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Wear Testing of Composite, Gold, Porcelain, and Enamel Opposing a Removable Cobalt–Chromium Partial Denture Alloy

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Abstract

Purpose: Eighty percent of all removable partial denture (RPD) frameworks are fabricated from cobalt–chromium (Co–Cr) alloys. The advantages of this material include low density and high modulus of elasticity, hardness, and strength. Hardness is of particular concern when related to excessive wear of natural teeth or restorative materials. The purpose of this study was to compare the differences in localized wear among enamel, composite, gold, and porcelain by a Co–Cr alloy RPD.
Materials and Methods: Thirty-two polished specimens were prepared and positioned in an acrylic-filled custom fixture for testing. Upon optical examination, the highly polished surfaces of the specimens were scratch-free. They were mounted into a water bath fixture and subjected to 250,000 cycles in a wear simulator equipped with a conical Co–Cr stylus specially fabricated to produce localized wear. A posttest was generated, and the profiles were fitted and evaluated using software. The total volume loss and depth of the wear facet on each specimen were analyzed using ANOVA and Fisher's PLSD test.
Results: Volume loss (mm^3) was as follows: composite, 0.110; gold, 0.021; enamel, 0.008; porcelain, 0.006. The maximum depths (μm) were: composite, 92; gold, 22; enamel, 13; porcelain, 17. Resin composite had significantly higher values ($p < 0.0001$) of volumetric loss and maximum depth than the other materials. No significant differences were detected among volumetric loss and maximum depth values for gold, enamel, and porcelain.
Conclusions: Significant differences for mean wear volume loss and maximum depth were found between composite and gold, enamel, and porcelain. Enamel proved to be wear resistant to the Co–Cr alloy. Clinical implications: porcelain and gold appear to be good options for occlusal surfaces opposing a Co–Cr alloy; however, the test composite was not found to be a recommended option.

Wear of tooth structure and restorative materials has been studied using wear machines and measuring various physical properties such as hardness and coefficient of friction.[1] Two kinds of wear have been described by Kawai and Leinfelder: generalized contact-free area (CFA) and localized occlusal contact area (OCA), which has been considered more critical. Localized wear has been directly attributed to the presence of a contacting cusp on the occlusal surface of a restoration during bruxism and thegosis. OCA wear, which occurs in centric stops, may be two to three times as great as that in noncontact areas. As the magnitude of OCA wear increases, noticeable changes may develop in functional occlusion.[2] In a laboratory test, localized wear was evaluated using two-body wear for attrition and three-body wear for abrasion (in an abrasive slurry medium[3]).

It has been considered elementary to select restorative materials that have wear rates compatible with tooth structure and are able to bear occlusal forces. Composite resins have offered excellent esthetics, the ability to bond to tooth structure, and low thermal conductivity. They have inorganic filler particles dispersed throughout a resin matrix. The filler size, mode of filler bonding to the matrix, and mode of causing wear have determined the wear behavior of these materials.[4] The addition of high levels of filler particles in the resin matrix of the composite has reduced wear of the composites under a two-body test condition.[5] It has been suggested that the increase in filler loading enhanced the wear resistance of dental composites.[6] Packable resin composites generated lower attrition and abrasive wear than microfilled and microhybrid composites.[7] Suzuki et al[8] and Young and Suzuki,[9] testing posterior composite resins, found that zirconium silicate or quartz fillers caused greater antagonist enamel wear than did microfilled or barium silicate-filled composite resins.

