Quantitative Measurement of Tooth and Ceramic Wear: In Vivo Study

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Purpose: The aim of this study was to quantitatively measure tooth and ceramic wear over a 2-year period using a novel superimposition technique. Three ceramic systems—experimental hot-pressed ceramic (EC), Procera AllCeram (PA), and metal-ceramic—were used. ***Materials and Methods:*** A total of 90 posterior crowns in 48 patients were randomized into 3 groups, and impressions were made at baseline and at 6-month intervals for 2 years. Clinical images were taken after using a dye to highlight surface changes. The impressions were digitized and modeled as superimposable 3-dimensional colored surface images. The depth of wear at the occlusal contact areas was quantitatively measured at 6, 12, 18, and 24 months. ***Results:*** The quantitative evaluation showed more wear in Procera AllCeram at the occlusal contact areas, whereas the experimental and metal-ceramic systems showed less wear. There was a significant difference in the amount of enamel worn between all types of restorations ($P < .05$). There was a statistically significant difference ($P < .05$) in the mean depth of wear between all systems. ***Conclusions:*** The metal-ceramic and experimental systems showed less change, indicating improved wear resistance compared with Procera AllCeram. In addition, enamel opposing metal-ceramic and experimental crowns showed less wear compared to enamel opposed by Procera AllCeram crowns. *Int J Prosthodont 2008;21:245–252.*

For more than 100 years, dental ceramics have been widely used as esthetic restorative materials. These materials offer a natural tooth appearance and very good mechanical properties. Ceramics are wear resistant, brittle, technique sensitive to polish, and abrasive to the opposing dentition.[1,2] This abrasion of opposing natural teeth may be rapid, producing sensitivity and occlusal imbalance, especially when functional paths are generated by the ceramic surface.[3] It has been suggested[4] that ceramic should not be placed on occlusal surfaces because of the wear effect of ceramic on enamel. As a consequence, several modified ceramic materials have been developed in an attempt to decrease antagonistic tooth wear. New ceramic restorative systems and adhesive restorations have greatly contributed to the increased interest in esthetic dentistry.[5] The wear effects of currently accepted dental ceramic materials have been studied extensively under laboratory conditions. Unfortunately, laboratory studies that evaluate abrasion resistance may produce entirely different results from clinical studies of the same materials. Despite recently developed technologies, no sufficiently valid in vivo evaluation method of clinical wear for dental ceramic and opposing enamel has been published. There is a distinct need for controlled clinical studies of wear, since laboratory studies do not accurately simulate clinical performance, and the final test will always be clinical success. A new experimental glass-ceramic has been produced to be used as a nonlayered crown system and is expected to have a favorable wear behavior against tooth enamel.

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Table 1 Ceramic Systems and Luting Agent Used in the Study

Trade name	Composition	Manufacturer
Procera coping	Densely sintered, high-purity aluminum oxide	Nobel Biocare
AllCeram	Feldspathic porcelain	Ducera
Simidur S2 alloy	Gold, platinum, palladium, silver	Panadent
IPS Classic	Feldspathic porcelain	Ivoclar Vivadent
Experimental glass-ceramic	Glass-ceramic, densely packed rod like, lithium disilicate crystals	Ivoclar Vivadent
Panavia F	Dual-cure dental adhesive system	Kuraray

Table 2 Patient Age and Sex

Age (y)	Men	Women	Total
20–30	1	9	10
30–40	8	14	22
40–50	6	5	11
50–60	2	3	5
Total	17	31	48

Table 3 Restored Teeth

Tooth	Maxilla	Mandible	Total
First premolar	5	1	6
Second premolar	11	7	18
First molar	22	30	52
Second molar	5	9	14
Total	43	47	90

This prospective clinical study quantitatively reports the wear behavior of this experimental glass-ceramic crown system against tooth enamel and vice versa compared with 2 commercially available crown systems over a 2-year period.

Materials and Methods

Ceramic materials with significantly different microstructures were selected for inclusion in this study (Table 1). Patients were selected from the normal pool of patients attending a dental hospital for routine dental care. Age and sex of patients and distribution of teeth involved in this study were recorded (Tables 2 and 3). To maintain stable noncontact reference points, posterior teeth were selected that required crowns in an otherwise intact dentition without a history of erosion. Patients with reported parafunctional habits were excluded from this study. The study tooth to be crowned had to be opposed by a natural tooth of which the majority of the occlusal surface was enamel. The study had ethical approval from the Guy's and St Thomas' Hospitals Ethical Committee. All patients gave written consent. Patients were instructed to attend if they noticed any problems affecting either the restored teeth or opposing teeth.

