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ORIGINAL ARTICLE

A comparison of the wear resistance and hardness of two different indirect composite resins with a ceramic material, opposed to human enamel

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ABSTRACT

Objectives: The aim of this study was to compare the two-body wear resistance of two different indirect composites and lithium disilicate porcelain versus human enamel antagonists. **Materials and Methods:** Ten specimens of each material (BelleGlass NG, Kerr Corp.; SR Adoro, Ivoclar Vivadent AG; IPS e.max, Ivoclar Vivadent AG) were fabricated. Indirect dental composites and all-ceramic restoration were compared by an *in vitro* tribological test against human teeth antagonist. Wear loss of antagonist was calculated using an image analyzer (Leica) Wear behavior of restorative materials was investigated with a profilometer after each individual tribological test. A scanning microscope was used to examine the crystal morphology of the samples; the crystal phases were identified by an X-ray diffractometer. Microhardness test results were analyzed using ANOVA. Kruskal Wallis multi-comparison test was used for evaluating the corrosion data. In order to understand whether there is a relationship between mean friction co-efficients, wear rate, and hardness, the statistical non-parametric relation test was used. **Results:** The indirect composites showed lower wear rate and friction co-efficient than all-ceramic dental materials against enamel. As for the wear loss of the enamel antagonists, the all-ceramic restorations were more harmful to human teeth than the dental composites. **Conclusion:** Indirect dental composite is relatively more wear-friendly than all-ceramic restoration. Furthermore, indirect composites are favorable and less offensive. Therefore, the second generation of indirect composites is promising in long-life dental restorations.

Key words
Hardness, electron microscopy, profilometry, two-body abrasion

INTRODUCTION

Recently, indirect composite resin-based restorations have become an alternative to all-ceramic restorations for the esthetic treatment of posterior teeth. These materials have been promoted as hybridization of polymer and ceramic technologies. They are essentially composite resin matrix with different filler components.[1-4] Bisphenol glycidyl methacrylate has been the monomer of choice as the principal matrix monomer of all dental resins. Because of its high viscosity, additional monomers, such as triethyleneglycol dimethacrylate or ethyleneglycol dimeth-acrylate, are often used as diluents. Later, more complex monomers were introduced. Urethane dimetharcrylate was found to have increased tensile properties, faster and more complete conversion, and its lower viscosity allows its use without low viscosity diluents.[5] Fillers were added to improve inadequate properties of polymers. The main types of filler materials are glass, glass-ceramics, silicates, and silicon dioxides. The presence of fillers increases the mechanical properties. Li *et al.*[6] reported that changing the level of filler in composite altered the hardness, water sorption, compressive strength, and elastic properties. Rosentritt *et al.*[7] found that the composite of lower filler content had low fracture resistance.

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Although, those of esthetic advantage and enhanced mechanical properties, strong claims have been presented regarding failure due to occlusal wear.[2,8] Composite resins exhibit considerable wear *in vivo* in the long run, even though significant improvements have been made. A high wear resistance may contribute to the longevity and thus establishing durable aesthetics and function of dental materials. Ideally, wear of a dental

restorative material should be similar to enamel.[9] Wear of composites occurs mainly by abrasive, adhesive, corrosive, and fatigue wear processes.[10,11] Abrasive wear occurs when surfaces pass over one another and the harder materials cut at the softer material, resulting in the loss of material. The normal force acting to the two surfaces, which are moving against each other, may also cause local cold welding between particles on the surfaces. If the shear force results in tearing of the small pieces from the surface, the process is termed adhesive wear. Corrosive wear occurs when salivary enzymes or acids attack the surface. Fatigue wear occurs as a result of flaws becoming micro cracks that propagate through the material, leading to the separation of surface particles. This mechanism is especially, relevant to the matrix-filler relationship in composites. Moreover, calculating wear volume of antagonists is also valuable to interpret the wear properties of dental materials. In previous studies,[12,13] it was shown that the wear resistance of dental materials varied with microstructural distribution and orientation of the fillers. Several studies describe that the overall mechanical and wear properties of a composite are influenced by the type, size, and volume fraction of the filler particles and degree to which the filler is bonded to the resin matrix.[8,14,15] However, a study to establish the behavior of dental composites and dental all-ceramics against human enamel antagonists is rather limited.

