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Running (short) Title: Wear of dental materials opposing themselves

Clinical Relevance: Thanks to new composite resins and dental ceramics an excellent aesthetic may be clinically combined to outstanding functional features in the matter of their wear behavior, which proved to be very similar to that of the well-known traditional gold-alloys.

SUMMARY

The purpose of the present in vitro study was to compare the 2-body wear resistance of a type 3 gold alloy (Aurocast8), two lithium disilicate glass ceramics (IPS e.max CAD and IPS e.max Press), an heat-pressed feldspathic porcelain (Cerabien ZR Press), an yttria-stabilized tetragonal zirconia polycrystal ceramic (Katana Zirconia ML) and three heat-cured composite resins (Ceram.X Universal; Enamel Plus Function; Enamel Plus HRi) opposing antagonistic cusps made out of the same restorative materials. Ten specimens, 6 mm thick, and ten cusp-shaped abraders were manufactured with each test material according to standard laboratory procedures. All sample/antagonist pairs made of the same material were subjected to a two-body wear test in a dual-axis chewing simulator for over up to 120000 loading cycles. The total wear (mm) for each sample/antagonist pair was calculated as the sum of the sample wear depth (mm) and its antagonist wear (mm). Data were statistically analysed using a One-Way ANOVA.
The total wear for the gold-alloy was not significantly different compared to Ceram.X Universal, Enamel Plus Function, IPS e.max CAD and Cerabien ZR Press. Significantly increased wear values

were observed on Enamel Plus HRi and IPS e.max Press. The least values for total wear were registered on the monolithic zirconia.

INTRODUCTION

A huge number of dental restorative materials are nowadays available for prosthetic purposes. The ideal restorative should resemble as close as possible the tooth hard tissues to be replaced. Amongst material properties, the wear behavior seems of crucial importance as either a reduced wear resistance or an exaggerated abrasiveness may severely jeopardize over the years the esthetic and functional outcome of extensive occlusal rehabilitations, especially when treating patients with parafunctions.

Dental gold-based alloys showed wear characteristics very similar to the human enamel.[1,2] Teeth to receive cast gold restorations can often be prepared with minimal reduction to conserve tooth structure and decrease trauma to the tooth and pulp, also thanks to partial coverage preparations.[3] Despite their excellent marginal accuracy[4,5] and their uncontested mechanical/tribological properties,[3] an increasing demand for better esthetics persuaded clinicians to withdraw full-gold restorations in favor of alternative tooth-colored materials.

Dental ceramics exhibit superior optical properties, excellent color stability and proved biocompatibility.[6-8] Their clinical reliability has also increased[9-13] following the latest advances in adhesive dentistry[14-18] and the recent introduction of strengthened and enhanced ceramic systems.[19] Ceramic materials are wear resistant[20,21] but they may damage the opposing enamel.[22-25] The general belief that human enamel might be subject to accelerated wear when opposed by traditional porcelain-fused-to-metal crowns[26] was further confirmed *in vivo* in 2011 by Silva.[27] Contradictorily, in a similar *in vivo* study by Etman, metal-ceramic-crowns produced the least tooth wear in comparison to polycrystalline-alumina copings veneered with feldspathic porcelain and to hotpressed high-leucite glass-ceramics.[28] A recent review indicated that some all-ceramic crowns are as wear friendly as metal-ceramic crowns.[29] The author of the same review failed to find a strong association between tooth wear against ceramics and any specific causal agent,[29] including the material hardness or its chemical composition, thus underlying the compelling need for additional studies on this specific research topic. The most recent *in vitro* studies reported for some new all-ceramic systems an abrasiveness very close to that of human enamel[30] as well as a wear resistance similar to that that of traditional gold-alloys.[2]