Clinical Methods

One operator performed all treatment procedures. The general clinical procedures for each patient followed a standardized, predetermined protocol. Metal-ceramic (porcelain-fused-to-metal with the occlusal surface in metal) and Procera AllCeram crowns were inserted on suitably prepared abutment teeth and cemented using an appropriate resin luting agent (Panavia F, Kuraray). Routine treatment procedures were followed for metal-ceramic crowns and Procera AllCeram crowns.[6,7] The clinical procedures for experimental ceramic crowns were the same as for the Procera crowns. The laboratory fabrication of the experimental crowns followed the same technique as for IPS-Empress ceramic with the surface coloration technique.[8]

Baseline assessment took place when the patient was recalled 1 week after fitting the definitive restoration. At this visit, an oral examination was conducted, patient concerns were addressed, independent assessors completed the case report form, and crown adjustments were made, finished, and polished. Clinical photographs were also taken of each restoration. Full-arch polyvinyl siloxane impressions were made of both dental arches to provide accurate baseline records of the morphology of the restored teeth and their antagonists. Impressions were made at baseline and at each 6-month interval. Initially, scavenger alginate impressions were made, immediately followed by polyvinyl siloxane impressions using either a stock or custom-made tray depending on the shape and size of the dental arch. All impressions followed the same protocol, which was defined from a pilot study: *(1)* the same impression material was used for the whole period of study; *(2)* the impressions for the crowns and their antagonist teeth had to be of the same color and viscosity; *(3)* the same impression technique was used for the whole period of study.

It was determined from a pilot study that there was no difference in the recorded data between impressions made using stock trays or custom-made trays. The former is less time consuming and less expensive, but in some patients, the stock tray did not match the size of the dental arch, and thus impressions had to be made using a custom-made tray.

Figs 1a and 1b Articulating paper **(a)** and occlusal bite registration **(b)** were used to locate the occlusal contact points and areas that were likely to become contact points.

Quantitative Wear Measurement

The quantitative measurement of wear was conducted by digitizing the accurate impressions of the restored teeth and their antagonist teeth. Measurements of wear were made at tooth-restoration contact points that were identified before baseline recording using articulating paper, bite registration material, and clinical photographs taken using an intraoral digital camera (Figs 1a and 1b). Articulating paper (Surgident, Mile Dental Products) was used to identify tooth-restoration contact points by asking the patient to bring the maxillary and mandibular teeth into maximum intercuspation, tapping lightly, and then taking photographs of these highlighted contact areas. At the baseline measurement recording, the articulated contacts were used to identify selected measurement points for each subsequent recall visit. Areas selected for measurement were based on articulated points and points that were likely to become contact points. Up to 4 points were measured on the occlusal surface of each crown and its enamel antagonist. Reference points were selected in noncontacting areas of the tooth surface that were more likely to be stable over the course of the study, eg, the occlusal fossa.

A computerized noncontact coordinate measurement system was used to digitize the impressions used for wear measurement. All impressions were scanned with a noncontacting laser profilometer (Keyence LC-2400 series laser displacement meter). Data acquisition and analysis was performed with UBSoft (UBM Messtechnik) and 3-dimensional surface modeling software (Figs 2a to 2g). Scan-Surf mathematical fitting software was used to analyze the occlusal surfaces. In this method, a large number of profiles were assembled into an image of the tooth surface. Data collected from a longitudinal series of impressions of the same tooth surface were analyzed by superimposing the images of anatomically stable occusal areas using the Scan-Surf software.

Restoration surfaces and occlusal areas without anatomic changes were used as reference points in the fitting procedures. The material loss and changes in the occlusal contact areas of the restoration surfaces were measured and analyzed statistically. The data obtained were used to establish linear, area, and depth assessments of wear processes occurring on the restored teeth and their antagonists.

