM products. Therefore, the volume loss of new lithium-based glass-ceramic CAD/CAM materials after wear simulation is of interest to provide information for material selection.

2. Objectives

To evaluate the volume loss of four chair-side CAD/CAM materials after wear simulation

3. Materials and Methods

Four CAD/CAM block materials used in this study are listed in Table 1.

Table 1 Materials used in this study

Material	Code	Manufacturer	Composition
Amber Mill	AM	Hass, Gangneung, Korea	Lithium disilicate (submicrometric-nanometric crystals)
Celtra Duo	CD	Dentsply Sirona, Milford, DE, USA	Zirconia- reinforced lithium silicate
IPS emax CAD	EM	Ivoclar Vivadent, Schaan, Liechtenstein	Lithium disilicate (micrometric crystals)
n!ce	NI	Straumann, Freiburg, Germany	Lithium aluminosilicate reinforced with lithium disilicate

3.1 Specimen preparation

Each CAD/CAM block material was cut to fabricate a flat square-shaped specimen (8x8x4 mm^3) using a low-speed diamond saw (IsoMet, Buehler, Lake Bluff, IL, USA). Only EM and AM specimens were crystallized using a furnace (Programat P700; Ivoclar Vivadent AG) following the manufacturers' instructions. All specimens were polished using P1200, P2500, and P5000 silicon carbide abrasive papers (TOA Extra flex, Samutprakarn, Thailand) in a polishing machine (Minitech 233, Presi, Grenoble, France) under the water irrigation and cleaned with an ultrasonic bath for 5 min. The spherical steatite ceramic (SD Mechatronik GmbH, Westerham, Germany) with a diameter of 6 mm was used as an antagonist. Both specimens and antagonists were embedded in the wear simulation holders using auto-polymerized acrylic resin (Unifast Trad, GC Corp., Tokyo, Japan) as displayed in **Figure 1** and stored in deionized water at 37^{o}C for 7 days before wear testing.

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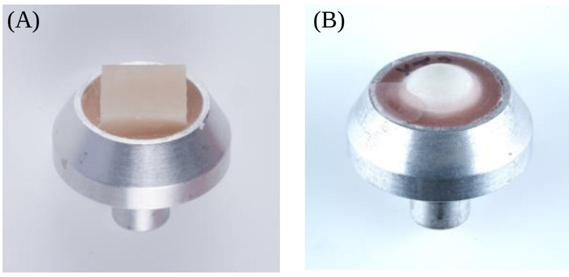

Figure 1 (A) CAD/CAM specimen and (B) steatite antagonist was embedded in a wear simulation holder using auto-polymerized acrylic resin

3.2 Two-body wear simulation

For specimen standardization, a contact profilometer (Talyscan 150 Laser Scanner, Taylor Hobson, Leicester, UK) was used to determine the specimen surface roughness before wear simulation. The setting parameters were set to 3x3 mm^2 of tracing area, 1500 µm/s of tracing speed, 0.25 mm of cut-off length, 1.0 µm in the X-axis, and 600 µm in the Y-axis of tracing space. The Ra values (µm) were averaged from 6 measurements in each specimen. Surface roughness (Ra) in each material was controlled by a variation of ±0.01 µm.

The two-body wear test was performed using a chewing stimulator (CS-4; SD Mechatronik GmbH, Westerham, Germany). The specimens and antagonists were mounted on a chewing station that contained room temperature water as shown in **Figure 2**. The simulation parameters were set to a vertical load of 50 N at a frequency of 1.34 Hz for 120,000 cycles. The wear pattern was simulated by the horizontal sliding movement of 0.5 mm as the steatite ball contacted and dragged over the specimen surface in one direction.

Figure 2 The specimens and their antagonists were mounted in a chewing simulator

3.3 Volume loss measurement

Volume loss of the specimen was determined using a contact profilometer with a precision stylus of a 2 µm tip radius. The setting parameters were set to 3x3 mm^2 of tracing area, 1000 µm/s of tracing speed, 0.5 µm in the X-axis, and 15 µm in the Y-axis of tracing space.

