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Wear Properties of a Novel Resin Composite Compared to Human Enamel and Other Restorative Materials

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Clinical Relevance

This *in vitro* study showed that the wear resistance of new resin composites may be similar to that of gold alloys and human enamel, which suggests that they are well suited for use as a restorative solution for the occlusal bearing surfaces of posterior teeth.

SUMMARY

The purpose of this in vitro study was to compare the two-body wear resistance of human enamel, a pressable glass-ceramic (Imagine PressX), a type 3 gold alloy (Aurocast8), three resins composites currently available on the market (Enamel Plus HRi, Filtek Supreme XTE, Ceram.X duo), and one recently introduced resin composite (Enamel Plus HRi-Function). Resin composites were tested after simple light curing and after a further heat polymerization cycle. Ten cylindrical specimens (7 mm in diameter) were manufactured with each dental material according to standard laboratory procedures. Ten flat enamel specimens were obtained from freshly extracted human molars and included in the control group. All samples were subjected to a two-body wear test in a dual-axis chewing simulator over up to 120,000 loading cycles, against yttria stabilized tetragonal zirconia polycrystal cusps. Wear resistance was analyzed by measuring the vertical substance loss (mm) and the volume loss (mm^3). Antagonist wear (mm) was also recorded. Data were statistically analyzed using one-way analysis of variance (ANOVA) (wear depth and volume loss) and Kruskal-Wallis one-way ANOVA on ranks (antagonist wear). Heat-cured HRi function and

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Aurocast8 showed similar mean values for wear depth and volumetric loss, and their results did not statistically differ in comparison with the human enamel.

INTRODUCTION

The term "wear" refers to the net loss of a material from its surface under operational conditions. The phenomenon takes place rather frequently in the oral cavity and is dependent on many different factors that interact almost simultaneously:[1] the abrasive nature of food, neuromuscular force,[2] parafunctional habits,[3] enamel thickness and hardness (which depend on degree of mineralization),[4,5] and pH and nature of the saliva. On the occlusal surfaces of teeth in direct contact, as in parafunctional habits (bruxism and clenching), attrition occurs. Abrasion, on the other hand, takes place in normal function in the presence of a third body, such as food particles, during mastication.

Excessive antagonistic wear may lead to several problems, including hypersensitivity, loss of occlusal contact, destruction of periodontal tissue, loss of masticatory efficiency, faulty tooth relationship, fatigue of masticatory muscles, and changes in the vertical and horizontal jaw relations, which may cause functional and esthetic impairments.[6-10]

As with enamel or dentin, restorative materials are subjected to wear, and the wear mode depends on the type of restorative material. Material loss may occur through microploughing, microcutting, microcracking, and microfatigue.[11]

When dealing with severely compromised teeth, different kinds of metal-free restorations are available as alternatives for metal-supported dental restorations. All ceramic restorations consist entirely of porcelain or, alternatively, a high-strength ceramic substructure, which is veneered with porcelain. Adhesively luted resin composite indirect restorations[12,13] (onlays and overlays) may also represent a valid[14-16] and conservative approach.

A novel resin-based composite (Enamel plus HRi-function, Micerium, Avegno, Genova, Italy) has been recently fabricated and proposed as a restorative for direct and indirect posterior restorations and as an esthetic veneering material over metal frameworks for fixed dental and implant supported prostheses. For this new material, the manufacturer claims that the wear characteristics are very close to that of human enamel.

The purpose of this study was to evaluate the *in vitro* two-body wear resistance of the recently introduced resin based composite (HRi-function) subjected to 120,000 chewing simulation cycles and to compare the results with the wear resistance of human enamel and different dental materials typically used to restore posterior teeth. The null hypothesis tested was that no difference could be detected among the materials under investigation concerning the wear properties.

METHODS AND MATERIALS

Materials used in this study included a silicon oxide (SiO) based pressable glass-ceramic (Imagine PressX, shade A1, Wieland Dental Ceramics, Pforzheim, Germany), a type 3 gold alloy (Aurocast8, Nobil-Metal, Villafranca d'Asti, Asti, Italy), three resin composites currently available on the market (Enamel plus Hri, Micerium, Avegno, Genova, Italy; Filtek Supreme XTE, 3M ESPE, Seefeld, Germany; Ceram.X duo, Dentsply DeTtrey GmbH, Konstanz, Germany), and a recently introduced microhybrid resin composite (Enamel plus HRi-function, Micerium).

