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Wear properties of adhesive dental ceramics and porcelains compared with human enamel

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ABSTRACT

Statement of problem. Contemporary pressable and computer-aided design/manufacturing (CAD/CAM) ceramics exhibit good mechanical and esthetic properties. Their wear resistance compared with human enamel and traditional gold based alloys needs to be better investigated.

Purpose. The purpose of this in vitro study was to compare the 2-body wear resistance of human enamel, gold alloy, and 5 different dental ceramics, including a recently introduced zirconia-reinforced lithium silicate ceramic (Celtra Duo).

Material and methods. Cylindrical specimens were fabricated from a Type III gold alloy (Aurocast8), 2 hot pressed ceramics (Imagine PressX, IPS e.max Press), 2 CAD/CAM ceramics (IPS e.max CAD, Celtra Duo), and a CAD/CAM feldspathic porcelain (Vitablocs Mark II) (n=10). Celtra Duo was tested both soon after grinding and after a subsequent glaze firing cycle. Ten flat human enamel specimens were used as the control group. All specimens were subjected to a 2-body wear test in a dual axis mastication simulator for 120 000 loading cycles against yttria stabilized tetragonal zirconia polycrystal cusps. The 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 with 1-way ANOVA tests (α=.05).

Results. The wear depth (0.223 mm) of gold alloy was the closest to that of human enamel (0.217 mm), with no significant difference (P>.05). The greatest wear was recorded on the milled Celtra Duo (wear depth=0.320 mm), which appeared significantly less wear resistant than gold alloy or human enamel (P<.05).

Conclusions. The milled and not glazed Celtra Duo showed a small but significantly increased wear depth compared with Aurocast8 and human enamel. Wear depth and volumetric loss for the glaze-fired Celtra Duo and for the other tested ceramics did not statistically differ in comparison with the human enamel. (J Prosthet Dent 2015;■:■-■)

Tooth wear is a multifactorial process based either on physiologic or pathologic mechanisms that finally leads to the noncarious loss of tooth surface substance with subsequent alterations in tooth anatomy.[1,2] In physiologic wear, gradual tooth surface deterioration normally takes place following abrasion, when a third body is present during mastication,[3] and attrition, when antagonist teeth are in direct contact during swallowing and occlusal movements.[4,5] As a result, cusps on posterior teeth tend to get flattened and lose convexity while anterior teeth show slightly shortened incisal edges and loss of mammelons.[6]

Pathologic wear is frequently associated with bruxism and clenching, conditions characterized by massive attrition and subsequent unacceptable tooth damage and alteration of the functional path of masticatory movements. Anterior teeth may also be involved, impairing both esthetics and the anterior guidance function, which can increase stresses on the masticatory system and subsequent temporomandibular joint dysfunction.[7-9]

Similarly, attrition and abrasion may also lead to the progressive wear of dental restorative materials, and the wear mode depends on the type of restorative material.[3] Ideally, a restoration should present wear properties similar to those of human enamel.[10,11] Excessive wear or extreme abrasiveness may adversely affect both

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Clinical Implications

All the dental ceramics investigated showed wear rates similar to those of human enamel and may be considered suitable for restoring the occlusal surfaces of posterior teeth. Clinicians should consider that the wear properties of the new zirconia-reinforced lithium silicate ceramic (Celtra Duo) may be improved by a glaze firing cycle.

the functional and the esthetic long-term outcome of occlusal rehabilitations.[12-16]

Apart from their esthetic limitations, gold-based casting alloys are considered the optimal restorative material because they are wear resistant and cause minimal wear of opposing enamel.[17-21] In a recent in vitro study, the lowest friction coefficient and the best wear resistance were reported when human enamel was opposed by Type III gold.[22] Ceramics are used for fixed dental prostheses (FDPs) as an alternative to gold-based casting alloys because of their greater esthetic potential: traditional FDPs typically consist of a high strength metal substructure and an esthetic veneering ceramic that provides excellent biocompatibility and color stability.[23] The use of a high strength framework helps reduce the high failure rates observed for some ceramics in posterior sites.[24] Some authors have reported abrasiveness toward the enamel as the main shortcoming of such restorations.[25-28] Mundhe et al[29] showed in vivo that glazed metal ceramic crowns caused more wear of antagonist enamel than monolithic polished zirconia crowns.

