Wear of enamel and veneering ceramics after laboratory and chairside finishing procedures

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Purpose. This in vitro study compared the wear of enamel against 3 types of ceramics with high esthetic potential (designed for layering techniques): feldspathic porcelain (Creation), aluminous porcelain (Vitadur α), and low-fusing glass (Duceram-LFC). Laboratory finishing (glazing / polishing) and chairside polishing with a Dialite kit were simulated to compare their respective effects on wear.
Methods. Tooth-material specimen pairs were placed in an artificial mouth using closed-loop servohydraulics. Constant masticatory parameters (13.5 N occlusal force, 0.62 mm lateral excursion; 0.23 second cuspal contact time) were maintained for 300,000 cycles at a rate of 4 Hz. The occlusal surface of each pair was mapped and digitally recorded before and after each masticatory test. Quantitative changes were measured in terms of depth and volume of wear. Quantitative wear characteristics were assessed by SEM.
Results. Significant differences were observed (2-factor ANOVA, $P<.05$). Duceram-LFC generated increased volume loss of enamel (0.197 mm^3) compared with Creation (0.135 mm^3) and Vitadur α (0.153 mm^3). Creation exhibited the lowest ceramic wear and lowest combined volume loss (0.260 mm^3; the sum of the data for enamel and the opposing material) compared with Duceram-LFC (0.363 mm^3) and Vitadur α (0.333 mm^3). The most significant differences among materials were observed in volume loss, not in depth of wear. For all 3 ceramic systems, qualitative SEM evaluation revealed an abrasive type of wear. Wear characteristics of chairside polished specimens were similar to those of laboratory finished specimens (glazed and polished).
Conclusion. Duceram-LFC was the most abrasive ceramic for the antagonistic tooth. Creation ceramic was the least abrasive material and most resistant to wear. Defects, brittleness, and the possibly insufficient toughness of LFC may explain its increased abrasiveness. Laboratory and chairside finishing procedures generated similar results. (J Prosthet Dent 1999;82:669-79.)

CLINICAL IMPLICATIONS

There were significant differences in the wear associated with 3 common veneering ceramics. Noncrystalline low-fusing glass appeared to cause more wear of opposing enamel compared with feldspathic or aluminous porcelains. In this study, intraoral finishing of ceramic restorations was not contraindicated because wear characteristics were similar to those restorations finished in the laboratory by glazing and polishing.

The wear of dental hard tissues is a natural and unavoidable process.[1] However, when opposed by ceramic, enamel may be subject to accelerated wear,[2] the pattern of which may vary according to the ceramic system and its surface characteristics.[3,4] A major step was taken at the end of the last decade, when in vitro studies demonstrated the excellent behavior of unshaded castable glass ceramics (Dicor system) compared with conventional feldspathic materials.[4-6] Wear rates, in terms of material removal and vertical height loss, proved to be similar to gold alloy.[7] The advent of machinable ceramics removed the "operator" factors that occur during processing, and provides improved microstructural control.[8]

Nevertheless, traditional feldspathic ceramics are still widely used,[9,10] despite the numerous scientific reports of their harmful behavior with regard to enamel wear.[2,3,5,7] This trend is easily explained by the very good esthetic results achieved with a natural stratification and the artisan work of the dental ceramist.[11] Cast or pressed glass ceramics and machined porcelains alone do not allow such artistry and thus limit their use in esthetic restorative dentistry. In addition, early

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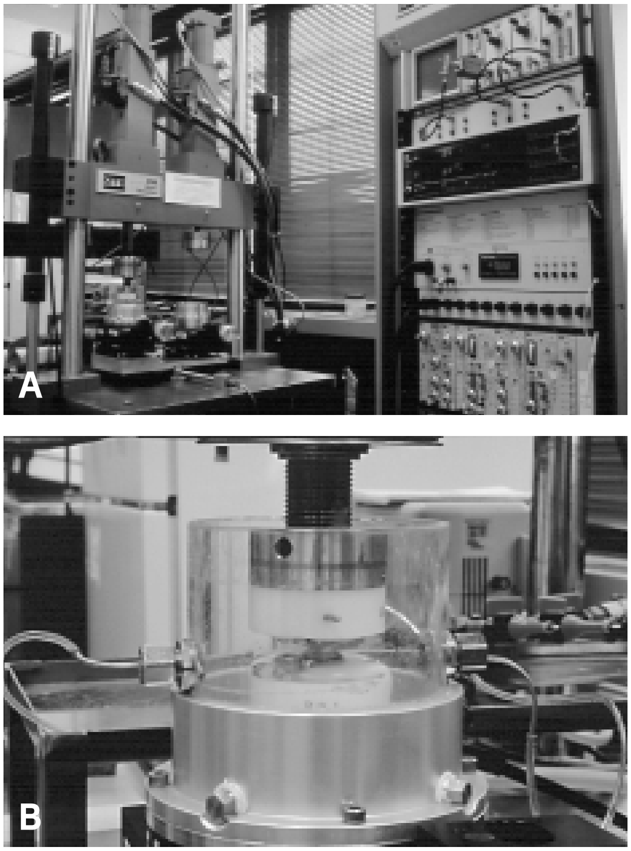

Fig. 1. Artificial, dynamic, oral environment developed by Douglas and DeLong. **A,** Test system (*left*) is activated by hydraulic pressure. Closed loop control by servomodule (*right*) allows maintenance of occlusal force (13.5 N), lateral excursion (0.62 mm), and cuspal contact time (0.23 s). **B,** Close-up view of environmental chamber. Jets bathe test specimens with deionized water at 37°C.

reports demonstrate that the latest polymers developed for prosthodontic use (so-called "ceromers") did not seem to be able to meet their original requirements with regard to clinical wear and failure rate.[12,13]

Meanwhile, Duceram-LFC (Ducera, Rosbach, Germany) hydrothermal low-fusing glass was introduced. It is designed to be applied over a conventional ceramic core and its manufacturer makes impressive claims about wear, solubility, and surface properties.[14] Unlike most ceramics, the flexural strength and resistance to disintegration of Duceram-LFC seem to increase significantly after hydrolysis testing.[15] Such accelerated aging is simulated by subjecting the material to 4% acetic acid solution at 87°C for 16 hours. However, few scientific studies have investigated its wear properties. Because of its glassy nature (no crystalline phase), Duceram-LFC is described as a homogeneous structure that should reduce wear of antagonistic enamel.[14] However, the high potential of Duceram-LFC is questioned in light of recent studies that could not consistently differentiate its wear pattern from other ceramics.[16,17]