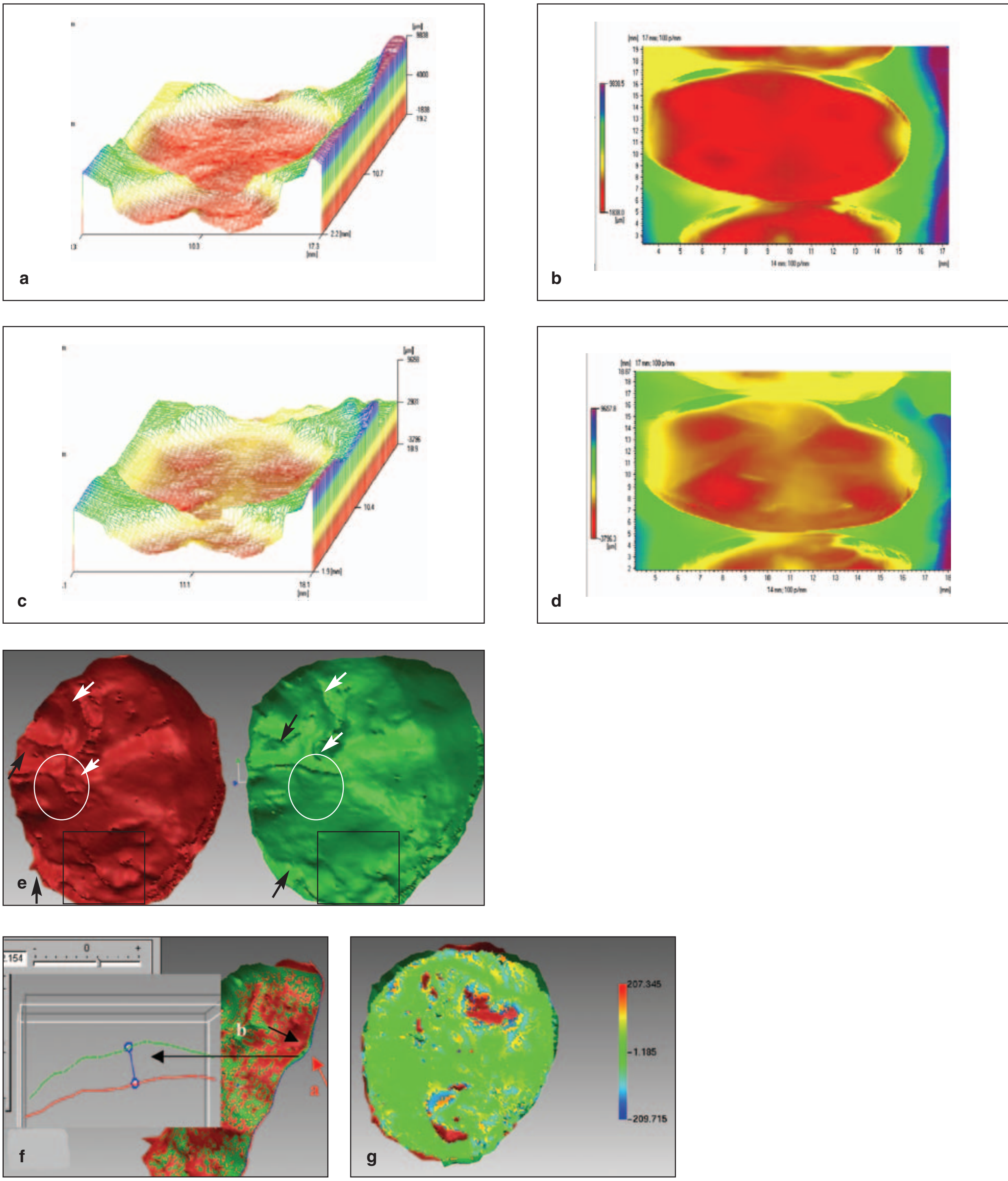
The amount of material loss was analyzed statistically using the SPSS statistical program (SPSS). A variety of general linear modeling descriptive statistics and comparison of means were used to analyze and compare mean values of the continuously distributed data from the various groups and time periods in the study.

Results

Quantitative Wear Measurement: Restoration Wear

The average wear values for the 3 restoration systems (loss of depth) at 6, 12, 18, and 24 months are plotted in Fig 3. The means and standard deviations are listed in Table 4. The 3 crown systems showed steadily increasing loss of material and were worn to different extents in the regions of the occlusal contact areas. All showed changes in the amount of material loss over the 2-year period.