Different CAD/CAM or pressable ceramic materials are available as alternatives to metal-based restorations. They allow the fabrication of either complete ceramic restorations or high strength ceramic substructures that are subsequently veneered with porcelain. Once adhesively luted, ceramic restorations show improved fracture strength and promising success rates.[30-35]

Several attempts have been made to relate the hardness of dental materials to their abrasiveness and wear resistance, but recent studies have demonstrated other factors that influence the wear properties of a ceramic, such as microstructure, porosity, crystal size, surface roughness, and environment.[36] Moreover, defining a strict correlation between hardness and wear for brittle materials seemed inappropriate because, unlike metals, they wear by subsurface fractures and not by plastic deformation.[6]

Clinical tests are essential for characterizing the complex oral wear situation but are also expensive and time consuming. They also do not allow control of variables such as individual mastication forces or oral conditions.[37] Thus, in vitro mastication still appears as a practical solution for ranking the wear performance of emerging new materials.[38-41] Different shapes[4,41,42] and substrates[30,43,44] have been suggested for the antagonistic cusps, but the need for a standardized form of artificial abrader has been well described.[45] Even if human enamel antagonists appear to achieve in vivo–like conditions in laboratory tests, the morphologic and structural differences of enamel complicate the standardization of wear testing. Therefore, as an alternative, yttria stabilized zirconia (YSZ) ceramic balls have been widely used,[3,43-45] with the aim of adequately assessing the wear properties in a standard in vitro assessment.[46] Contrary to popular belief, recent findings have suggested a moderate abrasiveness of monolithic YSZ on human enamel in vitro.[47,48]

The purpose of this in vitro study was to evaluate the 2-body wear resistance of human enamel, a gold alloy, and 5 different ceramic materials, including a recently introduced zirconia-reinforced lithium silicate ceramic, subjected to 120 000 mastication simulation cycles versus standardized YSZ cusps. The null hypothesis tested was that no difference would be detected in the wear properties among the materials under investigation.

MATERIAL AND METHODS

The in vitro 2-body wear resistance of 6 commercially available dental restorative materials was assessed and compared with the wear resistance of human enamel. The restorative materials investigated included a pressable silicon oxide (SiO) glass ceramic (Imagine PressX, shade A1; Wieland Dental Ceramics), a pressable lithium disilicate (LD) glass ceramic (IPS e.max Press; Ivoclar Vivadent AG), a CAD/CAM and LD glass ceramic (IPS e.max CAD; Ivoclar Vivadent AG), a CAD/CAM zirconia-reinforced lithium silicate (ZLS) ceramic (Celtra Duo; Dentsply DeTrey), a CAD/CAM feldspathic porcelain (Vitablocs Mark II; VITA Zahnfabrik), and a Type III gold alloy (Aurocast8; Nobil-Metal S.p.A.).

Ten Imagine PressX (n=10) and 10 IPS e.max Press (n=10) cylindrical specimens were fabricated according to the conventional lost wax technique by investing and eliminating acrylic resin disks (Plexiglas; Evonik Röhm GmbH) 7 mm in diameter and 6 mm thick. The void was filled with the pressable ceramic, which was pressed at 930°C for 20 minutes.

For CAD/CAM materials (IPS e.max CAD, Celtra Duo, and Vitablocs Mark II), 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 LD specimens were produced (n=10) and subsequently crystallized in a ceramic furnace (Programat EP 5000; Ivoclar Vivadent AG) at 840°C to 850°C. The ZLS slices (n=10) were, instead, glaze fired at 820°C, according to the manufacturer’s instructions. Further

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Table 1. Configuration of parameters set for wear method

Number of Cycles	120 000
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

CAD/CAM ZLS (n=10), together with CAD/CAM feldspathic porcelain (n=10) specimens, were similarly produced, but not subjected to any firing before the subsequent steps. Gold alloy specimens (n=10) were made using the traditional lost wax technique. For the control group, flat human enamel specimens (n=10) were produced as previously described[3] by abrading the buccal aspect of 10 caries-free human molars, collected as approved by the local ethics committee.

All specimens were stored for 24 hours at 37°C and then subjected to a 2-body wear test in a dual axis mastication simulator (CS-4.2; SD Mechatronik GmbH) against standard zirconia cusps with a slight conical shape and a 3-mm-round tip, according to the methodology described in detail elsewhere.[3] The mastication simulation parameters used are summarized in Table 1.