The aim of this research was to compare the wear behavior of three different types of commercial restorative materials with *in vitro* wear test. Two dental indirect composites and a lithium disilicate glass ceramic material were used for the tests. Wear behavior of each commercial restorative material against the antagonist was evaluated and compared by using a pin-on-disk tribometer. The volumetric wears of the dental materials were calculated by a surface profilometer and the maximal vertical depth of the trace made by the pin on the dental restorative materials. Volumetric loss of the antagonists was examined by using a computerized image analyzer. The microstructural morphology of the tested samples was analyzed by SEM and EDX, while the X-ray diffraction (XRD) was run to investigate the crystallinity.

MATERIALS AND METHODS

Sample preparation

Two indirect composite resins (BelleGlass NG, Kerr Corp., Orange, CA, USA; SR Adoro, Ivoclar Vivadent AG, Schaan, Liechtenstein) and a pressable all-ceramic (IPS e.max, Ivoclar Vivadent AG, Liechtenstein) were investigated. The chemical compositions of each material are listed in Table 1. The specimens (n=10/group; diameter 15, thickness 2 mm) were prepared.

As for the Belleglass NG samples, they were light cured for 20 s with a halogen lamp (Teklite, Belle de St. Claire) at 400-500 µm wavelength, and of 600 mW/cm^2 intensity. The final polymerization was performed in a nitrogen atmosphere at 135°C for 10 min. Pressure of 60 psi was applied to reduce the monomer vaporization from the matrix. After completion of the final polymerization, the samples were ground flat and polished by using 240, 400, 800, and 1200 grit SiC abrasive papers.

Table 1: Materials used in this study

Brand	Filler and particle size	Filler content (%)	Monomer	Manufacturer
SR Adoro	Copolymer grain 0.005~0.01 µm	65 vol	UDMA	Ivoclar Vivadent AG, Schaan, Liechtenstein
Belleglass NG	Borosilicate 0.6 µm and Barium glass 25 µm	85 vol	Bis-GMA TEGMA	Kerr Corp., CA, USA
IPS e.max	All-ceramic	-	Lithium disilicate (LS_2)	Ivoclar Vivadent AG, Schaan, Liechtenstein

UDMA – Urethane dimethacrylate; GMA – Glycidyl methacrylate; TEGMA – Triethylene glycol dimethacrylate

The monomer of SR Adoro matrix was free from any hydroxyl groups, thus its water absorption value was extremely low. As for the SR Adoro samples, they were initially light cured by a halogen lamp (Targis Quick, Ivoclar Vivadent AG, Schaan, Liechtenstein) of 600 mW/cm^2 intensity for 20 s. Before final polymerization, a glycerin gel (Targis Gel, Ivoclar Vivadent AG, Schaan, Liechtenstein) layer was coated on the entire surface of the specimens to avoid the presence of an oxygen-inhibited layer. Then, the samples were placed in a powercuring unit (Lumamat 100, Ivoclar Vivadent AG), which was internally mirrored and has 8 fluorescent lamps and the final polymerization cycle was 25 min. After completion of final polymerization, the samples were polished through the methods used on the Belleglass NG.

Ceramic samples (IPS e-max) were prepared by lost wax method in EP500 furnace at 1075°C under 5 bar heating pressure. Glazing of samples was done at 800°C for 6 min.

Antagonist enamel specimens were produced from the molars and premolars that were extracted from a 35-year-old female patient for periodontal reasons. The cusps were separated and embedded in acrylic resin moulds. The worn out, fractured or too sharp cusps were excluded from the subjects.

Characterizations

Microhardness of all of the specimens was measured using a Knoop hardness (KH) test (Dukson tester, Willson). At least five measurements were carried out

at different locations through application of 500 gf for 15 s. The averages and the standard deviation of the measurements were calculated by taking the mean average of five measurements from an individual specimen.