Two possible protocols can be used when placing ceramic restorations. The first one corresponds to the classical prosthodontic approach: A try-in appointment is usually planned when using traditional full coverages.[18] This specific chairside step includes meticulous occlusal adjustments, the restoration being returned to the dental laboratory for eventual corrections, surface polishing, and glazing. Such planning optimally allows the practitioner to seat and cement the restoration at the next appointment without further corrections of the restoration surface. These procedures are usually recommended because most authors have agreed that the laboratory can produce smoother and denser surfaces.[19] As a result, the way ceramic materials are tested often correspond to this protocol (laboratory finished surface). However, a different chronology and sequence occurs when placing bonded restorations such as porcelain inlays, onlays, and veneers. It is not recommended to adjust or check occlusion before the restoration is cemented because of the risk of fracture.[20] For this reason, the surface of the restoration is often adjusted and repolished intraorally after cementation.

A variety of commercial kits have been developed to improve intraoral surface finishing of the ceramic, and have been extensively studied in the literature.[19,21-24] Most of these experiments focused on the ceramic surface roughness that can be achieved and compared with an "ideal" glazed surface. It is often speculated that the rougher surfaces produced by polishing will generate increased enamel wear. Only a few studies extended their investigation to the influence of ceramic surface finishing on the wear characteristics and wear pattern against enamel.[25,26] Surprisingly, the same conclusion is found in these studies, namely, the absence of a significant effect of porcelain surface finish.

A problem with wear-related literature is the lack of standardization. A wide variety of abrasives, measuring instruments, and methods of wear testing make it difficult to assess study results that compare dental materials.[27] Experimental methods have varied from the simple design of the Wig-L-Bug technique[28] to a variety of more sophisticated systems. There has been no consensus about the method of laboratory wear tests or their clinical meaning. For instance, Mahalick[29] used a simple abrading apparatus and measured a 100× increase in mean volume loss for porcelain-to-porcelain when compared with gold-to-gold specimens. However, an in vivo study by Ekfeldt and Oilo[30] reported a volume loss per unit time for porcelain-to-porcelain that was only 5 to 10 times greater than type III or IV gold in contact with identical materials. This finding emphasizes the importance of using a system that reproduces, in an accurate way, the forces, movements, and physical environment of the human masticatory system. Such a method was proposed in 1983 by DeLong and Douglas,[31] who developed an artificial oral environment that correlated well with clinical occlusal contact wear (Fig. 1, *A* and *B*).[32,33]

This standardized, recognized protocol was used in our study to compare the wear properties of 3 ceramics designed for layering techniques, namely, veneering of a metal or ceramic core. Special attention was given to the surface finishing of the ceramic to simulate laboratory finished surfaces and clinical conditions related to porcelain inlays, onlays, and veneers, namely, surface roughening (occlusal adjustment) and the use of an intraoral porcelain finishing kit.

METHOD AND MATERIAL

Three groups of ceramics were tested: (1) low-fusing hydrothermal glass (Duceram-LFC), (2) feldspathic ceramic for porcelain-fused-to-metal (Creation, Klema, Meiningen, Austria), and (3) alumina-reinforced ceramic for aluminacore veneering (Vitadur α). For each material, 5 disks (12 mm in diameter and 3 mm thick) were produced from a silicon mold and fired over a platinum foil. All specimens were fabricated by a commercial laboratory experienced with the 3 ceramic systems. This laboratory has routinely used these ceramics for a minimum of 6 years. All ceramic specimens were made according to a realistic protocol for firing conditions and surface finishing. This included the reproduction of a distinct surface texture with superficial grooves (Fig. 2, *A*), which was standardized as much as possible by creating a defined number of evenly spaced grooves (14 per sample) using constant and reproducible rotation speed of the bur.

For group I (LFC) specimens, the hydrothermal glass is designed to be applied to a core of traditional feldspathic material. Therefore, a circular base of Creation porcelain was first constructed (2 firings under vacuum without holding time at 910°C, glazing without vacuum without holding time at 910°C) and veneered with 1-mm thick Duceram-LFC (2 firings under vacuum without holding time at 660°C, glazing without vacuum without holding time at 670°C). Glazing of Duceram-LFC ceramic did not follow manufacturer's recommendations (holding time of 2.5 minutes at 650°C). On the basis of the clinical experience, this procedure was chosen to prevent excessive translucency of the glass. Lack of brightness (insufficient light reflection) is inherent to Duceram-LFC ceramic and challenges the dental technician in his layering technique. The "modified" glazing protocol corresponds to a realistic way of using Duceram-LFC for anterior teeth when high esthetics is essential.

For group II (Creation) specimens, 2 firings under vacuum were performed without holding time at 910°C, glazing without vacuum without holding time at 910°C. For group III (Vita) specimens, 2 firings under vacuum were done without holding time at 950°C, glazing without vacuum without holding time at 930°C.

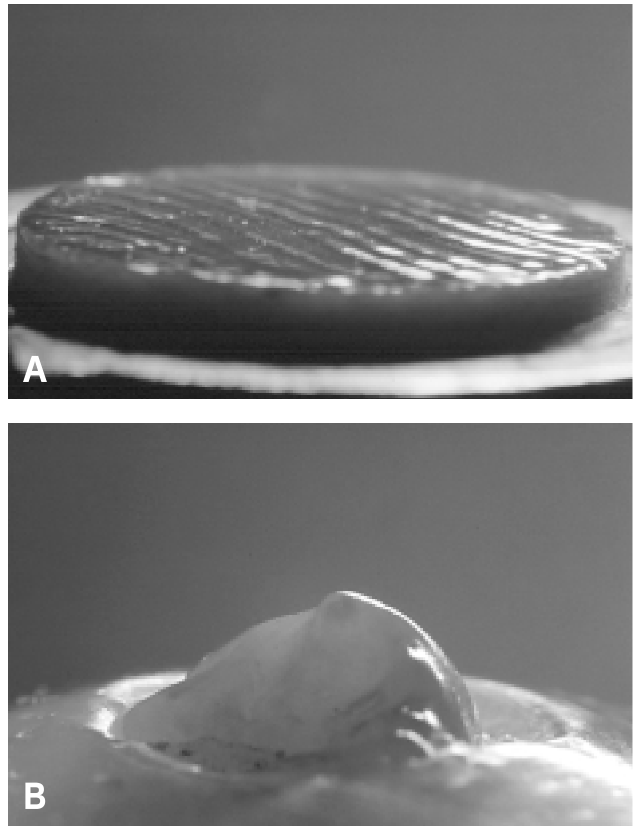

Fig. 2. A, Ceramic disk prepared with clinically realistic surface texture. **B,** Tooth specimen positioned in resin.

