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Esthetic Restorative Materials and Opposing Enamel Wear

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Clinical Relevance

The data obtained in this study can help practitioners with selection of the appropriate restorative materials to minimize further tooth and restoration wear, which is an important consideration during treatment planning.

SUMMARY

This *in vitro* study compared the effects of a gold alloy (Degulor M), four dental ceramics (IPS Empress, IPS Empress 2, Duceram Plus, Duceram LFC) and a laboratory-processed composite (Targis) on the wear of human enamel. The amount of wear of the enamel (dental cusps) and restorative materials (disks) were tested in water at 37°C under standard load (20 N), with a chewing rate of 1.3 Hz and was determined after 150,000 and 300,000 cycles. Before the test, the average surface roughness of the restorative materials was analyzed using the Ra parameter. The results of this study indicate that Targis caused enamel wear similar to Degulor M and resulted in significantly less wear than all the ceramics tested. IPS Empress provoked the greatest amount of enamel wear and Degulor M caused less vertical dimension loss. Targis could be an appropriate alternative material to ceramic, because it is esthetic and produces opposing enamel wear comparable to gold alloy.

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INTRODUCTION

Patients' demand for dental restorations that reproduce the beauty of natural teeth has stimulated the further development of composite and ceramic materials. Ceramic restoration seems to be the preferred choice when ultimate esthetic results are desired. To date, despite the popularity ceramic restoration, clinicians have been concerned about the abrasiveness of composite and ceramic materials against antagonistic natural teeth[1] since, *in vitro*[2-4] and clinical studies[5] have shown excessive wear of enamel opposing ceramic. To circumvent this problem, laboratory processed composite restorations could be an alternative for esthetic restorations. These materials are esthetic, non-cytotoxic[6] and cause less opposing enamel wear than ceramics.[7] However, there is concern about their durability due to the wear process resulting from masticatory function. To date, few studies have been published on the wear of laboratory processed composite restorations resulting from multiple cycle loading against enamel.[8-10]

Ideally, enamel wear caused by a restorative material should not increase physiological enamel wear[11]—about 20–40 µm per year[12]—otherwise, the occlusion may be destabilized and other problems could result.

With the increasing development of new esthetic restorative materials, the use of cast gold alloy restorations has declined. Nevertheless, such restorations are an excellent choice when esthetics is not an overriding consideration, because these restorations provoke less harm to the opposing enamel.[13]

Today, researchers are concerned about the excessive wear of both restorative materials and opposing teeth. Unfortunately, clinical documentation of enamel wear, when opposing restorative materials, is difficult to obtain. However, these data can be acquired from *in vitro* studies. Thus, this investigation analyzed enamel wear and its opposing restorative material after *in vitro* cycling and loading.

METHODS AND MATERIALS

The materials tested are described in Table 1. Eight samples of each material were produced in the shape of a circular disk, using a metal matrix as a mold to fabricate all disk-shaped specimens (8 mm x 3 mm). The firing and glazing processes followed the manufacturer's recommendations. The IPS Empress specimens were obtained from wax patterns that were formed within the metal matrix. The wax patterns were invested and, after the lost wax technique, the IPS material was hot-pressed. Then, according to the manufacturer's recommendations, shaded porcelain was handcrafted onto the external surface of the sample disks of IPS Empress to achieve the final color. To standardize all the ceramic samples, one side of each disk was finished and polished with a Shofu Laboratory Porcelain Veneer Kit (Shofu Dental Gmbh, Ratingen, Germany) before the glazing procedures, making circular motions for 2 minutes and 40 seconds, taking 40 seconds for each component. Care was taken to use a new kit for each group. For the Degulor M specimens, wax patterns were formed using the metal matrix; they were then invested and cast using a conventional lost-wax technique. The gold disks were polished on one side using brown and green abrasive wheels (Shofu Dental Corporation, Menlo Park, CA, USA). The Targis specimens were built in three layers (1 mm thick) within the metal matrix and initially polymerized in the intermediary Targis Quick Unit (Ivoclar-Liechtenstein) for 10 seconds. Then, an additional polymerization was accomplished in the Targis Power Unit (Ivoclar) for 25 minutes at 95°C. The Targis disks were polished on one side using a composite polishing kit (Shofu).