Historically, gold has been favored as a restorative material because of its biocompatibility, durability, and low abrasiveness against natural teeth.[10] The hardness of most noble casting alloys has been less than that of enamel and particularly less than that of base metal alloys. As the hardness of an alloy exceeds that of enamel, it may wear the enamel of opposing teeth.[11] In evaluating the level of wear of different restorative materials opposing abrasive disks, the least wear was observed by gold, cobalt–chromium (Co–Cr) alloys, and porcelain.[12] Gold was less prone to wear dental ceramics, because polished gold had a smoother surface than glazed porcelain.[13]

Low-fusing porcelain has been shown to abrade enamel less than traditional feldspathic porcelain. Less wear of enamel has been an obvious advantage in situations where esthetic demands have called for porcelain occlusal surfaces.[14,15] On the other hand, Mahalick et al suggested that porcelain opposing enamel and gold produced a higher rate of wear.[16] It was also found that unglazed and glazed porcelain produced no difference in enamel wear.[17] Enamel is thickest over cusp tips and incisal edges; due to its high content of hydroxyapatite, enamel is rigid and brittle and has a high modulus of elasticity.[18] Jagger and Harrison showed that enamel had good abrasion resistance against both amalgam and microfilled composite, but only moderate abrasion resistance against gold.[19] Co–Cr alloys have demonstrated a high modulus of elasticity, high strength, excellent corrosion resistance, and very high hardness, which make them very rigid and able to resist deflection, distortion, and wear.[20]

Leinfelder et al[21] and Leinfelder and Suzuki[22] developed an in vitro wear testing device that accurately represented clinical wear values. The loading mechanism consisted of four 20 cm diameter pistons, with an internal spring, and a stainless steel stylus. The vertical cross-sectional shape of the stylus was elliptical. The contact point was machined so as to form a 2 mm radius. Localized wear was produced with the conical stylus mounted in a spring-loaded piston. The stylus applied a vertical load of 7.6 to 8.0 kg onto the specimen. The specimens were mounted in a water bath fixture and subjected to a predetermined number of cycles. During the wear process, the stylus rotated clockwise 30° on the specimen's surface as the maximum load was achieved and then counter-rotated as the piston returned to its original position.

There have been several methods available for measuring wear, such as impression profiles, profilometer registrations, and the scanning electron microscope.[23] A quantitative method included an MTS closed-loop servohydraulic machine (MTS Systems Corporation, Eden Prairie, MN). Using this system, loss of surface could be analyzed in terms of magnitude, shape, and location. The data collected from a longitudinal series of replicas of the same surface could be analyzed by superimposing the "before" and "after" images using a mathematical fitting routine based on a least-squares fit. The accuracy and the precision of the 3D data acquisition depended on the surface inclination and roughness of the specimens.[24,25]

A software program (AnSur 3-D, Minnesota Dental Research Center for Biomaterials, Minneapolis, MN) was used to analyze the surfaces. An entire surface could be measured in 3D, over 20 to 40 seconds with a resolution of about 250,000 surface points. Without this fitting procedure, the method would be completely dependent on physically mounting the two surfaces in the same place in space.[26]

No study has been conducted to identify the best restorative material opposing a Co–Cr alloy. The purpose of this study was to determine and compare the differences of localized wear among enamel, composite, gold, and porcelain opposing a removable partial denture (RPD) alloy. The formulated hypothesis was that there were no significant differences of in vitro localized wear among composite, gold, enamel, and porcelain opposing a Co–Cr alloy.

Materials and methods

Thirty-two specimens (eight specimens each for composite, gold, porcelain, and human enamel) were prepared. Resin composite specimens were made in an acrylic-invested brass holder with a 6×3 mm^2 preparation in the center of the surface. The microhybrid composite (Filtek Z250, 3M ESPE, St. Paul, MN) was inserted in two increments. Each was light-cured (Elipar-Trilight, 3M ESPE) for 20 seconds; a Mylar band and a glass microscope slide were used to extrude any excess material from the surface before final curing. Gold specimens were made by casting a $10 \times 10 \times 1.5$ mm^3 piece of wax (medium soft pink wax No. 3, Hygenic, Akron, OH) with type III gold alloy (Aurolloyd, Bego, Bremen, Germany) according to the manufacturer's instructions. Low-fusing porcelain specimens (Vita Omega, Vita ZahnFabrik, Bad Sackingen, Germany) were prepared by initially mixing the porcelain powder and liquid into a smooth consistency on a glass slab. The mixture was vibrated by hand to eliminate air bubbles. Excess moisture was removed with a paper towel. Cylindrical-shape disks were made (10 mm diameter $\times$ 3 mm thick) and fired according to the manufacturer's directions.