Surface finishing

Two scenarios were simulated for each group of ceramics for surface finishing. The first, laboratory-finished surface, was conducted by glazing, followed by mechanical polishing with pumice and calcium carbonate (Sigolin, Thompson Siegel, Dusseldorf, Germany). Calcium carbonate is a common abrasive material used in dentifrice. It is softer and finer than pumice and allows excellent finishing of the porcelain surface.

The second scenario was an intraorally finished surface, which was performed to simulate an intraoral adjustment. All ceramic surfaces were abraded with a greenstone at low speed by a single operator. Repolishing was carried out with a 30 fluted tungsten carbide bur (ETUF 9 014, Brasseler, Savannah, Ga.) and a commercial intraoral polishing kit (Dialite, Ultra Polishers, Brasseler) consisting of 3 consecutive diamond-silicon points (coarse W 16DG-21, medium W 16DM-21 and fine W 16D-21) and with abundant water spray at 2000 rpm.

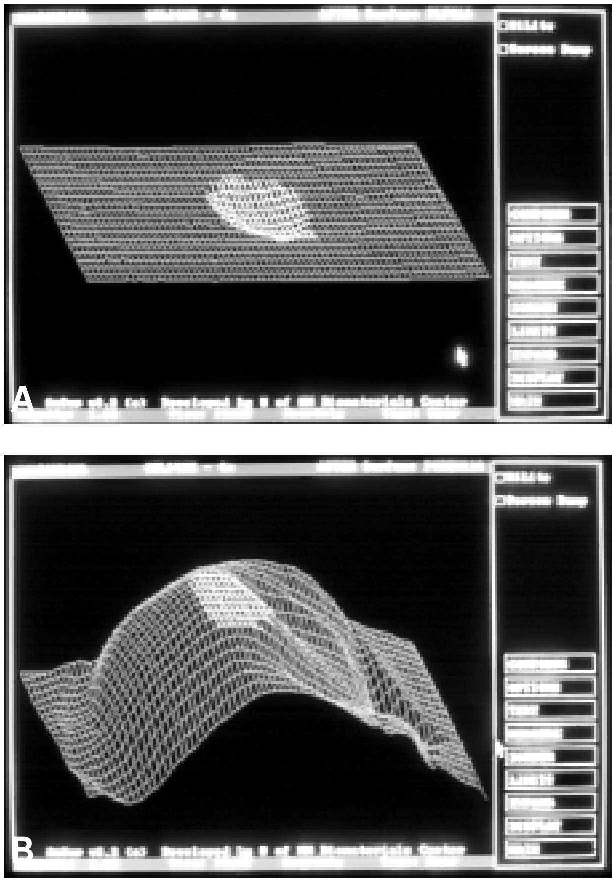

Fig. 3. Example of digitally mapped surfaces (ceramic disk and cusp tip with wear facets) in AnSur.

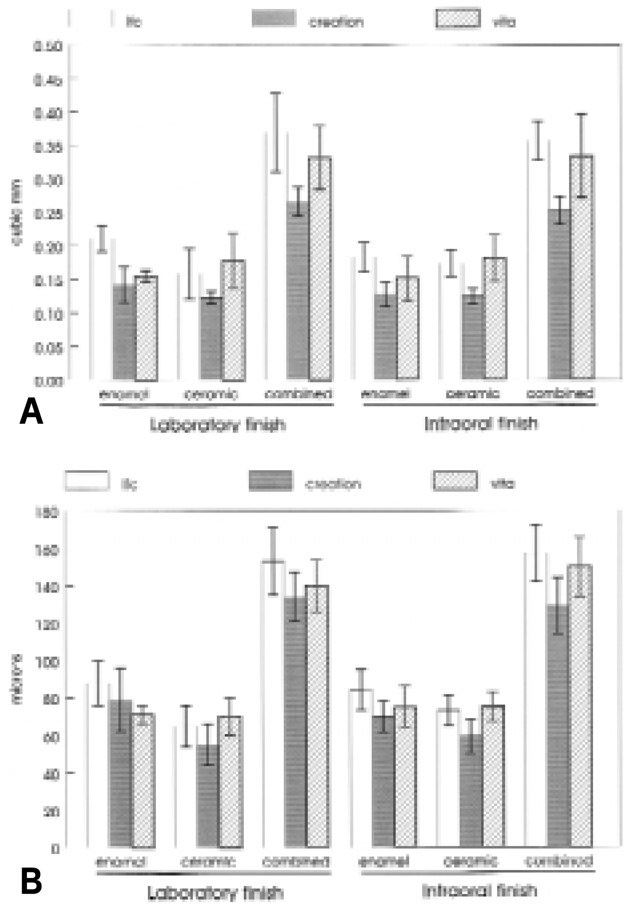

Fig. 4. A, Volume of material removed (mm^3) and **B,** mean depth of wear (µm) for enamel, ceramic and enamel/ceramic combined with both finishing techniques. Thin bars indicate standard deviation.

Preparation of tooth specimens and wear characterization

Thirty extracted maxillary third molars (5 teeth per material tested and per finishing procedure) were stored in deionized water and 0.2% azide until use. Teeth were collected from oral surgery clinics and prepared by removing the buccal cusps and isolating the mesiopalatal cusp. Each tooth was mounted in a flat polyethylene ring with the use of a chemically cured acrylic resin (Orthodontic resin, batch no. 651006, Dentsply International, Milford, Del.) (Fig. 2, *B*).

Masticatory movements and forces were simulated with an artificial mouth using closed-loop servohydraulics.[31] The chewing cycle was simulated by a mode change from isotonic to isometric contraction (stroke control to load control) as required by the physiology of the mouth. This device has been extensively described and shown to correlate well with clinical occlusal contact wear.[5,32-34] The ceramic disks were positioned in a polyethylene ring and used as the mandibular member of the system. For each sample, the maxillary member was represented by the palatal cusp of a maxillary third molar (described previously). Each experimental pair (disk and cusp) was stored in deionized water at 37°C for at least 24 hours before testing, then subjected to 300,000 defined masticatory cycles at a chewing rate of 4 Hz. Five specimens of each material type were placed in the artificial mouth and subjected to the following masticatory parameters: occlusal force at 13.5 N, lateral excursion at 0.62 mm, and cuspal contact time at 0.23 second. A continuous flow of deionized water was directed on the wear area, maintaining the environmental temperature at 37°C.