Ten pressable ceramic specimens (n=10) were fabricated according to the conventional lost-wax technique: plexiglass (Plexiglas, Evonik Röhm GmbH, Darmstadt, Germany) discs, 7 mm in diameter and 6 mm thick, were prepared, invested, and burned out by heat. The void was filled with the pressable ceramic material and pressed at a temperature of 930°C for 20 minutes.

Resin composite cylindrical specimens were obtained by placing uncured pastes inside translucent polyethylene cylindrical molds with an inner diameter of 7 mm and height of 6 mm. Each mold was put on a glass surface and then filled with composite resin in three increments of about 2 mm. Each layer was individually light cured for 40 seconds (L.E. Demetron I with a 1200 mW/cm^2 output, Sybron/Kerr, Orange, CA, USA). The distance of the tip from the specimen was maintained at 1 mm. Twenty samples were produced for each one of the three resin composites under investigation: half of them, ten for each material (n=10), were assigned to the light-cured groups. The remaining 40 cylinders (n=10) were subjected to an additional cycle of heat-curing in a composite oven for 10 minutes (LaborLux, Micerium) and assigned to the heat-cured groups. All composite surfaces were ground with 600-grit silicon carbide (SiC) paper under running water for 30 seconds and subjected to finishing and polishing procedures: diamond pastes (Shiny A, 3 μm, and Shiny B, 1 μm;, Micerium) were applied with a soft goat's-hair brush (Micerium) and then polished with aluminum oxide paste (Shiny C, Micerium).

Ten gold alloy samples were made using the traditional lost wax technique, according to the manufacturers' directions.

For the control group, flat human enamel specimens (n=10) were obtained from 10 caries-free, freshly extracted human molars, collected in accordance with the guidelines specified by the local human subjects oversight committee. The teeth were stored in an aqueous solution of 0.5% chloramine T (Delchimica Scientific Glassware, Napoli, Italy) at 4°C until the beginning of the experiment, but no longer than 1 week after extraction. The crown portion of each tooth was sectioned horizontally to the buccal cementoenamel junction, using a cylindrical diamond rotary cutting instrument (Intensiv 314, 1.4 mm in diameter, L.8.0 mm, Intensiv SA, Grancia, Switzerland) mounted on a high-speed handpiece (Bora L, Bien-Air Dental, Bienne, Switzerland) with water-spray cooling. Each crown was then abraded on the buccal aspect with 1200-grit abrasive paper and finished with 4000-grit abrasive paper to a depth of 0.5 mm in order to achieve a flat area of about 5 mm in diameter for loading during the wear test. The enamel surfaces were then examined under a stereomicroscope (Nikon SMZ10, Tokyo, Japan) to ensure that they were free of exposed dentin.

All specimens were stored in distilled water for 24 hours at 37°C before wear simulation.

Wear Testing and Measurements

Cylindrical specimens were embedded in acrylic resin and then subjected to a two-body wear test in a dual axis chewing simulator (Willytec, Munich, Germany). As antagonists, standard cusps with a slight conical shape and a round tip 3 mm in diameter (Figure 1) were milled from yttria stabilized tetragonal zirconia polycrystalline blocks, using a computer-aided milling machine (Dental CAD/CAM GN-1, GC, Tokyo, Japan). These specimens were finally polished with 6 μm diamond pastes.

Cusps were embedded in autopolymerizing acrylic resin using custom-made copper specimen holders. The masticatory cycle in this study consisted of three phases: contact with a vertical force of 5 kg, horizontal sliding of 0.7 mm, and separation of the specimen and its antagonistic cusp. All other test parameters have been summarized in Table 1. Each sample was loaded at 1.6 Hz for a total of 120,000 chewing cycles.