The statistical analysis using Scheffé multiple comparisons of means showed that there were significant differences ($P < .05$) in the amount of ceramic and metallic material worn away by the opposing tooth structure. Statistically, there were significant differences in the amount the restorations had worn be-



Figs 2a to 2g Measurements of the depth of material loss. **(a)** Wireframe digital image representing baseline. **(b)** Color contour map. **(c)** Wireframe digital image for the same crown after 24 months. **(d)** Color contour map. **(e)** Red-shell modeled surface for the same image in **(a)**, while the green shell represents the image in **(c)**; *arrows* in both images show the worn areas after 24 months. **(f)** Cross section of superimposed shells; distance between the red and green lines represents the depth of wear in the measured area. **(g)** Globally registered model; red areas represent the pattern and locations of wear.

tween the 3 restoration systems after a 2-year period. There were significant differences in the mean amount of material loss between the 3 systems at 6, 12, 18, and 24 months. The mean values showed significant differences in loss of depth for each material over the 4 time intervals.

Quantitative Wear Measurement: Tooth Wear

The results showed that the opposing tooth enamel wore at all contact areas with the 3 crown systems. These materials also caused reciprocal enamel wear in the occlusal contact areas. Different amounts of enamel were worn away by the 3 types of restorations. The contact areas of all teeth showed a circular defect of approximately 1 to 2 mm in diameter in the occlusal contact areas.

The mean depths of tooth wear after 2 years are shown in Table 5. The metal-ceramic crowns produced the least tooth wear and the least loss of material. Procera AllCeram was the most abrasive ceramic and was responsible for more tooth loss than the metal-ceramic and the experimental ceramic. It also suffered the greatest loss of test material. The experimental ceramic caused less enamel wear than Procera AllCeram but more than the metal-ceramic.

Statistically, 1-way analysis of variance confirmed that there was a significant difference in the degree of enamel loss between the 3 materials ($P < .05$). This also confirmed that the type of ceramic system opposing enamel influenced enamel wear. The Scheffé test showed that enamel wear opposing the ceramic systems was significantly different from one material to another. However, metal-ceramic crowns demonstrated the least wear in the opposing enamel, and the Procera AllCeram system exhibited the greatest effect on the opposing enamel.

Although there was a significant difference from one material to another in terms of causing wear to the opposing tooth enamel, the 3 materials caused a dramatic increase in tooth wear in the first 6 months in the occlusal contact areas. After 6 months, the 3 materials showed slower rates of wear, but even so, a steady increase in tooth wear in the same areas was evident. Fig 4 shows that the mean wear differed significantly from one material to another; further, the mean wear differed significantly over each time period for the same material.

Discussion

The aim of this investigation was to examine the wear of tooth enamel that may be caused by 2 commercially available crown systems and 1 experimental ceramic. The wear effect of the tooth enamel on these crown

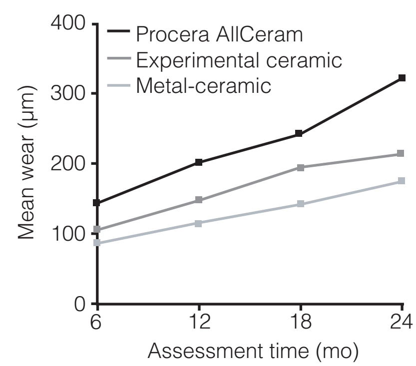


Fig 3 Mean wear of restorations over 24 months.

Table 4 Wear of the Restorations Over 24 Months

Assessment time/ Crown system	Mean	SD	SE	Minimum	Maximum
6 mo					
Procera AllCeram	143.60	9.47	2.99	129	161
Experimental ceramic	108.50	4.87	1.54	99.4	118
Metal-ceramic	87.06	2.96	0.94	83.6	92.6
12 mo					
Procera AllCeram	201.18	10.22	3.23	183	216
Experimental ceramic	148.16	6.38	2.02	138	160
Metal-ceramic	116.30	4.74	1.50	106	122
18 mo					
Procera AllCeram	243.70	7.31	2.31	232	254
Experimental ceramic	194.18	11.92	3.77	163	206
Metal-ceramic	142.30	3.91	1.24	138	150
24 mo					
Procera AllCeram	321.60	12.79	4.04	305	344
Experimental ceramic	214.76	4.96	1.57	204	220
Metal-ceramic	176.00	3.93	1.24	171	186