Profiling

Paired occlusal surfaces were mapped and digitally recorded at the beginning and end of each masticatory test. The profiling device was designed and built in the Minnesota Dental Research Center for Biomaterials and Biomechanics (MDRCBB).[35] Its design is unique because the tip of the stylus does not move during profiling (tip used as a "null point"); instead, the surface being profiled moves. This method is distinct from a

Table I. Means of volume loss, mean depth of wear, and combined wear

	Laboratory finish		Intraoral finish		Average	
	Volume loss (mm³)	Mean depth (μm)	Volume loss (mm³)	Mean depth (μm)	Volume loss (mm³)	Mean depth (μm)
Enamel						
Creation	0.143 (0.026)	79 (17)	0.128 (0.018)	70 (8)	0.135	75
LFC	0.211 (0.020)	88 (12)	0.183 (0.022)	84 (11)	0.197	86
Vitadur α	0.155 (0.008)	71 (5)	0.152 (0.033)	75 (11)	0.153	73
Ceramic						
Creation	0.123 (0.010)	55 (11)	0.125 (0.011)	59 (9)	0.124	57
LFC	0.158 (0.038)	65 (11)	0.174 (0.019)	73 (8)	0.166	69
Vitadur α	0.177 (0.041)	70 (10)	0.182 (0.034)	75 (8)	0.180	72
Combined						
Creation	0.266 (0.021)	134 (13)	0.253 (0.021)	129 (15)	0.260	131
LFC	0.369 (0.058)	153 (18)	0.357 (0.029)	157 (15)	0.363	155
Vitadur α	0.332 (0.048)	140 (14)	0.334 (0.062)	150 (16)	0.333	145

SD are indicated in parentheses.

Table II. Outcome of 2-way ANOVA and description (Bonferroni method). Superscript lines show material that was not statistically different in post-hoc tests

	Volume loss		Mean depth of wear	
Factor	*P* value	Description	*P* value	Description
Enamel				
Finish	.08		.53	
Material	.0000	Creation Vitadur α Duceram-LFC	.0362	Post-hoc tests not significant
Finish * material	.48		.46	
Ceramic				
Finish	.48		.11	
Material	.0006	Creation Duceram-LFC Vitadur α	.0035	Creation Duceram-LFC Vitadur α
Finish * material	.85		.90	
Combined				
Finish	.63		.58	
Material	.0001	Creation Duceram-LFC Vitadur α	.0078	Creation Vitadur α Duceram-LFC
Finish * material	.91		.58	

displacement stylus and was developed specifically to meet the rigorous challenge of profiling the surface of teeth with ultrahigh accuracy. The tungsten carbide stylus (radius 76 μm) is connected to the movable arm of an MTS 623.26 extensometer (MTS System Corporation, Eden Prairie, Minn.), the specimen being positioned on 2 computer-controlled sliding tables (Automation Gages, Rochester, N.Y.). Three computer-controlled DC servomotors move the x-, y-, and z-axes. The combination of the sample mounted on the platform of the z-axis slide table, the z-axis servomotor, and the extensometer signal from the stylus contacting the surface form a closed loop control system. The PC software "Capture," developed in the MDRCBB, controls the surface mapping, corrects the surface data for the shape of the stylus, and produces a 3-dimensional digital image. For this study, the image definition was limited to 40 profiles (Y-step of 100 μm), each profile consisting of 150 points (X-step of 50 μm).

The wear area was isolated by fitting the "before" and "after" data with the AnSur surface analysis computer graphic software (Regents of the University of Minnesota, Minneapolis, Minn.) (Fig. 3). Qualitative changes on occluding surfaces were examined visually, with computer graphics and SEM photomicrographs.

Null hypothesis and statistical analysis

It was hypothesized that the wear characteristics of enamel and the different veneering ceramics are similar. This null hypothesis was tested using a 2-way analysis of variance (ANOVA). The 2 factors analyzed were the type of ceramic and finishing technique. After using ANOVA to determine the significance of ceramic type, finishing technique, and the interaction of ceramic type and finishing technique, the ceramic type was examined to determine why this effect was significant. The latter was performed with standard errors from the ANOVA and by applying Bonferroni's method within the

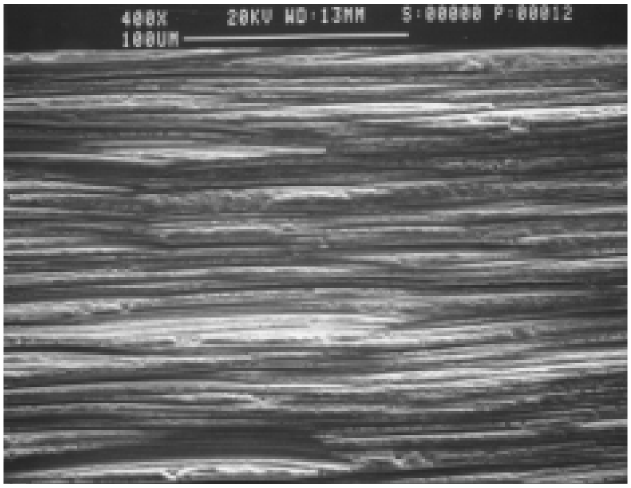

Fig. 5. Typical surface of enamel wear facet opposing Duceram-LFC material. (Original magnification ×400.)

ceramic type effect. In comparing the 3 ceramic types, 3 comparisons were made, each with a type I error rate of $\alpha = .05/3 = .0167$. A comparison was declared significant if $P<.0167$.

RESULTS

Summaries of material loss (volume and mean depth) are presented in Table I and Figure 4, *A* and *B*. Outcome of ANOVAs and corresponding description are listed in Table II. The combined loss of volume and height was obtained by summing the data for the enamel and opposing material.

Finishing technique

ANOVA failed to show significant differences for the type of surface finish, either in volume loss or depth of wear ($P>.08$). Neither enamel, ceramic, or combined wear measurements revealed any differences between surfaces finished in the laboratory by the dental technician or chairside by the clinician.