The volume loss of the antagonist was determined using a stereomicroscope (Olympus SZ61, Olympus Corporation, Tokyo, Japan) to measure the height of the antagonist before and after the wear simulation. The calculation formula for antagonist volume loss was obtained from a previous study (D'Arcangelo et al., 2018) as shown below.

$$V = \frac{\pi h^2(3R-h)}{3}$$

V = antagonist volume loss (mm^3)
h = spherical cap height (mm)
R = spherical radius (mm)

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3.4 Statistical analysis

In this present study, EM was used as a control. The study's null hypothesis is that there is no significant difference in volume loss of new CAD/CAM block materials after wear simulation compared to EM. Data were analyzed with statistical software (IBM® SPSS 22.0, Armonk, NY) with the level of significance set to $\alpha = 0.05$. Shapiro-Wilk test was applied for the normality test. Levene test was used to check the homogeneity of variance of the data. The specimen volume loss was statistically analyzed using one-way ANOVA, followed by Games-Howell post hoc analysis. The antagonist volume loss of each material was statistically analyzed with one-way ANOVA, followed by Tukey's HSD post hoc analysis.

4. Results and Discussion

4.1 Results

One-way ANOVA revealed statistically significant differences in both specimen volume loss (Welch=103.882, $p < 0.001$) and antagonist volume loss ($F = 18.437$, $p < 0.001$). Means, standard deviations, and a statistical result of volume loss in each CAD/CAM material and its opposing steatite antagonist after 120,000 chewing cycles are described in **Table 2**.

Table 2 Mean ± SD of the specimen and antagonist volume loss

Group	Volume loss (mm^3)	
	Specimen	**Steatite antagonist**
AM	0.10 ± 0.02^{a}	0.35 ± 0.08^{b}
CD	0.48 ± 0.06^{c}	0.46 ± 0.10^{b}
EM	0.51 ± 0.10^{c}	0.35 ± 0.05^{b}
NI	0.27 ± 0.03^{b}	0.16 ± 0.04^{a}

Different letters in the same column indicate significant differences between groups (p<0.05)

EM demonstrated the highest specimen volume loss, followed by CD, NI, and AM. EM showed no significant difference in specimen volume loss when compared to CD ($p > 0.05$) while demonstrating significantly higher volume loss than NI and AM ($p < 0.05$). The specimen volume loss in NI exhibited significantly greater than that in AM ($p < 0.05$).

CD exhibited the highest antagonist volume loss, followed by AM, EM, and NI. The antagonist volume loss in AM, CD, and EM showed no significant difference compared to each other ($p > 0.05$) while demonstrating significantly greater than NI ($p < 0.05$).

4.2 Discussion

Wear occurs when two surfaces come into contact. Restorative materials are unable to avoid this situation in the oral cavity during mastication and might result in a variety of negative consequences. Therefore, the wear resistance of dental materials should be concerned. The present study aimed to investigate the two-body wear of the four chair-side glass-ceramic CAD/CAM materials. Based on the present results, the null hypothesis was rejected since the significant differences in the volume loss between the tested materials and EM were found.

Assessment of the wear resistance of dental material could be obtained from either clinical or laboratory methods. Clinical wear evaluation may be difficult to control and take a long time to generate results. Laboratory study is another option that is useful for rapid assessment. In vitro studies on wear resistance of dental materials are usually performed under a simulation machine that could control load, speed, and movement distance. The in vitro study of wear mechanisms involving dental materials requires a machine that could mimic the oral environment. There are several designs of the wear testing devices, for instance, Pin-on-disc, reciprocating, one-way slide and static end load, ball and crater, twin disc, and chewing simulator (Lewis & Dwyer-Joyce, 2005; Zhou & Zheng, 2008). This present study performed a two-body wear simulation using a chewing simulator (CS-4; SD Mechatronik GmbH, Westerham, Germany). The chewing simulator has been developed to simulate more sophisticated oral chewing cycles. The testing

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machine could move in two directions, horizontally and vertically. The testing stations are located in a plastic chamber that could contain either water or an abrasive medium. According to the set-up parameters of the current study, the 50 N force was chosen because it approximated the biting force during chewing (Gibbs et al., 1981). The 0.5 mm sliding distance represented the long centric movement of teeth (Dawson, 1989). The frequency of 1.34 Hz used in the present study was within the average chewing frequency that ranged from 0.94-to 2.17 Hz (Po et al., 2011). The 120,000 loading cycles corresponded to an average of a one-year chewing cycle (Yilmaz, 2020).