Forty-eight extracted maxillary premolars were used. The teeth were prepared by sectioning the palatal cusp, using a handpiece under water spray irrigation, leaving only the buccal cusp. Then, the roots were sectioned to obtain 12-mm long specimens.

The specimens, buccal cusps and disks were embedded in acrylic resin inside stainless steel holders. These samples were then fastened to the wear machine. Figure 1A illustrates the dental wear tester used in this study. This equipment is similar to that described by Suzuki and others.[14]

For each test, eight restorative samples were fastened to the wear machine, and the individual cusps were screwed onto the ends of the loading rods. The disks were placed beneath each rod and clamped to the horizontal table of the machine. A load of 20 N was added to the loading rod to produce a standard contact force between the specimens. Both the upper (teeth) and lower (disks) specimens were seated in a water bath at 37°C, with a chewing rate of 1.3 Hz (80 cycles/minutes[15]). Each cusp was rotated 30 degrees as soon as it made contact with the ceramic surface and was then counter-rotated while unloading until it returned to its 00 cycles (Figure 1B). Before each test, the occlusal surfaces of each enamel cusp and disk were traced using a digital technique (Contracer Series 218, Mitutoyo, Japan, Figure 1C). The X, Y and Z coordinates of surface points (Figures 1D-E) were collected and arranged into three profiles per sample before cycling and after 150,000 and 300,000 cycles. The wear was determined by using a computer program (Formpak, Mitutoyo, Japan) that compared the three profiles to determine the vertical height loss for the cusps and the maximum depth of the wear track in the disks.

The average surface roughness (Ra) of surface specimens was recorded before the wear tests using a surface analyzer (Surftest SJ 201 P, Mitutoyo,

Table 1: *Restorative Materials Tested*

Materials	Characteristics (firing temperature)	Manufacturer
IPS Empress	leucite reinforced pressed ceramic (1075°C)	Ivoclar Vivadent, Schaan, Liechenstein
IPS Empress 2 (Empress 2)	apatite layering ceramic (800°C)	Ivoclar
Duceram Plus (D Plus)	conventional feldspathic ceramic (910°C)	Degussa, Dentsply, Rosbach, Germany
Duceram LFC (D LFC)	low-fusing ceramic with an amorphous glass containing hydroxyl ions and with non crystalline phase (680°C)	Degussa
Targis	laboratory processed composite with barium glass and mixed oxide fillers in BisGMA and urethane dimethacrylate resin	Ivoclar
Degulor M	Type IV gold: 70% gold casting alloy	Degussa

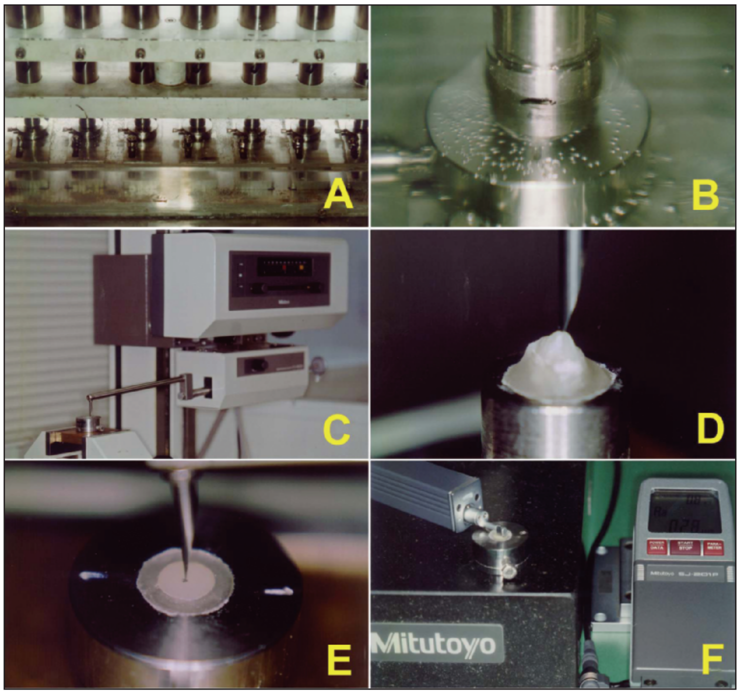

Figure 1. *Illustration of methods and materials: (A) The* in vitro *wear testing device; (B) Inserted mounting specimen during movement; (C) Contracer series 218; (D) Premolar cusp specimen inside a stainless steel holder; (E) Ceramic specimen inside a stainless steel holder; (F) Roughness surface analyzer.*