The samples were mounted in epoxy resin prior to the wear test. The tribological tests were performed in artificial saliva (simulated body fluid (SBF)) using a pin-on-disk tribometer (CSM Instruments, Switzerland) at a load of 7 N, rotating speed of 2.5 cm/s and sliding distance of 300 m. The wear track diameter was 1 cm and data acquisition frequency was 1 Hz. The tribometer measures the tangential force between the two contacting surfaces and calculates the co-efficient of friction as the ratio of the tangential force to the load by the software TriboX2.0 (CSM Instruments, Switzerland).

Human teeth were chosen as the antagonist and fixed on stainless steel holder. The wear loss of the antagonist was calculated by comparing the area loss of the vertical surface using an image analyzer (Leica DFC-320, Leica, and Solms, Germany).

To investigate the wear behavior of restorative materials, the surface profile of the sample was measured by using a stylus profilometer (surtronic 3+, Taylor Hobson Precision Ltd.) after each individual tribological test to determine the wear track depth and wear area. The cross-sectional area of the wear track was calculated by averaging the wear area of four points of maximum mutual distance (90° spacing) on the wear track of the disk following the wear test, from the profiles recorded at the four locations. Then the wear volume was calculated by multiplying the cross-sectional area of the wear track by the circumference of the track.

The SBF was prepared according to the instructions given by Kokubo *et al.*[16] It was buffered at a pH of 7.25 with Tri (hydroxymethyl) aminomethane and 0.1 M HCl solution. The chemicals used and their quantities in SBF are given in Table 2. All specimens were immersed in SBF for 12 h before the wear test started, and clamped and supported on the sample stage located at the bottom of the wear cell filled with SBF. The level of SBF in the wear cell was maintained such that the specimen remained immersed in the fluid during the entire duration of the test.

A scanning electron microscope, SEM (Jeol 6400), was used to examine the crystal morphology of the samples. The quantitative analysis was determined by energy dispersive spectroscopy (EDS). The crystal phases were identified using an X-ray diffractometer, XRD (Rigaku Geigerflex-DMAK/B). Scans were run from 20° to 50° (2θ) at a speed of 2°/min with 0.02° increment using Cu–Kα radiation.

Kruskal Wallis multi-comparison test was used for evaluating the corrosion amounts. ANOVA test was used for the statistical evaluations of microhardness findings. In order to understand, whether there is a relationship between mean friction co-efficients, wear rate and hardness, the statistical non-parametric relation test was used.

RESULTS

Figure 1 illustrates XRD patterns obtained from the free surface of bulk dental materials. There was no crystalline peak from SR Adoro and Belleglass NG, while the crystalline patterns could be detected from IPS e.max.

Figure 2 illustrates the micrographs taken from the fracture surface of the commercial dental materials studied. Any fiber shape of fillers can't be observed in dental composite materials, but the particles of small size are homogeneously distributed. When this is compared with IPS e.max, the grain sizes were about 5-6 μm and look relatively dense and strong.

Quantitative EDS analysis was shown in Table 3. Only silicon dioxide is detected from SR Adoro. The XRD

Table 2: Chemicals and their quantities in simulated body fluid in 1 litre distilled water

Chemical	Quantity (g)
NaCl	7.996
$NaHCO_3$	0.350
KCl	0.220
K_2HPO_4	0.174
$MgCl_2\ 2H_2O$	0.305
$CaCl_2\ 2H_2O$	0.368
$NaSO_4$	0.071
Tri (hydroxymethyl) aminomethane	6.057
1M HCl	40 (ml)

NaCL – Sodium chloride; $NaHCO_3$ – Sodium bicarbonate; KCl – Potasium chloride; K_2HPO_4 – Dipotassium phosphate; $MgCl_2\ 2H_2O$ – Magnesium chloride hexahydrate; $CaCl_2\ 2H_2O$ – Calcium chloride dihdrate