In a direct comparison between properties, such as flexural strength, hardness or optical behavior, ceramic/glass-ceramic materials are generally superior to dental composites.[31] Nevertheless, thanks to continuous innovations in filler composition, morphology and particle size, current micro/nano-hybrid composites definitely show proper aesthetic/mechanical features for a successful use in all areas of the mouth.[32,33] Additionally an increasing appeal of composite resins is warranted by their ease of use, the possibility of an easy and invisible intra-oral repair of minor defects induced by function, the opportunity to employ them both following a direct and an indirect approach.[31] Those characteristics are extremely attractive as minimally invasive solutions seem nowadays preferred in every branch of dentistry.[34-36] Composites are traditionally considered more wear friendly than dental ceramics. In general, resins based materials produce lower enamel antagonist wear than ceramic based ones, both in the manually polymerized and in the CAD/CAM versions.[37] In a recent *in vitro* study, resin composite antagonists led to the lowest wear on the opposing enamel, significantly reduced compared to the enamel wear recorded against lithium disilicate glass-ceramic abraders.[38]

Moreover, innovative and enhanced resin composites have been recently introduced, showing promising *in vitro* wear resistance values, statistically similar to those of human enamel and gold based alloys.[1]

So far, several studies have analyzed the in vitro wear resistance of restorative materials opposing either human enamel antagonists or dedicated artificial abraders.[1,2,20,21] The abrasiveness of gold-based alloys, resin composites, feldspathic porcelains, glass-ceramics and polycrystalline zirconia-based materials towards tooth hard tissues has been also subject of extensive investigation.[26-30] On the other hand, little is known about the in vitro wear behavior of a specific dental restorative material opposing itself or other different restorative materials. To our knowledge, only one *in vitro* study has so far investigated the two- and three-body wear between resin composites used both as samples and as antagonistic abraders.[39] Yet such an information seems particularly important not only when planning extensive occlusal rehabilitations involving antagonistic teeth within the opposing hemiarches, but also when selecting the appropriate material to restore one or more teeth that face already restored antagonists.

On these bases, the purpose of the present in vitro study was to assess the 2-body wear of a type 3 gold-alloy, an yttria stabilized zirconia polycrystalline ceramic, an heat-pressed feldspathic porcelain, a lithium disilicate glass-ceramic (milled and heat-pressed) and three different heat cured resin composites opposing standardized antagonistic cusps made out of the same restorative materials. Each sample was subjected to 120000 mastication simulation cycles. The null hypothesis tested was that no difference could be detected in the wear resistance among the materials under investigation

METHODS AND MATERIALS

A complete list of the materials tested in the present study, together with some data about their composition, is given in Table 1.

Ten IPS e.max Press (n=10) and ten Cerabien ZR Press (n=10) cylindrical specimens were fabricated according to the conventional lost wax technique by investing and eliminating acrylic resin disks (Plexiglas; Evonik Rӧhm GmbH) 7 mm in diameter and 6 mm thick. The void was filled with the pressable ceramic, following the pressing parameters by the respective manufacturer.

For CAD/CAM materials (IPS e.max CAD and Katana Zirconia ML), ceramic blocks were secured to the arm of a saw (Micromet M; Remet s.a.s.) and subjected to consecutive cuts to obtain 6-mm-thick slices. Ten lithium disilicate specimens were produced (n=10) and subsequently crystallized in a ceramic furnace (Programat EP 5000; Ivoclar Vivadent AG) at 840-850° C. The zirconia slices (n=10) were, instead, sintered at 1500° C for 2 hours.

For each one of the three resin composites under investigations (Ceram.X Universal, shade A2; Enamel Plus Function, shade EF2; Enamel Plus HRi, shade UE2), ten cylinders (n=10) were manufactured using transparent polyethylene molds measuring 7 mm in diameter and 6 mm in height. The mold was positioned on a glass surface and then filled. The resin composite was applied in three 2-mm thick layers. Each layer was individually polymerized for 40 seconds (L.E. Demetron I; Sybron/Kerr, Orange, CA, USA with a 1200- mW/cm2 output). After mold removal, composite cylinders underwent a further heat-curing cycle (Laborlux; Micerium) at 70°C for 10 minutes.