Following a 3-dimensional surface analysis with a CAD/CAM contact scanner (dental scanner; Renishaw plc),[3] the wear depth (mm) and the volumetric loss (mm^3) of all specimens were calculated. Moreover, the difference between the pretest and posttest height of each zirconia cusp was assumed as the antagonist wear (mm).

The means and standard deviations for wear depth, volume loss, and antagonist wear were calculated. Having assessed that all data were normally distributed, mean values were compared with 1-way analysis of variance (ANOVA) and Tukey Honestly Significant Difference (HSD) tests (α=.05).

RESULTS

Table 2 summarizes the mean values for wear depth and volume loss recorded on the different restorative materials after 120 000 mastication simulation cycles. The wear recorded for the antagonistic cusps is also shown. The 1-way ANOVA tests showed that the differences observed in the mean values for wear depth (F=3.161; *P*=.006) and volume loss (F=2.682; *P*=.016) were statistically significant. Following the Tukey post hoc test, no statistically significant differences were observed when the dental ceramic materials were compared (*P*>.05). After a glaze firing cycle, the ZLS-based CAD/CAM ceramic (Celtra Duo) showed mean values for wear depth and volume loss statistically similar to those of gold alloy and human enamel (*P*>.05), while the same comparisons led to a statistically significant difference in wear depth when Celtra Duo was used soon after grinding (*P*<.05). Volume loss for the milled Celtra Duo was statistically significantly greater than for the gold alloy (*P*<.05). The wear depth and volume loss of all the remaining dental ceramics did not statistically differ from those of the gold alloy and human enamel (*P*>.05).

Table 2. Mean values (and standard deviations, SD) for wear depth, volume loss, and antagonist wear achieved in experimental groups

	Wear Depth (SD) (mm)	Volume Loss (SD) (mm^3)	Antagonist Wear (SD) (mm)
Human Enamel	0.217 (0.095)^{a}	0.393 (0.178)^{a,b}	0.004 (0.003)^{a}
Aurocast8 by Nobil-Metal	0.223 (0.072)^{a}	0.331 (0.138)^{a}	0.004 (0.005)^{a}
IPS e.max Press	0.295 (0.057)^{a,b}	0.459 (0.137)^{a,b}	0.005 (0.003)^{a}
IPS e.max CAD	0.253 (0.060)^{a,b}	0.355 (0.133)^{a,b}	0.003 (0.002)^{a}
Wieland Imagine PressX	0.306 (0.067)^{a,b}	0.508 (0.150)^{a,b}	0.005 (0.004)^{a}
Milled Celtra Duo	0.320 (0.060)^{b}	0.542 (0.115)^{b}	0.005 (0.004)^{a}
Glaze-fired Celtra Duo	0.278 (0.061)^{a,b}	0.384 (0.176)^{a,b}	0.004 (0.002)^{a}
Vita Mark II	0.281 (0.060)^{a,b}	0.472 (0.133)^{a,b}	0.004 (0.003)^{a}

Same superscripted letters indicate no statistically significant differences.

Table 3. Manufacturers' data for Vickers hardness (MPa) and flexural strength (MPa) for materials investigated

	Vickers Hardness (MPa)	Strength (MPa)
Aurocast8 by Nobil-Metal	1078.8-1373	320-350*
IPS e.max Press	5800 ±100	400 ±40
IPS e.max CAD	5800 ±200	360 ±60
Wieland Imagine PressX	Not available	Not available
Milled Celtra Duo	Approx 6900	210
Glaze-fired Celtra Duo	Approx 6900	370
Vita Mark II	6276.5 ±196.1	113-154

*As ductile material, yield strength reported instead of flexural strength.

Concerning the antagonist wear, the Kolmogorov-Smirnov test confirmed that the data set was normally distributed (*P*>.05), while the Brown-Forsythe test found no statistically significant differences in the sample variances (*P*=.188). The 1-way ANOVA showed no statistically significant differences for the antagonist wear mean values among the experimental groups (F=0.661; *P*=.704).

DISCUSSION

In selecting an appropriate restorative material, its wear behavior in the oral cavity should be considered. An ideal restorative material maintains, as closely as possible, the characteristics of natural enamel[11] both in terms of adequate wear resistance and reduced abrasiveness.