Subsequently, samples were subjected to a quantitative surface analysis using a CAD/CAM three-dimensional contact scanner (Renishaw Dental Scanner, Renishaw, Wotton-under-Edge, UK). From each worn surface, a three-dimensional mesh was obtained. Vertex position accuracy in the mesh could be approximated to 1 μm, according to the information provided by the scanner manufacturer (Renishaw). The three-dimensional mesh was imported into a computer-aided design software (AutoCAD 2009, Autodesk Inc, San Rafael, CA, USA). A reference plane for depth measure was defined, using three points on the mesh, chosen on the flat unworn surface surrounding the abraded area. In this way, the unworn surface was aligned to the XY plane. The most distant vertices from the reference plane were detected. The three-dimensional coordinates of the deepest vertex were measured and its Z coordinate, expressed in millimeters (mm), was assumed as the vertical substance loss for that sample. The volume delimited between the reference plane and the worn surface was calculated and assumed as the volumetric loss (mm^3). Moreover, the height of each zirconia cusp was measured before and after each test using a digital caliper with an accuracy of 1 μm. The height difference between the pretest and posttest measurements of each cusp was recorded as the antagonist wear (mm).

After the three-dimensional evaluation, the wear facets on the abraded samples were also sputter coated (except the gold alloy samples) and subjected to a scanning electron microscope (SEM) analysis (EVO 50 XVP LaB6, Carl Zeiss SMT Ltd, Cambridge, UK) at different magnifications.

Statistical Analysis

Mean and standard deviation values for wear depth, volume loss, and antagonist wear were calculated in each group. Data were statistically analyzed using SPSS 11.0 statistical software (SPSS Inc, Chicago, IL, USA).

After determining that both wear depth and volume loss data were normally distributed, mean values were compared using one-way analysis of variance (ANOVA) tests; multiple comparisons were performed according to the Tukey method.

Data for antagonist wear was not normally distributed. As a consequence, a Kruskal-Wallis one-way ANOVA on ranks was performed to compare the median values; multiple comparisons were executed according to Dunn's method. The significance level was set at $\alpha=0.05$ in all tests.