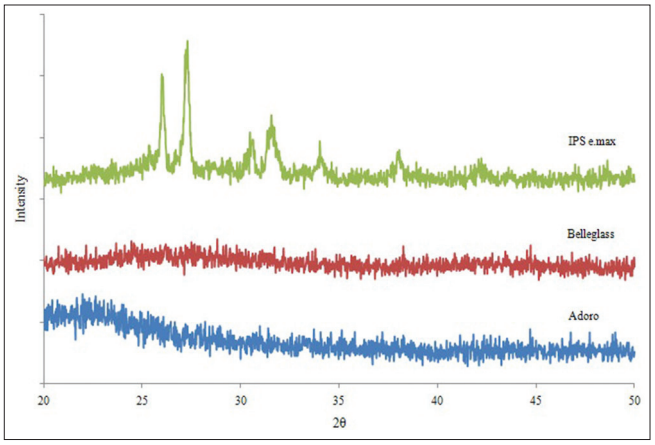

Figure 1: X-ray diffraction patterns of the commercial dental materials tested

patterns of SR Adoro suggested that this SiO_2 is an amorphous. Belleglass NG contains Ba, Al, and silicates compounds. It matches well with the quotation of the suppliers. IPS e.max is composed of several chemical compounds to form all ceramic microstructure.

The values of KH, wear rate, and mean friction co-efficient for the commercial dental materials, and the wear losses of the enamel antagonist are presented in Table 4. The numbers in parentheses indicate the standard deviation of the data from the averages. ANOVA test was used for the statistical evaluations of microhardness findings. The KH value of IPS e.max is much higher than those of dental composites. The KH value of Belleglass NG is 60.01 (±3.37), while that of SR Adoro is 49.88 (±4.92). The higher inorganic volume fraction of Belleglass NG showed the higher microhardness value. As for the size of fillers, it is a micro scale in Belleglass NG, while it is sub-micro size in SR Adoro, as mentioned in Tables 1 and 3.

Table 3: Energy dispersive spectroscopy analysis of the commercial dental materials

Samples	Elements (atom conc. %)					
	Na	K	Ba	Si	Al	O
SR Adoro				33.33		66.67
Belleglass NG			2.92	28.65	3.28	65.15
IPS e.max	2.96	4.99		22.22	7.87	61.09

Na – Sodium; K – Ba – Potasium- Barium; Si – Silicium; Al – Aluminium; O – Oxygen

Table 4: Knoop hardness, wear rate, mean friction coefficient and wear loss of antagonist

Material	Knoop hardness	Wear rate ($m^3/N·m$)	Mean friction coefficient	Wear loss of antagonist (mm^2)
SR Adoro	49.88 (4.92)	1.79 (0.45) ×10-5	0.12	409 (12)
Belleglass NG	60.01 (3.37)	2.45 (0.19) ×10-5	0.15	807 (18)
IPS e.max	427.54 (4.97)	1.88 (0.38) ×10-4	0.68	1414 (23)

In this study, IPS e.max showed the highest wear rate among dental materials, while SR Adoro showed the most wear resistant property against human enamel antagonist *in vitro* condition.

Kruskal Wallis multi-comparison test was used for evaluating the corrosion amounts. The wear rates of the dental materials were found to increase with increasing the KH values. A statistical closeness could not be found in wear rate between the materials ($P<0.05$).

In order to understand whether there is a relationship between mean friction co-efficients, wear rate and hardness, the statistical non-parametric relation test was applied. No statistical relation was found between friction co-efficient, microhardness and wear rates of IPS e max ceramic samples.

A positively strong relationship was determined between friction co-efficient and microhardness values of samples in SR Adoro system ($P<0.05$, $r=0.9$) Furthermore, a positively strong relationship was determined between friction coefficient and hardness quantities of samples in BelleGlass NG ($P<0.05$, $r=0.9$).

BelleGlass NG material, which has a higher microhardness value, has shown higher wear rate and friction co-efficient. SR Adoro system, which has a low microhardness value, has shown lower wear rate and friction co-efficient.