Material type

ANOVA was systematically significant when comparing materials using either volume or mean depth data. Enamel, ceramic, and combined measurements revealed *P*-values that were always lower for volume loss ($P<.0006$) compared with depth of wear ($P<.0362$). Enamel volume loss generated by Creation and Vitadur α were similar (0.135 and 0.153 mm^3, respectively) and differed from enamel volume loss created by LFC (0.197 mm^3). Post hoc tests failed to show differences between materials for enamel depth of wear (range: 73 to 86 μm). Ceramic wear was consistently lower for Creation either in volume loss (0.124 mm^3) or depth of wear (57 μm) compared with LFC (0.166 mm^3 in volume or 69 μm depth) and Vitadur α (0.180 mm^3 and 72 μm). The same trend occurred for the combined volume loss. Combined depth of wear, however, failed to differentiate between Creation and Vitadur α.

The interaction between finishing technique and material type was not significant ($P>.46$); the finishing technique had the same effect on the different materials.

Qualitative SEM analysis

The typical aspect of enamel wear facets is depicted in Figure 5. All cusps exhibited deep, well-defined wear grooves. This aspect of enamel wear facets was consistent and similar for all test conditions and materials. Typical ceramic surfaces are depicted in Figures 6 through 8. Laboratory finished surfaces (Figs. 6, *A*, 7, *A*, and 8, *A*, right side) systematically exhibited smoother aspects than chairside finished surfaces (Figs. 6, *B*, 7, *B*, and 8, *B*, right side). On average, more air voids and macroscopic defects were found at the surface of Duceram-LFC specimens compared with the others (Fig. 6, *A*). However, high magnification views of chairside finished Duceram-LFC (Fig. 6, *C*) tended to demonstrate fewer microscopic defects than others (Figs. 6, *C*, 7, *C*, and 8, *C*). All ceramic wear facets demonstrated grooves characteristic of abrasive wear (Figs. 6, *D*, 7, *D*, and 8, *D*) with a trend for more brittle chipping in the case of Duceram-LFC.

DISCUSSION

Dental esthetics are becoming more important, and the emphasis on quality ceramics is consistent with the improving skills of dental technicians and the use of layering techniques. Developing veneering ceramics with sophisticated optical properties has also contributed to the rise in esthetic standards. By design, the "man made" external layers of ceramics that are responsible for the unique and individual beauty of the restoration are carried onto the occluding surfaces and thus influence wear phenomena. Machinable ceramics, even though proven to be wear-friendly,[8] were not included in our study because of the focus on veneering porcelains with high esthetic potential.

Studies in the artificial oral environment have demonstrated that volumetric wear changes linearly with time. This has been correlated with clinical data[31-33] and can be used to predict clinical conditions. When comparing the same class of ceramics (porcelain-fused–to–metal), our results show a good correlation with a previous investigation by DeLong et al.[5] At 300,000 cycles, those authors found an average enamel volumetric loss of 0.162 ± 0.057 mm^3 compared with 0.143 ± 26 mm^3 for laboratory-finished Creation ceramic. The similarity of these values indicates the lack of improvement during the last decade of feldspathic veneering porcelains with regard to wear.

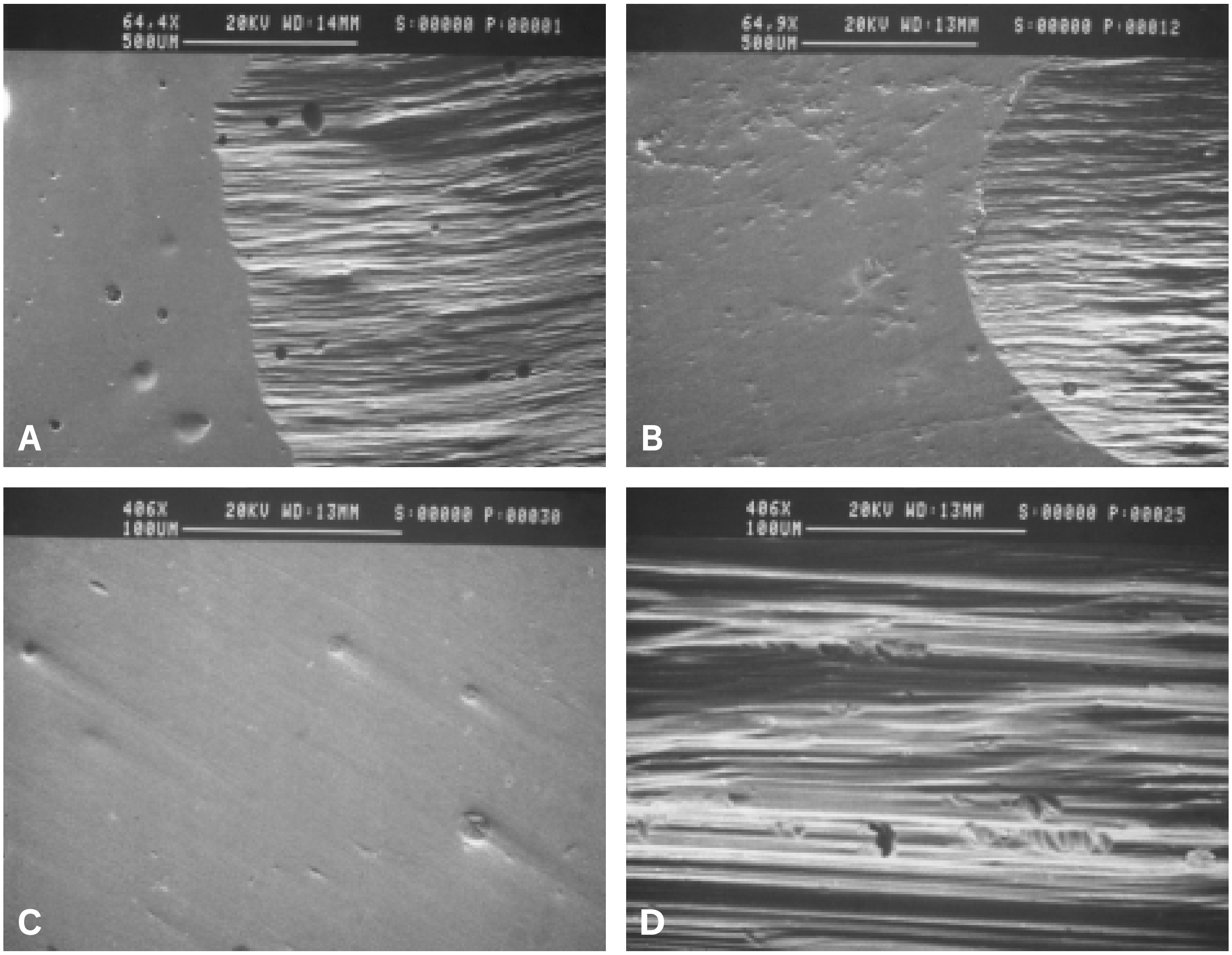

Fig. 6. Typical surfaces of Duceram-LFC material. **A,** Ceramic disk with laboratory finish and **B,** intraoral finish at edge of wear facet. (Original magnification ×64 and ×65, respectively.) **C,** Detail of polished surface of **B** (original magnification ×406); **D,** detail of ceramic wear facet (original magnification ×406). Numerous brittle chipping fractures are visible.