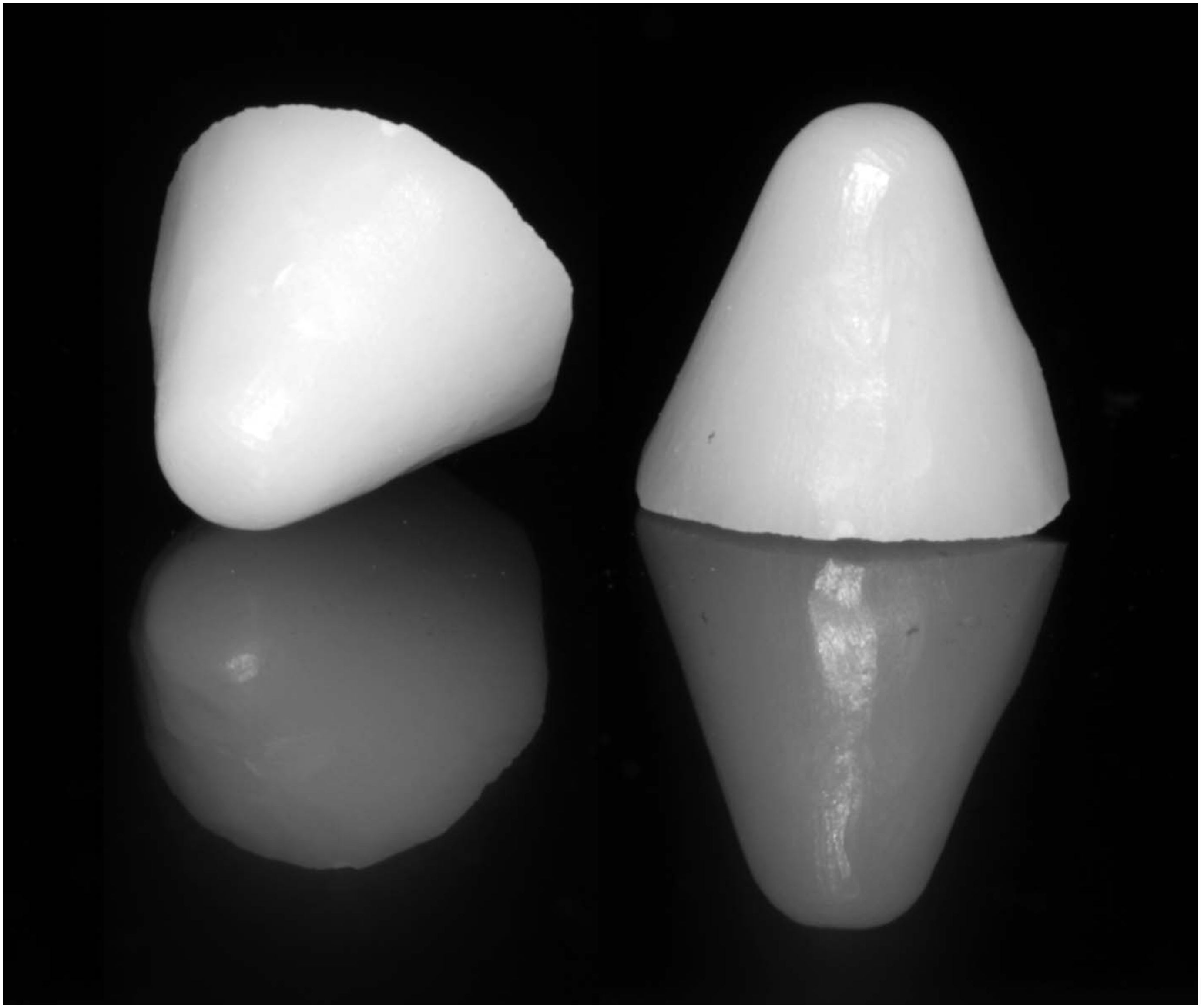

Figure 1 *Standard zirconia cusps used as abraders in the chewing simulation test.*

Table 1: *Configuration of the Parameters Set for the Wear Method*

PARAMETER	VALUE
Number of cycles	120,000
Force	5 kg
Height	3 mm
Lateral movement	–0.7 mm
Descendent speed	60 mm/s
Lifting speed	60 mm/s
Feed speed	40 mm/s
Return speed	40 mm/s
Frequency	1.6 Hz

RESULTS

Table 2 displays the mean values for wear depth and volume loss recorded in each category after 120,000 chewing simulation cycles. The wear recorded for the antagonistic cusps is also shown. Representative SEM images of the wear facets that could be observed in the experimental groups are shown in Figure 2. Samples made of pressable glass-ceramic (Imagine PressX), heat-cured novel resin composite (Enamel Plus HRi-function), and type 3 gold alloy (Aurocast8) led to statistically similar wear depth and volumetric loss values, which were generally lower than what was observed for the remaining groups; moreover, these materials were not statisti-

Table 2: ***Mean Values (and Standard Deviations) for Wear Depth, Volume Loss, and Antagonist Wear Achieved in the Experimental Groups^{a}***

	Wear Depth (S.) (mm)	Volume Loss (S.. (mm^3)	Antagonist Wear (SD) (mm)
HRi light-cured	0.485 (0.064)^{e}	1.452 (0.245)^{d}	0.010 (0.007)^{a,b,c}
Filtek XTE light-cured	0.464 (0.069)^{e}	0.972 (0.247)^{c}	0.004 (0.002)^{a,b,c}
Ceram.X duo light-cured	0.416 (0.073)^{d,e}	0.894 (0.259)^{c}	0.007 (0.007)^{a,b,c}
HRi-Function light-cured	0.335 (0.069)^{b,c,d}	0.529 (0.139)^{a,b}	0.006 (0.001)^{a,b,c}
HRi heat-cured	0.463 (0.063)^{e}	1.016 (0.198)^{c}	0.015 (0.013)^{a,b}
Filtek XTE heat-cured	0.459 (0.068)^{e}	1.017 (0.239)^{c}	0.016 (0.017)^{a,b}
Ceram.X duo heat-cured	0.409 (0.118)^{c,d,e}	0.806 (0.397)^{b,c}	0.015 (0.011)^{a,b}
HRi-Function heat-cured	0.276 (0.058)^{a,b}	0.464 (0.191)^{a}	0.016 (0.003)^{a}
Wieland Imagine PressX	0.303 (0.065)^{a,b,c}	0.531 (0.143)^{a,b}	0.002 (0.002)^{c}
Aurocast8 by NobilMetal	0.219 (0.060)^{a}	0.328 (0.140)^{a}	0.004 (0.005)^{b,c}
Human Enamel	0.216 (0.070)^{a}	0.404 (0.200)^{a}	0.013 (0.004)^{a,b}

[a] *Same superscript letters indicate no statistically significant differences ($p > .05$).*

cally different in mean wear values compared with human enamel. The highest mean values for wear depth were recorded in the Enamel plus HRi and Filtek Supreme XTE light-cured groups, with no statistically significant differences in comparison with the Ceram.X group.