Eight caries-free extracted human mandibular incisors were used to make the enamel specimens. The root of each tooth was removed. The facial surface of each tooth was carefully ground to create a flat surface, so the wear surface consisted entirely of enamel. Gold, porcelain, and enamel specimens were attached to the brass holder with autopolymerized acrylic resin. All specimens were polished using wet 600, 1200, 2400, and 4000 grit silicon carbide paper on a polisher (Ecomet, Buehler GmbH, Düsseldorf, Germany) at a speed of 300 rpm, rinsed clean, and then ultrasonically cleaned for 5 to 10 minutes in H_2O. Upon optical examination, the surfaces of the specimens were shiny and scratch free. All specimens were stored in distilled water for 72 hours prior to testing (Fig 1).

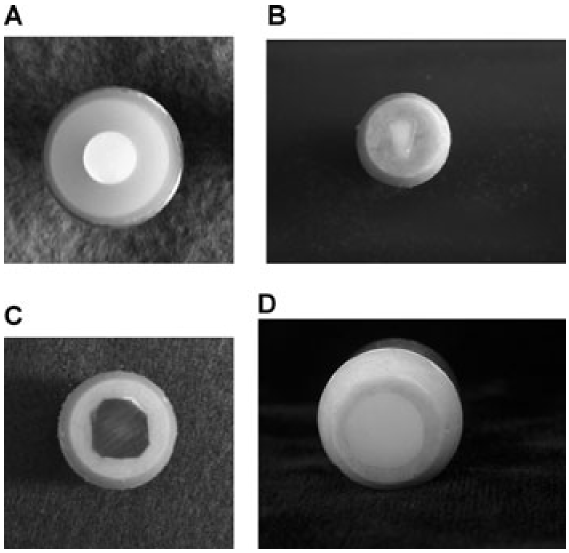

Figure 1 Restorative material and enamel specimens ready for localized wear testing. (A) Composite; (B) enamel; (C) gold; (D) porcelain.

A wear stylus was prepared from a Co–Cr alloy (Wironium, Bego, Bremen, Germany). A stone mold was fabricated to create a cylindrical matrix (25-mm length × 10-mm diameter). Wax specimens were prepared in this mold and carefully sprued, invested with phosphate-bonded investment material (Wirovest, Bego, Bremen, Germany), and cast by centrifugal force according to the manufacturer's instructions.

These Co–Cr alloy cylinders were machined to accurately duplicate the geometry of the original stainless steel tips (Fig 2). Before and after testing, each of the pistons was calibrated with a universal testing machine (Mini44 Instron, Canton, MA). Exacting calibration was necessary to determine the precise load applied by each spring at a given displacement.

Specimens were then subjected to 250,000 cycles in a Leinfelder wear simulator (Fig 3) equipped with the Co–Cr alloy styli specially fabricated to produce localized wear.

The posttest surface was scanned using a surface profilometer and software (MTS Systems Corporation, Eden Prairie, MN). The set-up had three degrees of translational freedom. Sequential profiles of the same specimen showed a reproducibility of ±7 μm. Volumetric loss (mm^3) and maximum depth (μm) of the worn facets were generated by subtracting differences between the before and after digitized profiles using software (AnSur 3-D, Minneapolis, MN). The goodness of the fit was determined by the root means square of the difference between the images and was expressed in microns.

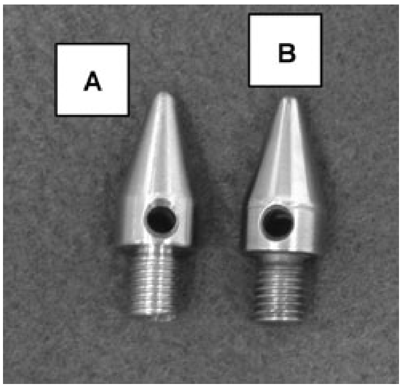

Figure 2 Cobalt–chromium (A) and a stainless steel stylus (B).