Gold alloy specimens (n=10) were made using the traditional lost wax technique.

Eight sets of ten standard cusps (n=10) having a slight conical shape and a 3-mm-round tip were also manufactured employing each one of the eight restorative materials under investigation and according to the respective manufacturer's indications. After manufacturing, resin composite cusps were heat-cured as explained for composite cylindrical specimens.

All specimens and cusps were stored for 24 hours at 37°C and then subjected to a 2-body wear test in a dual axis chewing simulator (CS-4.2; SD Mechatronik GmbH) according to the methodology described elsewhere.[1] Each specimen was tested against a standard cusps made out of the same restorative material. The chewing simulation parameters used are summarized in Table 2.

After testing, a 3-dimensional surface analysis of all specimens was performed with a CAD/CAM contact scanner (dental scanner; Renishaw plc) and the wear depth (mm) was calculated.[1] Moreover, the difference between the pretest and posttest height of each antagonistic cusp was measured and assumed as the antagonist wear (mm). The total wear (mm) for each sample/antagonist pair was finally calculated as the sum of the wear depth and the corresponding antagonistic cusp wear.

Means (and standard deviations) for the total wear of each material were calculated and then compared using a 1-way analysis of variance (ANOVA) and Tukey Honestly Significant test (α=.05).

RESULTS

Table 3 shows the mean total wear values recorded for each test material after 120000 mastication simulation cycles against antagonistic cusps made out of the same restorative material. The contribution of mean antagonist wear and mean sample wear depth to the ultimate calculation of the total wear is also given. The 1-way ANOVA test showed that the differences observed for the total wear mean values were statistically significant (F=26.995; P<.001).

The least total wear mean values were recorded on zirconia samples opposing zirconia cusps, with a statistically significant difference compared to the total wear of the gold alloy facing gold alloy cusps (P=.044). Compared to the gold alloy, slightly increased, but not significantly different, total mean wear values were registered on heat-cured Enamel Plus Function (P=.044), heat-cured Ceram.X (P=.311), Cerabien ZR Press (P=.217) and e.max CAD (P=.074). The use of heat-cured Enamel Plus HRi and e.max Press was associated to the highest total wear mean values, significantly increased compared to what observed in all the other experimental groups, but with not statistically significant difference between one another (P=.775).

DISCUSSION

The null hypothesis tested in the present study had to be rejected. Significant differences were observed in the wear behavior of the restorative materials under investigations. In an experimental model where every material was tested against an antagonist made out of the same material, the highest total wear values were recorded on the heat-pressed lithium disilicate (e.max Press) and on a particular heat-cured nano-hybrid composite (Enamel Plus HRi, shade UE2), specifically commercialized by the manufacturer as an aesthetic material for anterior restorations.

Sample/antagonist pairs made out of Katana Zirconia ML showed the least total wear mean values, confirming the high wear resistance exhibited by zirconia-based polycrystalline ceramics in previous investigations.[40]

Two innovative resin based composites were also tested in the present study. Enamel Plus Function was recently introduced by the manufacturer as a clinical alternative to Enamel Plus HRi for posterior teeth, with the ambition to increase mechanical properties and improve the long-term outcomes when used on load bearing occlusal surfaces.[1] It lacks some of the favorable optical properties of Enamel plus HRi, but has been formulated putting the greatest efforts toward optimizing the bond between the filler particles and the resin matrix.[1] Ceram.X Universal, on the other hand, is based on a proprietary filler technology called SphereTEC™ and contains granulated spherical sub-micron glass fillers. According to the manufacturer, this new filler technology, in combination with an optimized resin matrix, improves both aesthetics and polishability, providing also exceptionally high fracture toughness, claimed to be similar to that of natural dentin.

After 120000 chewing simulation cycles against antagonistic cusps made out of the same material, both the heat-cured Enamel Plus Function and the heat-cured Ceram.X Universal showed an extremely promising wear behavior, very similar to that of the gold based alloy.