DISCUSSION

Wear in the oral cavity is a relevant factor that should be carefully considered when selecting the appropriate restorative material in clinical dental practice. An ideal material possesses both high wear resistance and minimum abrasiveness: a restorative material that replaces enamel and/or opposing enamel should have functional characteristics as similar as possible to natural enamel.[17]

The null hypothesis tested in the present study, which assumed no difference in terms of wear properties among the several restoratives under investigation, has to be rejected.

The type 3 gold alloy (Aurocast8) showed wear behavior very similar to that of human enamel. Over the past decades, the clinical choice of placing metal or gold on the occlusal surfaces proved to be a valid alternative in all cases where the prosthetic occlusion was in contact with enamel, resin composite, porcelain, or a combination of such materials:[18] it has been previously reported as a fairly appropriate solution from a functional point of view,[19] causing minimal or no wear to the opposing occlusal materials.[20] It may be supposed that gold-based alloys hardly interfere with the occlusal balance of patients subjected to prosthetic rehabilitations.[21] The unsightly display of

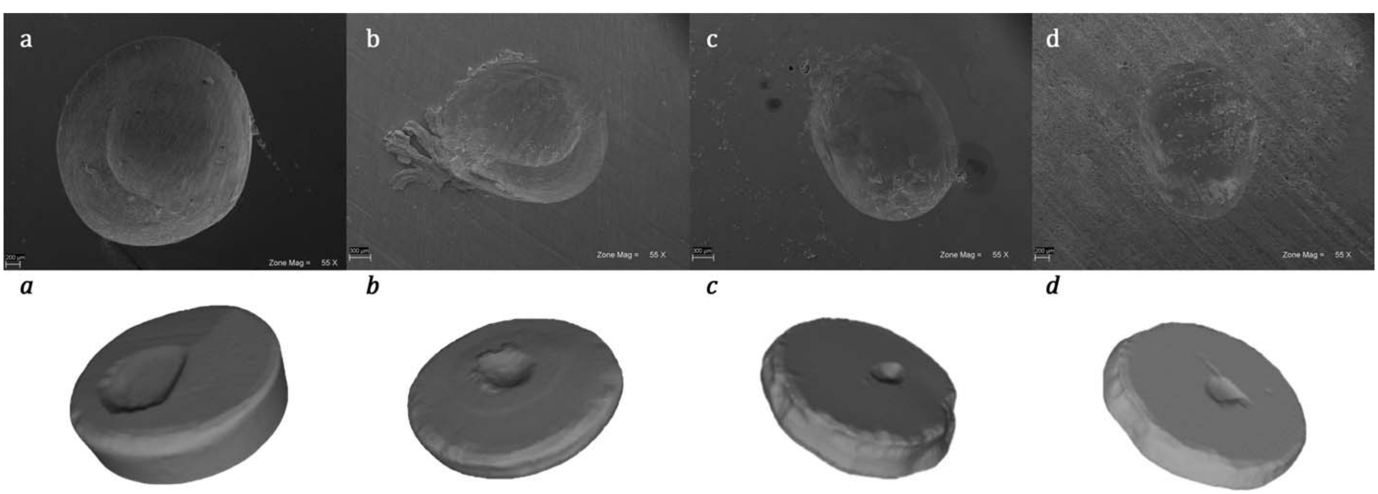

Figure 2 *Scanning electron microphotographs (upper row; original magnification 55×) and three-dimensional meshes (lower row) showing the wear facets of some representative samples from the Filtek XTE heat-cured group (a), Aurocast8 gold alloy group (b), HRi-Function heat-cured group (c), and Imagine PressX glass-ceramic group (d).*

metal is considered one of the main disadvantages of using gold occlusal surfaces.

Also, the new heat-cured resin composite HRi-function, whose wear depth and volume loss were statistically comparable to those of gold, was not significantly different from human enamel. In our opinion, dental materials that show a wear behavior as close as possible to natural tooth hard tissues should always be preferred in clinical practice, as they are unlikely to interfere strongly with the patient's musculoskeletal equilibrium.