The null hypothesis tested in the present study, which assumed no difference in terms of wear properties among the evaluated materials, was partially rejected. The Type III gold alloy had wear behavior closely resembling that of human enamel. The use of gold or metal restorations on the occlusal surfaces has been a consistent choice among clinicians,[18] mainly because of their advantageous functional properties.[19] They cause

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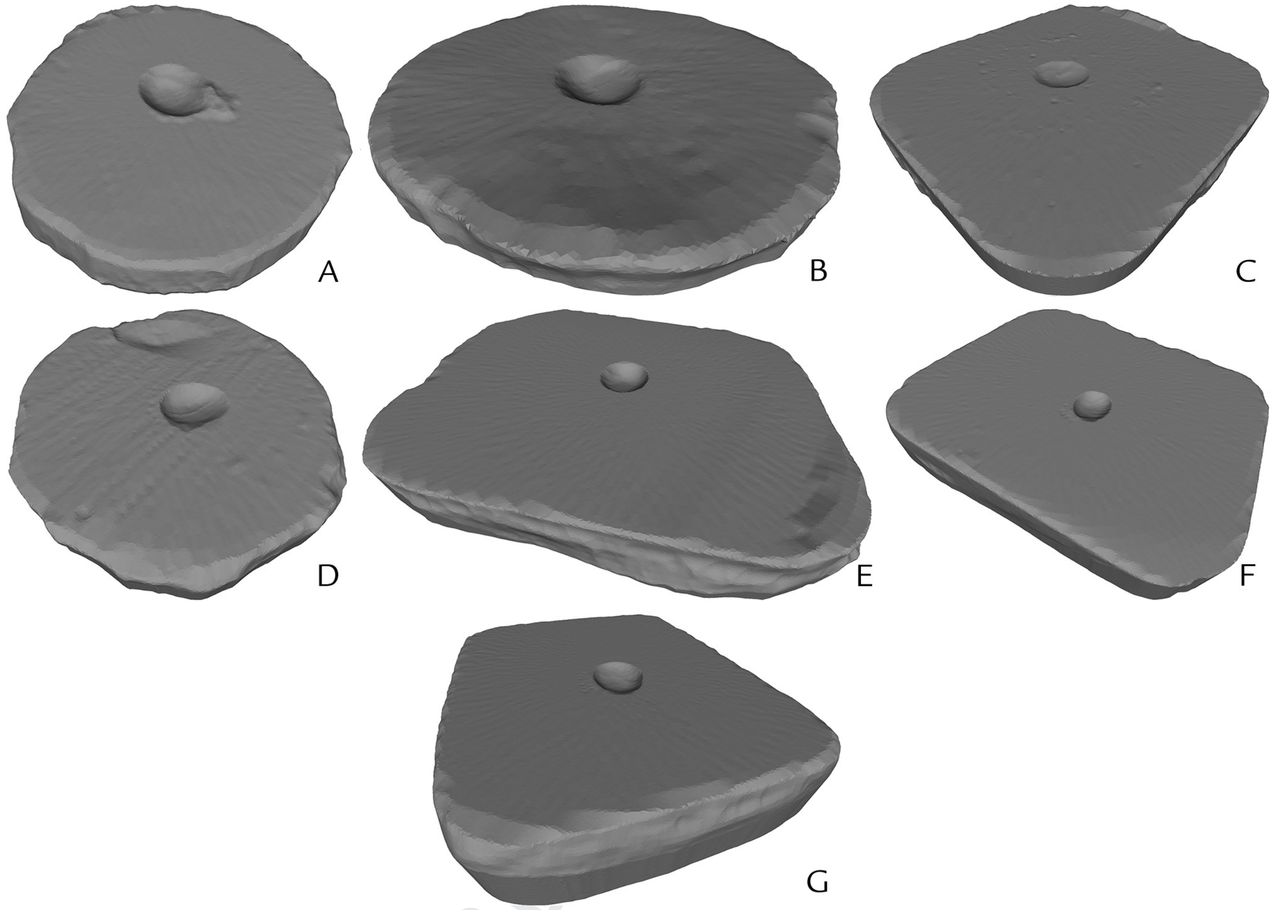

Figure 1. Three-dimensional meshes showing wear facets on representative specimens. A, Aurocast8 gold alloy. B, IPS e.max Press. C, IPS e.max CAD. D, Wieland Imagine PressX. E, milled Celtra Duo. F, Glaze-fired Celtra Duo. G, Vita Mark II.