Figure 1F). Five surface profile tracings per specimen were recorded, and the mean of the five readings was considered to be the surface roughness for that specimen. Each of the five profiles was 2.4 mm in length and was traced across the potential wear track on the ceramic specimen surface with an approximate distance of 1 mm between each of the five profile tracings.

The analysis of the cusp and restorative material wear was done using one-way ANOVA analysis complemented by Tukey's test, with a level of significance of 5% (α=0.05). A contingency test was used to explore the correlation between the initial surface roughness and opposing enamel wear. The level of significance was 5% (α=0.05).

RESULTS

All the results are summarized in Table 2. The opposing enamel wear to the laboratory-processed composite (Targis) and the gold alloy (Degulor M) was similar and significantly less than that caused by all the ceramics tested ($p \leq 0.01$). IPS Empress was the ceramic that caused the greatest enamel wear at the opposing dental cusps when compared to all the other groups ($p \leq 0.01$). Additionally, ceramics Empress 2, D Plus and D LFC caused similar enamel wear to the opposing dental cusps.

A comparison made between enamel wear after each 150,000 cycles revealed that wear occurred significantly faster during the first 150,000 cycles than during the subsequent 150,000 cycles ($p \leq 0.05$), except for the Targis group, where this difference was not statistically significant.

The wear track depth of the restorative materials after 300,000 cycles showed that wear of Degulor M was significantly less than that of all the other materials tested ($p \leq 0.01$). Targis presented wear similar to Empress 2, D Plus and D LFC. D Plus and D LFC presented similar vertical height loss, which was significantly greater than Empress 2 ($p \leq 0.05$). Additionally, IPS Empress and Empress 2 presented similar wear.

Figure 2 shows the total vertical dimension loss of the different groups represented by the sum of the restorative materials height loss and the respective opposing enamel height loss after 300,000 cycles. The IPS Empress group caused the greatest vertical dimension loss ($p \leq 0.01$). The Empress 2, D Plus and D LFC groups presented similar results, which were significantly greater than that of the Targis group ($p \leq 0.01$). Among all the experimental groups, Degulor M resulted in the least total vertical dimension loss ($p \leq 0.01$).

The restorative materials tested showed initial roughness with statistically significant differences except for Degulor M and D Plus, which showed similar smooth surfaces. Empress 2 presented the greatest roughness

Table 2: *Mean ± SEM (standard error of the mean) of the Enamel and Restorative Material Wear, Vertical Dimension Loss and Restorative Material Roughness*

Restorative Material	Enamel Wear (mm) First 150,000 Cycles	Enamel Wear (mm) Second 150,000 Cycles	Enamel Wear (mm) Total	Restorative Material Wear (mm)	Roughness (Ra)
IPS Empress	0.51 ± 0.03*	0.21 ± 0.02	0.72 ± 0.04a	0.14 ± 0.01a	0.33 ± 0.009a
Empress 2	0.28 ± 0.01*	0.09 ± 0.01	0.38 ± 0.01b	0.20 ± 0.01a,c	0.45 ± 0.006b
D Plus	0.21 ± 0.01*	0.11 ± 0.002	0.32 ± 0.02b	0.26 ± 0.02b	0.22 ± 0.003c
D LFC	0.21 ± 0.02*	0.13 ± 0.007	0.34 ± 0.02b	0.26 ± 0.01b	0.19 ± 0.003d
Targis	0.05 ± 0.003	0.02 ± 0.003	0.08 ± 0.005c	0.21 ± 0.02b,c	0.26 ± 0.006e
Degulor M	0.10 ± 0.007*	0.02 ± 0.003	0.12 ± 0.006c	0.20 ± 0.001d	0.23 ± 0.003c