The total wear mean values for the milled lithium disilicate ceramic (e.max CAD) and the for the heat-pressed feldspathic porcelain (Cerabien ZR Press) were also not statistically different from the gold alloy. Nevertheless, the wear behavior of ceramics should not be considered similar to that of metal or composite resin. To some extent, ceramics wear by microfractures, while metal and composite resin wear through a mechanism involving plastic deformation and adhesion.[38,41]

For decades, the use of metal or gold on the occlusal surfaces has been considered a valid solution in all cases where the prosthetic occlusion was in contact with natural enamel, resin composite, porcelain, or a combination of such materials,[42] causing minimal wear to the antagonist[43] and most likely no interferences with the patient occlusal balance.[20] In recent in vitro studies, a type 3 gold alloy exhibited the same wear rates of human enamel.[1,2] As a consequence, dental materials that closely resemble the gold alloy in their wear behavior should be probably considered the most physiological substitutes for the lost tooth hard tissues.

Excessive wear or exaggerated abrasiveness, on the other hand, should be avoided as they may lead to unacceptable restoration and/or antagonist damage, with possible alterations of the functional path of masticatory movements. When anterior teeth are involved, both esthetics and the anterior guidance function are impaired, finally leading to increased stresses on the masticatory system and likely temporomandibular joint dysfunctions.[44-46]

Many studies have attempted to relate the wear resistance and/or the abrasiveness of dental materials to specific material properties, such as surface topography, fracture toughness or hardness.[47-49]

According to Fischer, for most materials, metal in particular, the wear resistance can indeed be considered directly proportional to the hardness.[50] However, for the abrasion caused by most ceramics, hardness and wear are probably not strictly associated with each other.[51-53] The wear caused by ceramics appears more related to surface roughness and fracture toughnesss,[50,54,55] and should be conveniently considered as a multifactorial condition.[56]

Unlike the case of ceramics, composites produce wear on their antagonist through hard filler protruding from the abraded resin matrix and the hardness is thought to be a reliable predictor of their abrasiveness.[48,49]

According to the general knowledge about wear between 2 contacting materials, a softer material is abraded more easily than an opposing harder one.[49]

However in the present study each tested material was also used to manufacture the respective antagonistic abrader, in order to in vitro mimic the common clinical situation of two opposing restorations made out of the same dental material. Thus, in each test both samples and antagonistic abraders showed exactly the same mechanical properties. Furthermore, the total wear (sample wear depth + antagonist wear) was calculated and assumed as the parameter under investigation. In a similar experimental scenario, hardness is maybe less correlated with the total wear because, even assuming that an harder material would easily abrade its antagonist, probably it is also less likely worn out compared to a softer one, and vice-versa. Interestingly, even though the manufacturer reports the same Vickers hardness value for both the heat-pressed and the milled versions of lithium disilicate (5800 MPa), in this study a statistically significant difference was detected in the wear properties of e.max Press and e.max CAD. This finding confirmed that the wear behavior of a brittle substrate (like ceramic) is maybe different from that of a composite and, consequently, the use of hardness as a wear predictor for all the materials tested did not seem an appropriate solution.

As a general rule, well conducted randomized controlled clinical trials should be considered the best method to evaluate the quality of dental materials. However they are costly, time consuming and hard to standardize. Therefore in vitro research still remain an indispensable step for initial screening of material properties and dynamic tests appears extremely valuable in predicting the clinical performance of biomaterials subjected to the cyclic solicitations generated by the human body's physiological movements.[23,57,58]

CONCLUSIONS

Within the limitations of an in vitro model that involved specimens tested for the two-body wear resistance against antagonists made out of the same material, the following conclusions could be drawn:

1. among the esthetic and adhesive materials nowadays available, some specific composite resins and some dental ceramics show a wear behavior statistically similar to the traditional type 3 gold-alloys;

2. the total wear observed on monolithic zirconia was significantly reduced compared to the gold alloy and to all the other tested materials;

3. the two-body wear behavior of ceramic-based materials seems poorly predictable on the basis of the hardness, as statistically significant differences in total wear were detected between the heat-pressed and the milled lithium disilicate glass-ceramics, in spite of their equal Vickers hardness.