little or no wear to the antagonistic teeth and/or materials.[20] Although gold alloy restorations cause minimal occlusal interference,[21] their unnatural appearance is a major disadvantage. The esthetics and biocompatibility of ceramic restorations are better than those of metal or metal ceramic restorations; however, a major drawback of some ceramics has been their high clinical failure rate in posterior sites,[24] although adhesive luting has reduced this rate.[31-35]

On the basis of the obtained findings, almost all the ceramic materials tested exhibited more than acceptable wear properties in that their wear depth and volume loss behaviors were statistically comparable with those of gold and not significantly different from human enamel. Excessive wear is undesirable, especially when dealing with patients with parafunction, because it may compromise the occlusal contacts and impair mastication effectiveness. This can alter tooth and jaw relationships, leading to muscular fatigue and ultimately compromise both function and esthetics.[12-16]

LD ceramics, introduced in 2006, have a unique microstructure, composed of 70% small interlocking and randomly oriented lithium disilicate crystals.[49] The LD crystals cause cracks to deflect, branch, or blunt, and this reduces their propagation.[50] The flexural strengths of approximately 360 MPa have been reported for the milled version and 400 MPa for the hot pressed version (Table 3).[51] Despite these flexural strength differences, in the present study, no statistically significant differences were recorded between the wear properties of the hot pressed (e.max Press) and the CAD/CAM (e.max CAD) versions of the LD-based materials investigated; moreover, both materials behaved similarly to human enamel and gold alloy (P>.05) in terms of wear.

The manufacturer of the ZLS-based Celtra Duo (Dentsply DeTrey) claims a reduced working time compared with lithium disilicate because a crystallization firing is not necessary and it can be polished and adhesively luted immediately after grinding. This would make it especially suitable for the chairside fabrication of adhesively luted inlays or onlays. However, even if not mandatory, a glaze firing cycle is still suggested by the manufacturer to optimize the esthetics and increase the flexural strength from 210 MPa to 370 MPa (data provided by the manufacturer). On this basis, in the present study, the wear resistance of ZLS was investigated both soon after grinding and after a subsequent glaze firing cycle. Although no statistically significant differences could be directly detected between the wear properties of ground and glazed ZLS (P>.05), the wear depth and volume loss recorded for the glazed ZLS were statistically similar to those of human enamel and gold alloy (P>.05). In contrast, statistically significant differences in wear depth were found when the ground ZLS was compared with both gold and human enamel (P<.05). This may indicate that the glaze firing cycle is a process that causes a slight improvement in wear resistance for ZLS-based materials.

The wear behavior of a CAD/CAM feldspathic porcelain was also investigated. Feldspathic porcelains are composed mostly of glass and show the highest esthetics. Manufacturers routinely add small amounts of filler particles to control the optical effects that mimic natural enamel and dentin. Reducing the filler particle content leads to an increase in translucency and esthetics but may impair the mechanical properties.[49] In addition to its inherently lower mechanical properties, the feldspathic porcelain evaluated showed a promising wear pattern when compared with the other glass ceramics tested and did not significantly differ from gold alloy and human enamel in terms of wear depth and volume loss (P>.05). Nevertheless, its reduced flexural strength[52] (Table 3) makes it a less than ideal material when esthetics are required but limited thickness is available.

As in previous research,[3,38-41] the device earlier known as the Willytec chewing simulator and currently distributed under the trade name of CS-4.2 by SD Mechatronik GmbH was used to assess the in vitro wear resistance of dental restorative materials. When human enamel cusps are used in vitro as antagonistic abraders, they are in some cases subjected to different kinds of poorly repeatable preparations in the attempt to round the tip and standardize the shape. Even in those cases where they are used untouched, the inherent variability in the degree of mineralization and thickness of different enamel tissues from different patients or from different teeth in the same mouth must still be considered as a possible source of bias. Therefore, as proposed in the literature,[45] zirconia ceramic balls were used in the present study as artificial antagonistic abraders. They retained their shape during the entire test period, limiting the influence of any change in the antagonist surface on specimen wear.[30,43]

CONCLUSIONS

Based on the findings of the in vitro testing, the milled and not glazed Celtra Duo showed a small but significantly increased wear depth, compared with Aurocast8 and human enamel. The wear depth and volumetric loss for the glaze-fired Celtra Duo and for the other tested ceramics did not statistically differ from human enamel.

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Figure 1.

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