**Significantly higher than the wear of the same material during the second 150,000 cycles; Different letters indicate significant statistical differences among the different materials.*

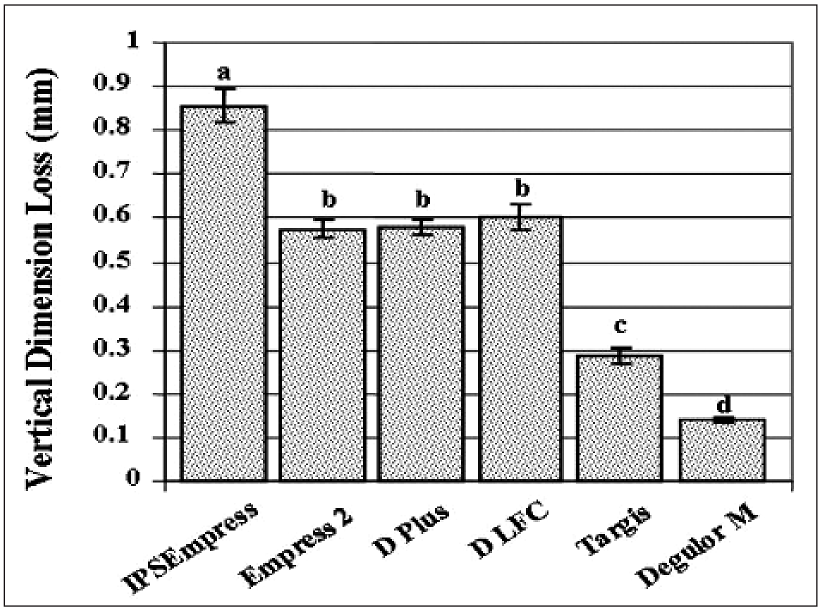

Figure 2. *Mean ± SEM (standard error of the mean) of total vertical dimension loss (the sum of the enamel height loss and the restorative material height loss) from the experimental groups. Different letters show significant differences.*

among all the materials tested ($p \leq 0.01$). In addition, D LFC presented less roughness than D Plus ($p \leq 0.05$) and all the others materials tested ($p \leq 0.01$).

There was no correlation between the initial surface roughness and enamel wear (C=0.29; p=1.0).

DISCUSSION

Restorative dental materials must fulfill many desirable properties, one of which is wear comparable to human enamel.[11] Wear is an important consequence of occlusal interactions. If not controlled, wear could lead to poor masticatory function, with a concomitant reduction in quality of life and possible deterioration of systemic health.[16-17] Thus, rather than considering esthetic improvement as the main criterion for material selection, tooth conservation should be the primary goal of treatment planning.

There are many commercially available dental restorative materials, and this study analyzed enamel wear against four different ceramics, a laboratory processed composite and a gold alloy. A wear-testing device was used to attempt to create a combined impact that simulates masticatory function. Human tooth cusps against flat restorative material specimens have been previously used in many *in vitro* investigations in order to study the wear of enamel opposing restorative materials.[2,4,7,18-21] The rate of cycling used was based on a review by Bates and others,[15] where 80 cycles per minute was reported to approximate the natural chewing rate.[15] Measurement of the total height loss of both material and enamel has clinical relevance, since it might correlate with a diminishing of occlusal vertical dimension and its consequences.[19-20]

In this experiment, the laboratory-processed composite (Targis) caused enamel wear similar to that of the gold alloy and significantly less than all the ceramics tested. These results are in agreement with Hudson and others,[7] who found that other laboratory-processed composites also caused enamel wear similar to that of a gold alloy.

The greatest wear of enamel resulted from abrasion against IPS Empress. This finding has been previously observed.[4] This result could be due to differences in the inner composition and the nature of the external surface of this ceramic. This indicates that shading surfaces should be avoided when enamel opposes the restoration,[19,22] and the use of IPS Empress on functional contacting surfaces should be avoided.