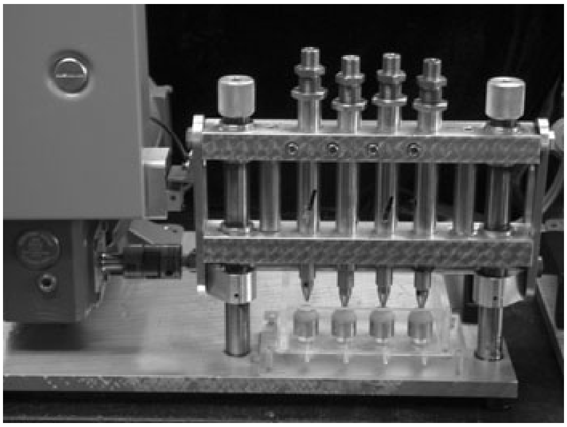

Figure 3 Leinfelder wear simulator.

The mean values for all groups were calculated and compared using one-way ANOVA and Fisher's PLSD test for comparisons of means at the 0.05 level of significance.

Results

Software illustrations of the worn surfaces of composite and porcelain specimens are shown in Figure 4. The mean values of enamel and restorative materials worn by Co–Cr alloy tips are shown in Figure 5 for volume loss and Figure 6 for maximum depth. The results of ANOVA indicated that the material significantly affected volumetric loss and maximum depth ($p < 0.0001$) (Table 1). Fisher's PLSD intervals ($p = 0.05$) for comparisons of means among four materials were 0.02 mm^3 for volumetric loss (Table 2) and 18 μm for maximum depth (Table 3).

Porcelain specimens presented the minimum amount of wear, while composite showed the maximum wear value for both volumetric loss and maximum depth after 250,000 wear cycles. Composite samples wore significantly more than gold, enamel, and porcelain opposing the Co–Cr alloy tips. There were no statistical differences found among gold, enamel, and porcelain specimens for both maximum depth and volumetric loss. Excluding composite and comparing gold, enamel, and porcelain specimens only, gold was statistically different from enamel and porcelain in volumetric loss ($p < 0.05$); no statistical difference in maximum depth was detected among these three materials (Fig 7).

Discussion

Many studies have attempted to determine the material best suited for restored occlusal surfaces opposing enamel. The Leinfelder in vitro wear device has been used to reliably predict

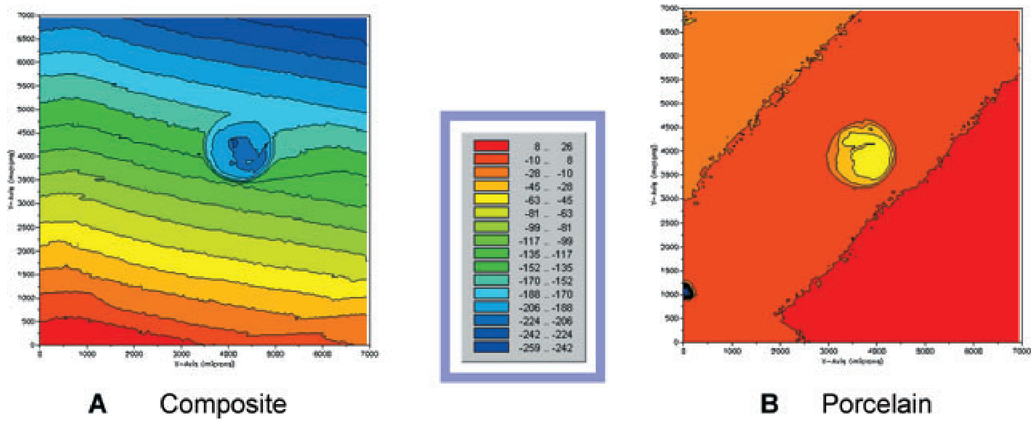

Figure 4 Graphic comparison of the worn surfaces of a composite specimen (A) Composite wear occurred to a depth of - 259 microns according to the AnSur 3-D software. (B) Porcelain wear occurred to a depth of - 63 microns according to the AnSur 3-D software.