All the other resin composites tested in the present study (Filtek Supreme XTE, Enamel Plus HRi, Ceram.X duo) led to increased wear values in the light-cured and the heat-cured groups. In clinical conditions, excessive occlusal wear is not desirable as it may determine loss of occlusal contact, loss of masticatory efficiency, altered tooth and jaw relationships, and muscular fatigue, ultimately compromising both function and esthetics.[6-10] This is clinically quite relevant mainly when dealing with parafunctional patients.

The Hri-function resin based composite tested in the present study was recently introduced by the manufacturer with the aim of improving mechanical properties and achieving predictable long-term clinical outcomes when used to restore occlusal surfaces on posterior teeth. From this point of view, it can be considered novel, as it is not simply an evolution of Enamel Plus HRi: it is basically a different material. The enamel masses of Enamel Plus HRi are nano-hybrid resin composites, studied to guarantee the best esthetics, mainly on anterior teeth, thanks to the same refractive index (RI) as human enamel. On the other hand, Hri-function has to be considered as a micro-hybrid resin composite: it lacks the favorable optical properties of Enamel Plus HRi (same RI as human enamel) and has been formulated putting the greatest efforts toward optimizing the bond between the filler particles and the resin matrix.

In this study the HRi-function mean wear values appeared extremely promising. They were the closest to human enamel among the light-cured resin composites under investigation. Furthermore, the heat-cured samples were statistically similar to the wear values achieved with Aurocast8 gold alloy. These results may suggest that the newly proposed Hri-Function is a restorative material functionally similar to gold alloy in terms of wear behavior, while maintaining all the advantageous peculiarities of a resin composite: a good esthetic appearance, ease of handling and workability, an established predictability of the achievable clinical results, and low cost. Moreover, being a resin composite, this material is primarily suitable for direct use, though it probably exhibits the best functional performances in indirect use for manufacturing adhesively luted indirect partial restorations and as an esthetic veneering material over the metallic frameworks of fixed dental or implant supported prostheses.

In the present study the wear resistance of a SiO-based glass ceramic was also investigated, as glass ceramics are among the most commonly used materials for metal-free single crowns and inlays or onlays; its wear behavior was fairly favorable as it was statistically similar to human enamel in wear depth and volume loss. However glass-ceramic materials for fixed reconstructions require a certain thickness to have adequate fracture resistance, whereas resin materials are more fracture resistant even in thin reconstructions.[22-24] Moreover, it was previously reported that the wear characteristics of resin-based materials offer some advantages over glass ceramics as they yield less wear in the antagonist as opposed to human enamel.[22,25,26] Finally, dental ceramics cannot be used in a direct technique, making the intraoral repair procedures less reliable and generally leading to a higher overall restoration cost.

As clinical evaluation of wear is expensive, time consuming, and methodologically rather complicated, mastication simulators have been developed in an attempt to simulate the oral environment and produce wear in test specimens.[27] Previous *in vitro* studies[28] used the Willytec chewing simulator[29] and thermal cycling[30] to evaluate two-body[31] or three-body [1] wear resistance of different materials. Antagonists of different shapes[1,32-34] and structures[35,36,37] have also been used in previous research. Heintze and others[38] emphasized the need for using a standardized form of artificial antagonist for comparisons because human enamel requires extensive preparation to achieve an adequate shape of the abrader. Moreover its natural substrate may show wide variability from one person to another and among different teeth in the same mouth concerning the degree of mineralization and thickness.

Therefore, zirconia ceramic balls have been proposed [38] as antagonistic abraders to properly evaluate the wear of human enamel and dental materials[30] in standardized experimental conditions. In comparison with other artificial abraders (ie, steatite), zirconia ceramic balls retained their shape during the entire test period, so the influence of changes in the antagonist's surface on wear of specimens can be minimized.[35,37]

CONCLUSIONS

The ongoing evolution of dental restoratives is leading to the development of resin composites that are becoming comparable to that of gold alloys in terms of functional qualities, although they maintain their inherent esthetic features, ease of use, and low cost.

The wear properties of the newly introduced HRi-function resin composite proved to be similar to that of the Aurocast8 type 3 gold alloy and human enamel, indicating that it is a suitable material for the occlusal bearing surfaces of posterior teeth.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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