Volume loss versus depth of wear

Height loss is described in wear studies because of its ease of measurement (no digital devices required) and clinical relevance regarding the vertical dimension of occlusion. However, volume loss is a more sensitive method because it changes linearly with time.[36] Accordingly, it was not surprising that the most significant differences between materials were observed in volume loss and not in depth of wear. Each of these results is consistent with previous in vivo findings.[37] The difference between wear measured in volume and in height is largest when opposing surfaces feature cuspal morphologic structures. This difference is reduced as cuspal structure is removed and opposing surfaces become flat.

Effect of material type

There is agreement that veneering porcelains can be associated to an abrasive type of wear.[36] Abrasive wear implies that the abrader (in this situation, ceramics) is much harder than the material being abraded (enamel). Interpenetration of the 2 surfaces produces a ploughing effect, which is characteristic of the abrasive type of wear.[36] This specific wear mechanism was reported for the 3 materials tested as demonstrated by SEM qualitative evaluation (Figs. 6, *D*, 7, *D*, and 8, *D*; with similar aspect of grooves).

Hardness of Duceram-LFC ceramic is claimed to be approximately 420 VHN,[14] which is close to enamel's hardness, 408 VHN.[38] Therefore, the Duceram-LFC-enamel wear mechanism was expected to be "soft abrasive" as defined by Richardson,[39] namely, resulting in lower wear rates of enamel when compared with feldspathic ceramic-enamel couples. The results of our study clearly show that this hypothesis is not applicable to ceramics. Another wear study showed that the extreme-

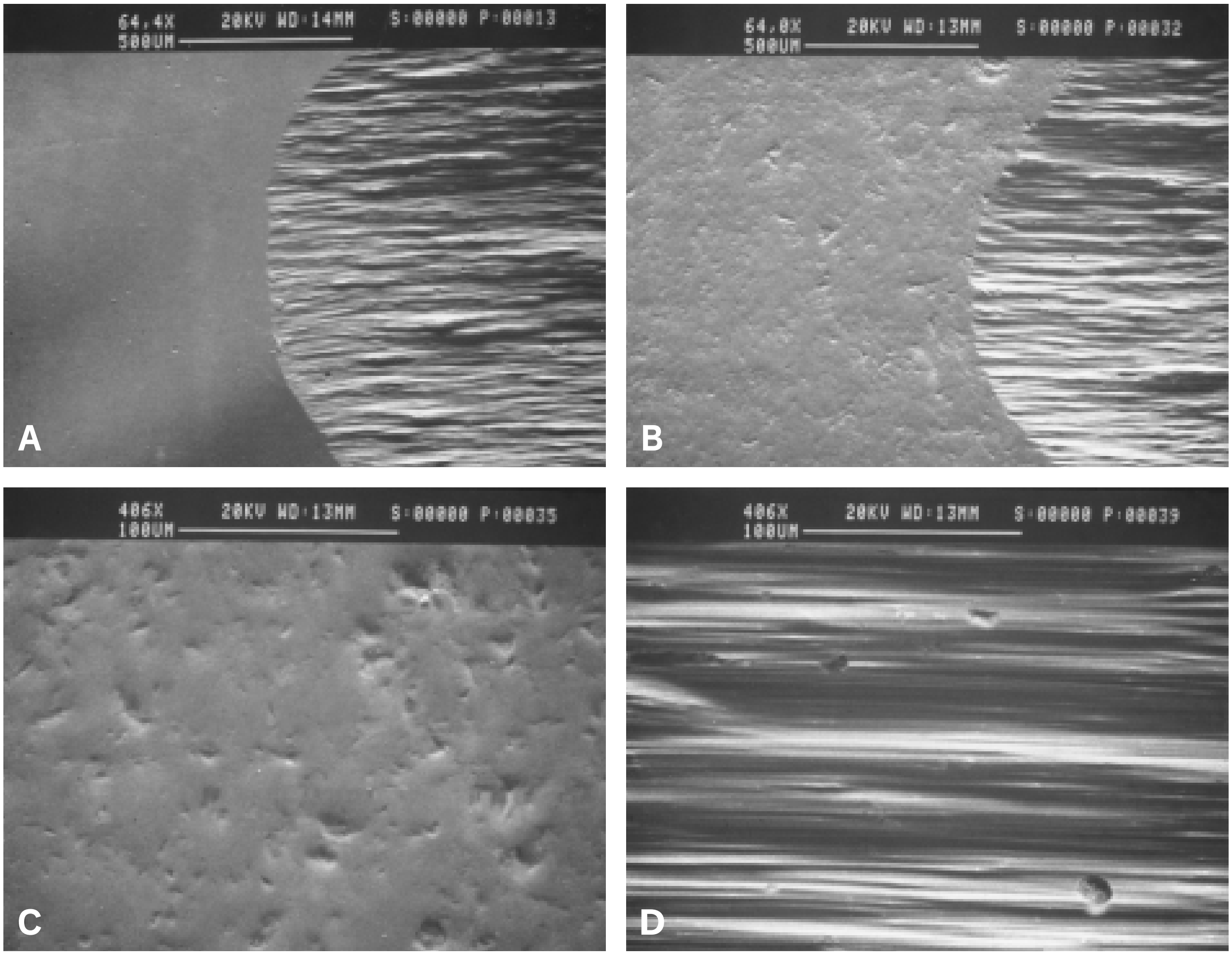

Fig. 7. Typical surfaces of Creation. **A,** Ceramic disk with laboratory finish and **B,** intraoral finish at edge of wear facet. (Original magnification ×64.) **C,** Detail of polished surface of **B** (original magnification ×406); **D,** detail of ceramic wear facet (original magnification ×406).

ly hard In-Ceram core, made of glass infiltrated alumina, was less destructive than its corresponding veneering ceramic.[40] In fact, hardness and wear appear to be poorly correlated as demonstrated by Seghi et al.[6] In our study, Duceram-LFC showed a significant increase in volume wear of enamel compared with Creation or Vitadur α. The volume loss of enamel opposed to Duceram-LFC ceramic exceeded the volume loss of Duceram-LFC itself, whereas the loss of ceramic was similar to the loss of antagonistic enamel for both Creation and Vitadur α materials.