The amount of wear loss of the opposing enamel antagonists varied with each dental material. The wear loss of the antagonist was 409 (±12) mm^2 when it had contact with SR Adoro *in vitro* as measured from the microscope images. However, it increased to 1414 (±23) mm^2,when it had contact with all-ceramic dental materials. From Figures 3-5 show the geometric changes of antagonists after contacting with different dental materials. For the contact with SR Adoro [Figure 3], the maximum vertical

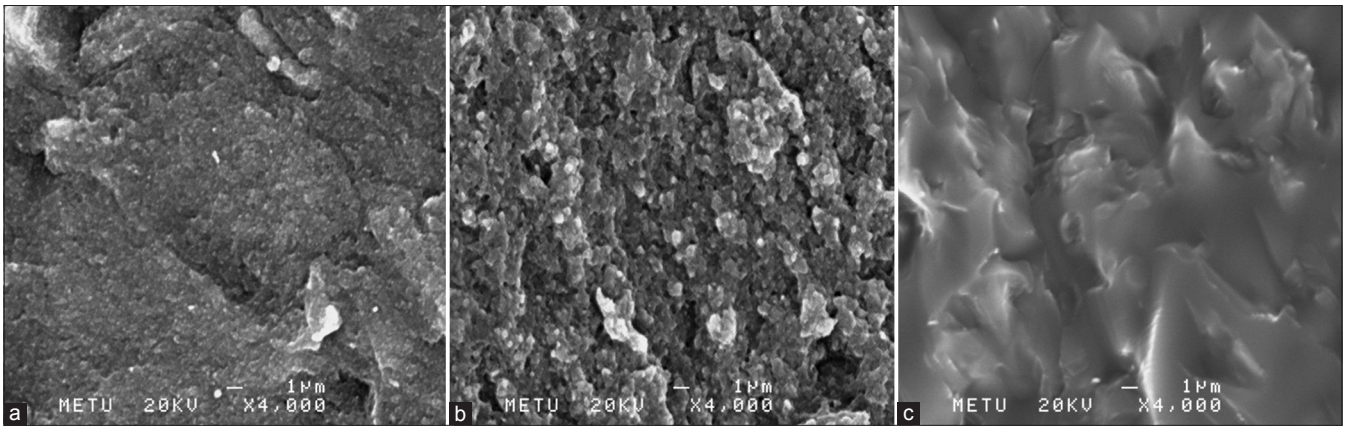

Figure 2: (a) SEM micrographs taken from the fracture surface of SR Adoro, (b) SEM micrographs taken from the fracture surface of Belleglass NG, (c) SEM micrographs taken from the fracture surface of IPS e.max

length of the antagonist was 0.047 mm; while with the IPS e.max contact [Figure 5] it was 0.232 mm. With increasing the vertical length loss, the wear volume of the human enamel increased.

Variation in the friction coefficient of the commercial dental materials with sliding distance is presented in Figure 6. The friction coefficient of IPS e.max is between 0.5 and 0.7, while those of indirect composites are between 0.1 and 0.2. The friction coefficient value of SR Adoro is lower than that of Belleglass NG. Figure 7 shows the wear track of the dental materials. IPS e.max with high wear rate and friction co-efficient showed the wide and deep wear track marks, while Belleglass NG and SR Adoro showed relatively narrow and swallow wear marks.

BelleGlass NG is an indirect composite system that incorporates advanced nano-particle and submicron filler technology. It has high polish and shine, along with superior strength and wears characteristics. It has "biomimetic" properties, similar to tooth structure, including less wear to opposing dentition than porcelain. The SR Adoro is a microfilled composite veneering system, which consists of large filler particles that are combined with microfillers by using splinter polymers.

Based on XRD examinations, it is thought that the amount of filler content is low or the particle size is small in dental composites. As for the IPS e.max, the detected crystal patterns are believed to lithium disilicate, which may be formed during heat treatment.[17]

KH value of IPS e.max was much higher than both indirect composites. However, Belleglass NG has a higher KH value than SR Adoro indirect composite. The reason for this difference may come from the different amount of fillers, their types, and their size.[6] Due to high inorganic volume of Belleglass NG, the microhardness value was higher.