EM was served as a control in this study since there have been several studies on the wear behavior of this material (Preis et al., 2013; Rosentritt et al., 2020; Tribst et al., 2019; Wille et al., 2021). In the present study, EM demonstrated insignificant differences in specimen volume loss when compared with CD ($p>0.05$). The comparable specimen volume loss between EM and CD in this current study might be due to the comparable mechanical properties between the two materials. According to previous studies, surface hardness and elastic modulus between CD (463.5 HV, 107.6 GPa) and EM (452.9 HV, 102.5 GPa) exhibited comparable values (Lawson et al., 2016; Lubauer et al., 2021). This result was in line with a previous study (Lawson et al., 2016). In contrast, another study performed a wear simulation between various restorative materials as opposed to zirconia (3Y-TZP) for 120,000 loading cycles using a chewing simulator. The result revealed that milled-polished CD had a significantly larger volume loss than EM ($p<0.05$) (De Angelis et al., 2020). The difference between the two studies might be explained by the difference in mechanical properties of the antagonist material. The steatite had a lower modulus of elasticity and fracture toughness (120 GPa, and 2.0 MPa $m^{1/2}$) (Alves et al., 2019) than 3Y-TZP (200-210 GPa, and 3.5-4.5 MPa $m^{1/2}$) (Zhang & Lawn, 2018).

EM demonstrated a significantly greater volume loss than AM and NI ($p<0.05$). The differences in EM, AM, and NI wear behavior might attribute to variations in reinforcing crystallite size, distribution, and form (Dupriez et al., 2015; Fuertes et al., 2019). EM is the only material that showed micrometric elongated crystals (>1 µm in size) with a 70% crystal volume fraction (Lubauer et al., 2021). These pointed-elongated crystals share the potential to increase the wear rate of EM during wear simulation. NI contains the greatest amount of crystallinity, which is 80.6% crystal volume fraction, among tested materials and entirely nanometric (≤ 100 nm) crystals (Lubauer et al., 2021). The nanocrystals act as solid lubricants, allowing the body to slide and reducing the friction coefficient (Fuertes et al., 2019). This could explain the low wear rate in NI. AM contains 66.2 % crystal volume fraction of submicrometric and nanometric crystal sizes. It contained an additional 6% crystal volume of Quartz in the nanometric range, with no residual lithium metasilicate (Li_2SiO_3) (Lubauer et al., 2021). The micro-nano structured ceramics with high crystalline concentrations in AM could reduce wear rate and wear track because nanoparticles contained in AM could act as a barrier that has strong interfacial bonding to resist the wear from the antagonist (Fuertes et al., 2019).

Steatite is a preformed material that contains mainly magnesium silicate. It is not considered to be the enamel substitution. Steatite (683.5 kg/mm^2) had a higher microhardness value than enamel (332.3 kg/mm^2) resulting in a difference in wear pattern (Shortall et al., 2002). However, the advantages of employing steatite include its consistency in size and quality. It enables the interpretation of wear rates and material grading (Preis et al., 2011). The wear of the steatite opponent could be affected by the amount and form of the reinforcing crystals of the occluding materials (Dupriez et al., 2015). This current study revealed that steatite demonstrated the least volume loss when opposed to NI. This might be due to the nanometric crystallite in NI acting as a self-lubricating particle (Fuertes et al., 2019).

Considering the fabrication process, the crystallization firing is required for EM and AM, but not necessary for NI and CD. AM exhibited better wear resistance for crystallization-fired materials than EM. While NI demonstrated superior wear resistance for materials that do not require the furnace more than a CD.

Limitations of the present study included that the in vitro scenario is not able to mimic the real clinical situation. The occluding surfaces in the oral cavity are tooth to tooth contact with the multi-directional movement and variation of load. However, comparing the value of substance loss in clinical investigations is complicated and time-consuming. Therefore, in vitro studies, which provide a controlled environment, are better suitable for the material wear resistance rating. This might be a useful guide for choosing dental ceramic restorations that are less prone to wear and damage. Suggestions for future studies include clinical studies

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with long-term follow-up. The different antagonist materials such as stainless steel, zirconia, and composite might provide a better understanding of the wear resistance property of these new CAD/CAM materials.

5. Conclusion

Within the limitations of the present study, new lithium-based glass-ceramic materials, especially nice, showed better wear resistance and caused less abrasion to antagonists when compared with the IPS emax CAD.

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