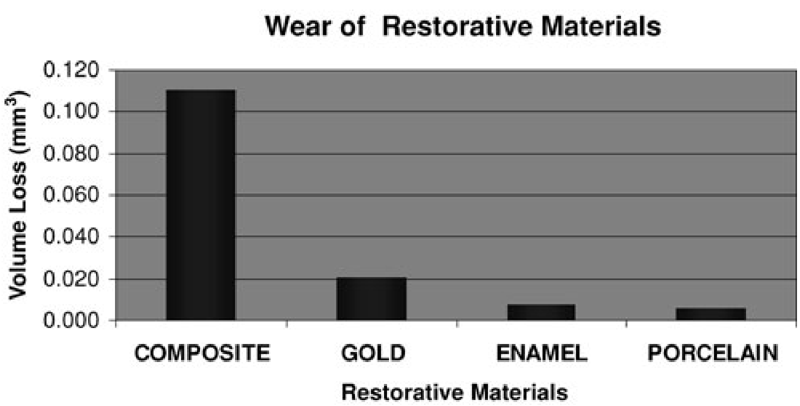

Figure 5 The mean values of volumetric loss of enamel and restorative materials worn by cobalt–chromium alloy tips.

clinical performance of restorative materials using a stainless steel stylus as a counter body.[2,27,28]

The Co–Cr alloy is commonly used for both fixed and removable restorations. It is the hardest dental alloy. Its high modulus of elasticity makes it very rigid, with great ability to resist deflection, distortion, and wear;[20,29] however, no study has been done to test its influence on other restorative materials. Therefore, the Co–Cr alloy was used to make the test stylus for the Leinfelder in vitro wear simulator to determine its influence on localized wear of enamel, composite, porcelain, and gold. A pilot study was first conducted to determine the number of wear cycles required. Porcelain was chosen, because it was the hardest test material.[13] Porcelain specimens were tested for 100,000, 250,000, and 500,000 wear cycles against one Co–Cr stylus. The specimen showed noticeable wear at 250,000 cycles. After 850,000 cycles, no wear was detected on the stylus. These results were confirmed by using a profilometer and related software. Thus, a 250,000-cycle test was

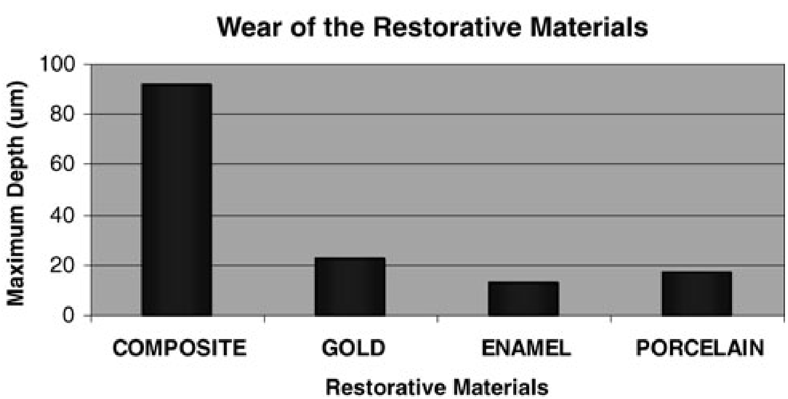

Figure 6 The mean values of maximum depth of wear of the enamel (control) and restorative materials.

Table 1 ANOVA for volume loss and maximum depth of composite, enamel, gold, and porcelain

	DF	Sum of squares	Mean square	*F*-value	*p*-value
Volume loss	3	0.060	0.020	45.591	<0.0001
Maximum depth	3	33,534.684	11,178.228	37.604	<0.0001

Table 2 Fisher's PLSD for volume loss (mm^3)

	Mean difference	Critical difference	*p*-value
Composite–gold	0.089	0.021	<0.0001
Composite–enamel	0.102	0.021	<0.0001
Composite–porcelain	0.104	0.021	<0.0001
Gold–enamel	0.013	0.021	0.2277
Gold–porcelain	0.015	0.021	0.1618
Enamel–porcelain	0.002	0.021	0.8402

Significance level 5%.