On the basis of SEM observations, the main differences among the 3 materials can be first explained by the presence of air voids at the surface of Duceram-LFC specimens (Fig. 6, *A*). Circular fractures were detected on the corresponding wear facets of Duceram-LFC ceramic (Fig. 9). This kind of defect is certainly associated with the presence of porosities just below the ceramic surface.[36] Many variables can affect the structural quality of a veneering ceramic, including technical aspects of the firing process.[41] For instance, in an evaluation of internal defects of some porcelains, Oilo[42] discovered that the firing schedule (starting temperature, holding time) was critical to generate an adequate flow of the glass and to limit the number and size of pores. Accordingly, for the 3 tested materials, the main firings were made exactly according to the manufacturer's recommendation. However, as reported by the dental laboratory in charge, the firing of LFC seems to be less predictable than ceramics with high sintering temperatures, which may be explained by the fact that regular ovens were not originally designed to be accurate in low temperatures and are best calibrated to work between 900°C and 1000°C. Issues concerning temperature regulation of the ceramic ovens when using low-fusing ceramics have been reported previously.[43] Further research is required to determine with precision how a regular oven must be adjusted to optimize the firing of

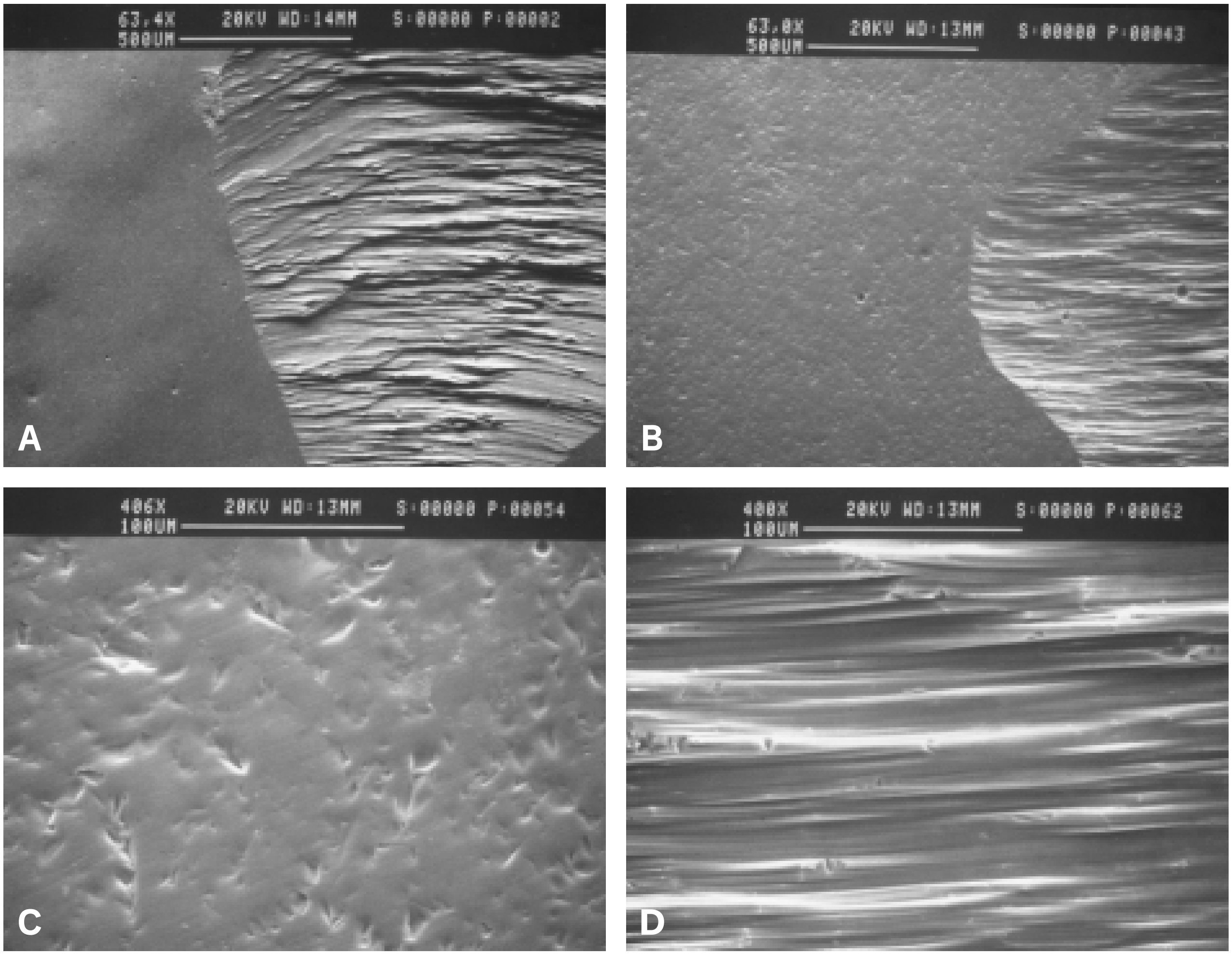

Fig. 8. Typical surfaces of Vitadur α. **A,** Ceramic disk with laboratory finish and, **B,** intraoral finish at edge of wear facet (original magnification ×63). **C,** Detail of polished surface of **B** (original magnification ×406); **D,** detail of ceramic wear facet (original magnification ×400).

Duceram-LFC ceramic. This problem may have created the characteristic macroscopic defects of this material.