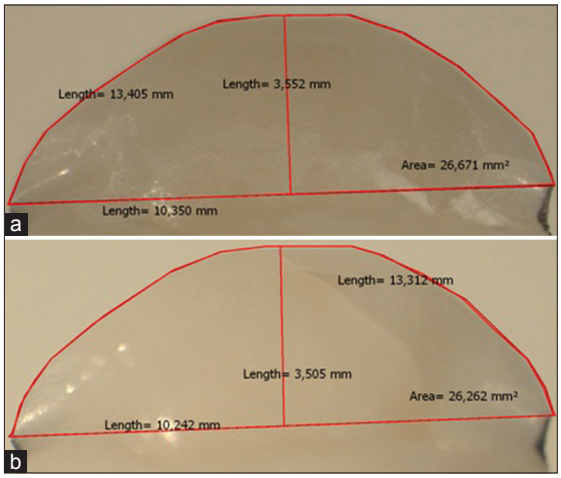

Figure 3: (a) The geometry of human enamel antagonist as contacted with SR Adoro before after wear test, (b) The geometry of human enamel antagonist as contacted with SR Adoro after wear test

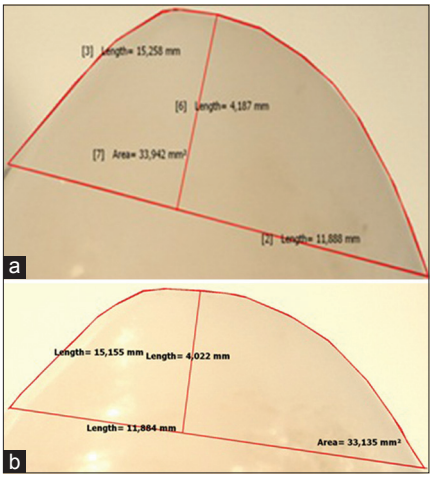

Figure 4: (a) The geometry of human enamel antagonist as contacted with Belleglass NG before wear test, (b) The geometry of human enamel antagonist as contacted with Belleglass NG after wear test

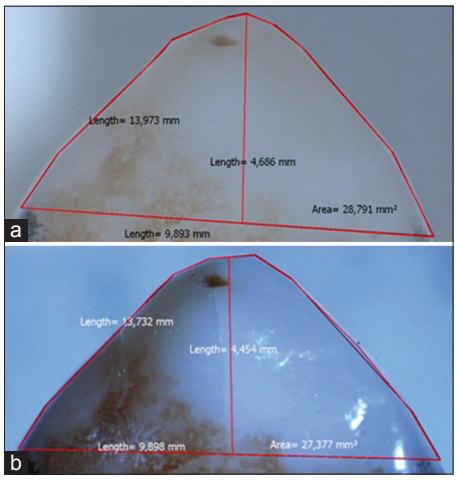

Figure 5: (a) The geometry of human enamel antagonist as contacted with IPS e.max beforewear test, (b) The geometry of human enamel antagonist as contacted with IPS e.max after wear test.

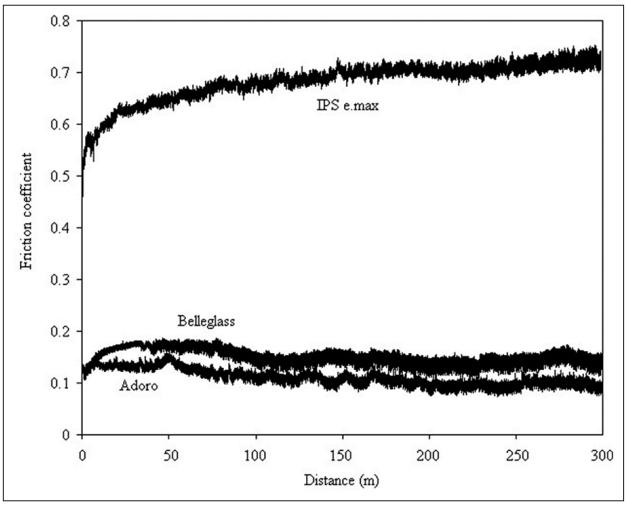

Figure 6: Variation in the friction coefficient with sliding distance for the tested dental materials