Table 3 Fisher's PLSD for maximum depth (μm)

	Mean difference	Critical difference	*p*-value
Composite–gold	69.410	17.659	<0.0001
Composite–enamel	78.754	17.659	<0.0001
Composite–porcelain	74.933	17.659	<0.0001
Gold–enamel	9.344	17.659	0.2877
Gold–porcelain	5.523	17.659	0.5269
Enamel–porcelain	–3.821	17.659	0.6610

Significance level 5%.

chosen for this study, and eight Co–Cr alloy custom-made tips were fabricated for use throughout the experiment. The testing sequence was resin composites, gold, enamel, and porcelain.

Filler particles have been incorporated into resin composites to improve mechanical properties, as well as to reduce the coefficient of thermal expansion, polymerization shrinkage, and heat evolved during polymerization. In this investigation, resin composite showed the greatest amount of wear when compared to the other materials tested. Nevertheless, highly filled composite was the softest material tested. In stress-bearing situations, composites, with their low modulus of elasticity, underwent more deformation resulting from possible crack formation.[30] A study by Latta et al,[31] using the same wear-testing device, subjected specimens to 400,000 cycles with a stainless steel stylus as an antagonist. The same measurement methods showed Z-250 composite with less volume loss and maximum depth than this study. The number of cycles, the dimensions of the stylus tip, and the counterbody appeared to have a great influence on wear.

Gold, enamel, and porcelain demonstrated good abrasion resistance to the Co–Cr alloy in this study; however, when comparing gold, enamel, and porcelain only, gold showed more wear than the other materials, most likely because the hardness of noble casting alloys is less than that of enamel and porcelain.[11] A previous study showed that gold wore less than dental ceramics, because polished gold had a smooth surface, while porcelain had abrasive features due to its grain size, fillers, particles, and pores.[32] Enamel demonstrated good abrasion resistance against gold and the greatest amount of wear by porcelain.[10,14,18]

In this study, porcelain showed the least amount of wear of the test materials in terms of volume loss and maximum depth. According to Craig and Powers, the strength and resistance to crack propagation depend on the nature and amount of reinforcing the crystalline phase.[11] The decrease of wear exhibited by fine grain porcelain may indicate irregularities or fractures created under load, which caused defects of smaller and less abrasive dimensions.[15]

It has been difficult to directly compare results from various investigations, because of the many different wear testing simulators and measuring methods; however, the Leinfelder in vitro wear device has been shown to be a reliable predictor of clinical performance.[22]

Conclusions

Within the limitations of this investigation, the following conclusions have been drawn:

1. Composite had significantly higher mean wear volume loss and maximum depth than gold, enamel, and porcelain.
2. Enamel, gold, and porcelain demonstrated good wear resistance to the Co–Cr alloy.

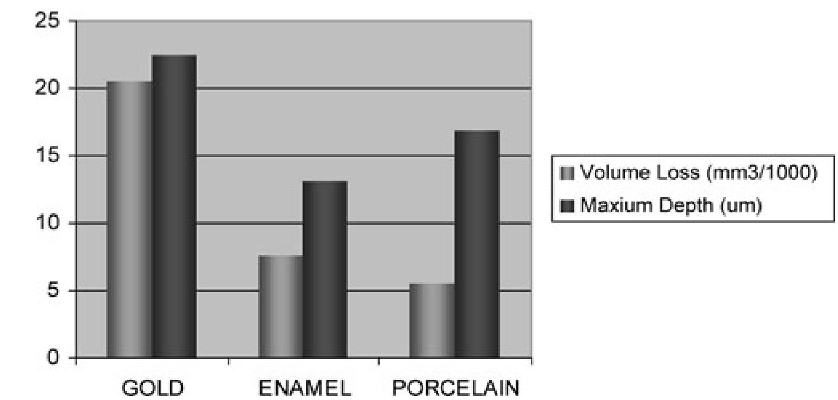

Figure 7 The mean values in volumetric loss and maximum depth of gold, enamel and porcelain.

Acknowledgments

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