However, the most important differences were found in the microstructure of the tested materials. Figure 10 shows the fractured surface of a Duceram-LFC specimen. The noncrystalline nature of Duceram-LFC ceramic is evident when compared with the Creation base. One can anticipate that such differences in microstructure will also result in differences in wear. Duceram-LFC ceramic is claimed to be friendlier to enamel. High magnification with SEM reveals the smoother aspect of LFC between the defects (Fig. 6, *C*), whereas, on similar views (Fig. 7, *C*, and 8, *C*), the "rougher" crystalline nature of the ceramic is evident for both Creation and Vitadur α. The presence of macroscopic defects might not be the only explanation for the poor performances of LFC. The brittleness and the possibly insufficient toughness of the glass may generate more abrasive particles. As wear proceeds in 2-body abrasion, some blunting of the hard asperities or particles will occur, thus reducing the wear rate. However, the wear rate can be increased by fracture of brittle particles, resulting in resharpening of the edges of the particle.[44] Such a phenomenon is illustrated in Figure 6, *D*. This "brittle" type of abrasive wear is typical of soda lime glass[45] (another low melting temperature glass), and could presumably affect the performances of the low-fusing hydrothermal glass. Porcelains did not show similarly extensive brittle wear.[36] Creation ceramic, which is appreciated by dental technicians for its optical properties (iridescence) and natural layering technique, also proved to give the best predicted clinical behavior with regard to wear, revealing the lowest average combined wear in both volume and depth.

Effect of finishing technique

Intraoral polishing of ceramic restorations is common when placing bonded restorations (inlays, onlays, veneers). As outlined in the introduction, final occlusal

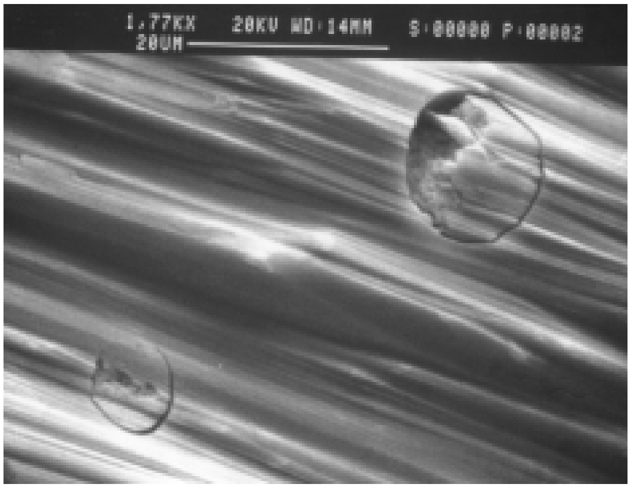

Fig. 9. Typical circular fracture found at wear facet of Duceram-LFC specimens. (Original magnification ×1770.)

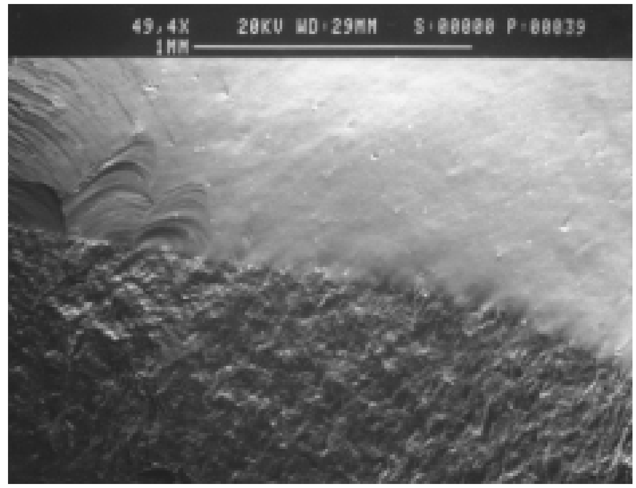

Fig. 10. General view of fractured surface of Duceram-LFC specimen. (Original magnification ×49.) Glassy structure (100%) of Duceram-LFC material (upper part) can be differentiated from crystalline structure of Creation feldspathic base (inferior part).

adjustments cannot be carried out during try-in procedures because of the fragility of the unbonded porcelain piece. Thus, our data have paramount clinical significance considering that (a) the 3 products tested can be used for the fabrication of inlays, onlays, and veneers, and (b) postbonding occlusal adjustments are almost unavoidable.

The use of 30-fluted carbide burs in combination with a Dialite polishing kit was chosen because of good results regarding surface roughness.[46] A number of polishing techniques are described in the literature and were compared with the "gold standard" given by the original glaze. Some authors initially demonstrated the superior smoothness of glazed porcelain.[23,47] Divergent work, on the other hand, favors the use of mechanical polishing.[22,48-50] Haywood et al[51,52] even concluded that intraoral polishing of porcelain can equal or surpass the smoothness of glazed porcelain. It is recognized that improved esthetic results are obtained by polishing[53]; however, the degree of success of any polishing technique is still dependent on having a well-condensed porcelain and adequate firing conditions because porosities in the porcelain are not completely eliminated by polishing as they are in natural glaze firing.[48] Therefore, the combined use of glazing and polishing can be advocated to improve both esthetic and surface characteristics. Qualitative SEM analysis showed the superiority of this technique, which was used for the laboratory finish, compared with the solely mechanical polishing of the simulated intraoral finish (Figs. 6 through 8).

The importance of such considerations on the wear characteristics might not be as great as speculated by most authors. Korber et al[54] reported that the abrasiveness of rough porcelain was initially greater than that of glazed porcelain, but fell to the same level after a 300-cycle wear-in period against enamel. Similarly, Krejci et al[4] showed that after a glazed surface was worn away, the wear rate was nearly the same for the polished and the glazed ceramic. The combined results of our study are in agreement with these findings because for each material, similar wear rates were obtained with glazed and polished surfaces, as they were in the studies by Jagger[25] and al-Hiyasat.[26]

CONCLUSIONS

An artificial oral environment (closed-loop servohydraulics) was used to compare the wear of enamel against 3 types of ceramics designed for layering techniques. Laboratory and chairside finishing of the ceramic were compared. The most significant differences between materials were observed in volume loss (ANOVA, $P<.05$):

1. Duceram-LFC was the most abrasive for enamel and generated, along with Vitadur α, the highest combined loss of enamel and ceramic. Defects, brittleness, and the possibly insufficient toughness of LFC may explain its increased abrasiveness.
2. Creation was significantly less abraded and generated the lowest combined loss of enamel and ceramics.
3. For the 3 materials tested, wear characteristics of intraorally polished specimens were similar to wear characteristics of laboratory finished samples (glazed and polished).
4. The same abrasive type of wear was revealed for all 3 ceramics.

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