Another interesting observation was that D LFC caused similar enamel wear when compared with D Plus and Empress 2. The hydrothermal ceramic D LFC has no crystalline phase. When hydrated, it forms a growing Si-hydroxyl surface layer that reaches a maximum thickness of 3 µm and, when this layer is taken off by mechanical forces, a new hydrolytic layer is built-up quickly. This layer significantly reduces surface hardness and increases its bending strength.[23] Therefore, it was expected that D LFC would reduce the wear of antagonistic enamel.[24] However, this was also not observed by Al-Hiyasat and others,[21] who also found no difference in the enamel wear pattern caused by D LFC when compared with other ceramics. In fact, it has been demonstrated that material hardness was poorly correlated with the abrasiveness of ceramic materials on human enamel.[11,25]

Previous studies suggested that, among ceramic properties, the inner compositions are more likely to be responsible for opposing enamel wear.[26] This is because enamel wear appears to be more related to microstructure differences between the different ceramic materials. Unfortunately, proprietary formulations have not been revealed, but generalizations can be made. Jung and others[27] postulated that the lifetime of dental restorations is limited by the accumulation of contact damage during oral function. Therefore, fracture resistance could be an important factor in enamel wear because, when a ceramic surface presents increased damage, it will become brittle, rougher and more abrasive.

The findings of the current study, which relate to enamel wear dynamics, showed that the wear rate was higher in the initial 150,000 cycles, then the wear decreased gradually. These results, which are in agreement with previous studies,[4,19-20] may be due to the size of the contact area between the couples. These areas, at the earlier cycle's stages, were less and, with time, they increased gradually, then the load became distributed over a greater area, producing a decreased wear rate.

Differences in wear of all the materials tested were observed. Ceramic wear is directly related to fatigue response after a large number of contact cycles.[28-29] In this study, a large number of contact cycles caused damage inside the contact area, which could have produced radial cracks. It is known that radial cracks can lead to rapid degradation in strength properties, signaling the end of the useful lifetime of the ceramic.[27] The microstructure of the ceramics, represented by amount, exposure and shape of the crystals, may also be another important factor in the ceramic restoration's lifetime.[26,30] Based on the results of the current study, it can be inferred that repeated contact causes different damage modes in ceramics, depending on their individual microstructures.

Based on previous studies,[31] Suzuki and others[10] stated that, although Targis exhibited the highest wear among the materials tested, it is still in the excellent wear resistance category when compared with direct composite materials.[10,31] When analyzing composite wear, one of the theories relates to occlusal contact wear and is based on the effects of microfracture and degradation of the silane coupling agent by hydrolysis and chemical absorption.[32] The microfracture mechanism of wear was proposed by Leinfelder and others.[33] The basis of this mechanism is that the filler particles have a higher modulus than the resin matrix; therefore, they deform less than the surrounding matrix during function and produce microfractures in the matrix.[33] Additionally, fatigue contact wear has been reported in dental composites.[34-35] Overall, ceramics and laboratory processed composite materials should have a microstructure relatively free of microcracking in order to achieve greater wear resistance.

The analysis of vertical dimension loss has relevance, since, when planning any restoration, the practitioner must consider establishing stable occlusal contacts. Otherwise, occlusal destabilization may occur. Targis, which caused an intermediate vertical dimension loss between ceramics and gold alloy, could be an alternative when esthetics are desired. This recommendation is supported by other authors, who showed that Targis has an attritional wear resistance comparable to enamel after contact cycle tests against enamel cusps.[8-9]

A positive correlation between the materials' surface roughness and opposing enamel wear would be expected; however, this was not observed in this study. Empress 2 and the D LFC presented the greatest and least initial roughness, respectively; however, both ceramics provoked similar antagonistic enamel wear. According to Metzler and others,[36] the surface of porcelain is important initially, but after this surface has been compromised, the nature of the underlying porcelain becomes the factor ultimately affecting wear rates. In fact, only initial roughness of the materials was recorded and compared to the final enamel wear, but, after 300,000 loading cycles, they may have changed, and the nature of the underlying material could have been more important than roughness for determining the final enamel wear.

CONCLUSIONS

The findings of the current study point to the recommendation that Targis could be an appropriate alternative to ceramic, since it is esthetic and produces wear similar to that of gold alloy. Additionally, placement of an IPS Empress ceramic restoration in the surface contact area would be contraindicated when opposed to natural teeth. Furthermore, additional studies are needed in an attempt to reduce opposing enamel wear when ceramic restorations are placed.

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