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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TABLE LEGEND

Table 1 Summary of the materials used in the experimental groups. Technical data were provided by the respective manufacturers.

Table 2 Configuration of parameters set for wear method.

Table 3 Mean values (and standard deviations, SD) for the sample wear (mm), antagonist wear (mm) and total wear (mm) achieved in the experimental groups. Total wear mean values were compared using a One-Way ANOVA test. Same superscripted letters indicate no statistically significant differences.

Table 1 Summary of the materials used in the experimental groups. Technical data were provided by the respective manufacturers.

Material	***Manufacturer***	***Technical data***
Katana Zirconia ML	*Kuraray Noritake Dental Inc., Miyoshi, Japan*	*Yttria-stabilized tetragonal zirconia polycrystal ceramic*
Aurocast8	*Nobil-Metal S.p.A., Villafranca d'Asti, Italy*	*Type 3 high-gold dental alloy (Au=85.4%, Ag=9.0%, Cu=5.0%, Pd<1.0%, Ir<1.0%)*
Cerabien ZR Press	*Kuraray Noritake Dental Inc., Miyoshi, Japan*	*Heat-pressed feldspathic porcelain*
IPS e.max Press	*Ivoclar Vivadent, Schaan, Liechtenstein*	*Heat-pressed lithium disilicate glass-ceramic*
IPS e.max CAD	*Ivoclar Vivadent, Schaan, Liechtenstein*	*Milled lithium disilicate glass-ceramic*
Enamel Plus HRi (UE2)	*Micerium S.p.A., Avegno, Genova, Italy*	*Nano-hybrid resin composite. Filler content: 80% W/W (12% zirconium-oxide fillers, 68% innovative proprietary glass-based filler). Mean particle size: 1000 nm.*
Enamel Plus Function (EF2)	*Micerium S.p.A., Avegno, Genova, Italy*	*Microhybrid resin composite. Filler content: 75% W/W. Mean particle size: 700 nm (including 40 nm fumed silica).*
Ceram.X Universal (A2)	*Dentsply DeTrey, Konstanz, Germany*	*Nano-ceramic composite. Filler content: 73% W/W. Particle size: 100 nm - 3 µm. Mean particle size: 600 nm.*

Table 2 Configuration of parameters set for wear method

Number of cycles	120000
Force	49 N
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

Table 3 Mean values (and standard deviations, SD) for the sample wear (mm), antagonist wear (mm) and total wear (mm) achieved in the experimental groups. Total wear mean values were compared using a One-Way ANOVA test. Same superscripted letters indicate no statistically significant differences.

MATERIAL	*Sample Wear (SD)* **A**	*Antagonist Wear (SD)* ***B***	*Total Wear (SD)* ***A + B***
Katana Zirconia ML	*0.018 (0.011)*	*0.092 (0.036)*	*0.109[c] (0.033)*
Aurocast8	*0.073 (0.017)*	*0.142 (0.074)*	*0.215[b] (0.085)*
Enamel Plus Function (EF2) heat-cured	*0.065 (0.033)*	*0.207 (0.078)*	*0.272[b] (0.092)*
Ceram.X Universal (A2) heat-cured	*0.087 (0.018)*	*0.204 (0.079)*	*0.291[b] (0.083)*
Cerabien ZR Press	*0.104 (0.022)*	*0.194 (0.041)*	*0.297[b] (0.061)*
IPS e.max CAD	*0.166 (0.029)*	*0.147 (0.063)*	*0.313[b] (0.076)*
Enamel Plus HRi (UE2) heat-cured	*0.234 (0.029)*	*0.211 (0.091)*	*0.445[a] (0.087)*
IPS e.max Press	*0.181 (0.037)*	*0.316 (0.042)*	*0.497[a] (0.059)*