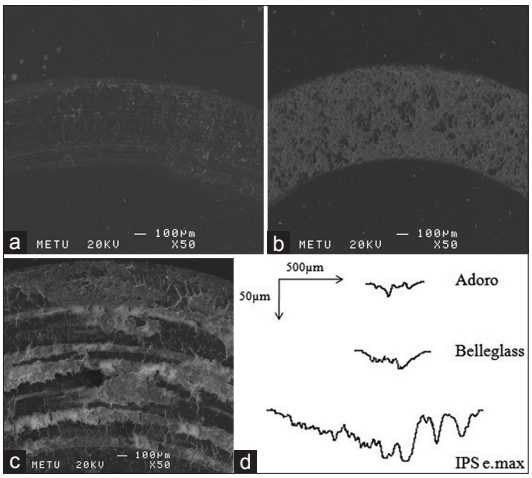

Figure 7: (a) Surface morphology and profiles of wear track of SR Adoro, obtained after *in vitro* wear tests, (b) Surface morphology and profiles of wear track Belleglass NG obtained after *in vitro* wear tests, (c) Surface morphology and profiles of wear track obtained after *in vitro* wear tests. IPS e.max, (d) Surface profiles

When wear loss amounts were compared, SR Adoro showed the least wear loss on the antagonist cusp. Belleglass NG follows SR Adoro, while IPS e.max was the most offensive in this experiment.

The wear rate of Belleglass NG was also found to be higher than that of SR Adoro and it may also be explained by the different amount of fillers and their types and size, matrix behavior and interface bond conditions. With increasing filler amount, the dental composites become less wear friendly. The positive correlation between the hardness of a composite and the wear resistance is matched well with other studies.[15,18]

The increased rate of ceramic wear and friction may be explained by the fact that after the loss of glaze, an increased rate of particle fracture would occur below the glazed surface of the ceramic. The collection of fine debris in the lubricant between rubbing surfaces would increase the friction and thus the abrasion both from antagonist and IPS e.max. The deep ploughing grooves, ridges and chips observed on the wear tracks are the features of abrasive and adhesive wear.[12,19]

Heintze *et al.*[20] compared *in-vitro* corrosion resistance of different dental materials including IPS Empress ceramic, Targis and BelleGlass NG indirect composite materials. Volume loss and corrosion quantities were ranked. While Targis samples were corroded more than IPS Empress and BelleGlass NG samples, it was determined that BelleGlass NG samples were corroded less than IPS Empress samples.

While certain researchers[6,21] state that high filler rate increases wear rate, some[22] state increasing filler rate increases wear rate. Mandikos *et al.*[15] examined this relation, composites including, larger and of a high percentage of filler display higher microhardness rates however, expose higher wear rate during tests.

Parallel with some studies[15,23,24] we find that BelleGlass NG indirect composite containing harder and higher percentage of filler corroded more than SR Adoro material containing softer and less percentage of filler, however, the friction coefficient and surface hardness of it was more.

Enamel and enamel like porcelain corrosives did polishing effect on the composite surfaces and caused less corrosion.[25] Besides, lower elastic modulus of the indirect composites may have done lubricant effect between the corrosive end and the composite material during the test. Whereas, IPS e-max material, which elastic modulus is higher, and is extremely hard and shows little deformation.

CONCLUSION

The wear properties of indirect dental composites and all-ceramic materials were compared with each other by *in vitro* tests. Human teeth were used as antagonists and their wear loss was calculated and the overall properties of a composite are found to be influenced by the volume fraction and types of fillers. The results of this study indicate that indirect dental composite is relatively more wear-friendly than all-ceramic restoration. As for the wear loss of the enamel antagonist, indirect composites are favorable and less offensive. Therefore, the second generation of indirect composites is promising in long-life dental restorations.

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