Table 5 Tooth Wear Over 24 Months

Assessment time/ Crown system	Mean	SD	SE	Minimum	Maximum
6 mo					
Procera AllCeram	130.96	15.08	4.77	109	148
Experimental ceramic	102.02	8.49	2.69	88.4	111
Metal-ceramic	75.52	7.15	2.26	62	85.2
12 mo					
Procera AllCeram	184.24	15.02	4.75	147	201
Experimental ceramic	149.70	6.59	2.08	138	160
Metal-ceramic	106.90	10.17	3.22	92.2	122
18 mo					
Procera AllCeram	216.84	14.14	4.47	198	239
Experimental ceramic	193.92	12.07	3.82	163	206
Metal-ceramic	133.82	6.94	2.19	126	148
24 mo					
Procera AllCeram	261.58	12.88	4.07	227	274
Experimental ceramic	214.86	6.09	1.93	200	220
Metal-ceramic	156.42	14.34	4.53	132	177

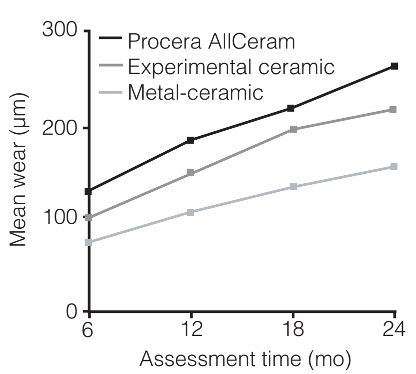


Fig 4 Mean values of tooth wear over 24 months.

systems was measured. The measurements of wear were conducted from a clinical perspective. Impressions were examined to obtain coherent data that could describe what was happening on the surface of the restorations and the opposing tooth enamel. All impressions made in this study were digitized. The scanning parameters, area to be scanned, scanning technique, and data analysis determined the accuracy and reproducibility of this technique. The amount of material loss from both sides was high in the first 6 months. This may relate to loss of the glaze layer from the ceramic materials and/or undetectable premature contacts during fitting of the crowns. After 6 months, the amount of material loss decreased but was still higher than physiologic tooth loss. This may be related to the abrasive nature of the restorative materials resulting from factors such as differences in hardness and microstructures. Wear of the restorative materials and opposing enamel is a factor in the selection of a restorative material, whereas wear of the restorative material is a predictor of the clinical longevity of a restoration. This in vivo investigation used various methods to rank wear of 2 dental crown systems and 1 experimental ceramic opposing enamel, and each method showed a different "best" material for clinical use. Thus, the type of wear evaluation should be considered when interpreting dental literature. The vertical height loss components in enamel wear, material wear, and total wear are important factors in wear assessment. Distinct occlusal wear can be determined by both direct and indirect methods. However, general wear of the restorative material caused by other factors, such as fracture, was not detected in this study when it was located outside the occlusal contact areas. Examples of this are shown in Figs 1 and 2. However, material loss outside the occlusal contact areas caused by bulk chipping or fracture of the surface layer influences the assessment, resulting in values that are lower or higher than the actual loss of material caused by wear.

With the technique employed in this study, not only was the depth at a specific location measured, but also the respective area of wear was determined. Using the 2 parameters, the overall volume loss of the materials can be calculated mathematically.

New low-fusing ceramic materials have been developed to minimize wear damage. The manufacturers claim that these ceramics are wear friendly because of their lower hardness, lower concentration of crystal phase, and smaller crystal sizes. Two all-ceramic systems with different microstructures were used in this study, along with a metal-ceramic. Procera AllCeram caused more wear to the opposing tooth enamel and showed more wear itself compared with the other materials, in spite of its low hardness and lower concentration of crystal phase. This finding agreed with evidence suggesting that the hardness of a restorative material alone is not a reliable predictor of the wear of opposing enamel.[9–11] In particular, the relationship of wear to hardness is not valid for materials that are brittle in nature. When ceramic slides against ceramic or enamel, wear does not occur by plastic deformation, as with metals, but by microfracture. This type of abrasive wear mechanism has been addressed.[12]

Miyoshi and Buckley[13] reported on the relationship between friction and wear of ceramics. They stated that "ceramics behave much like metals when they are brought into contact with solids." For example, when a silicon carbide surface is placed in contact with a diamond under relatively low contact pressure, elastic deformation can occur in both the silicone carbide and the diamond. Sliding occurs at the interface. A large increase in applied contact pressure, however, results in a complete reversal of the friction characteristic. Increased pressure causes plastic deformation in the silicon carbide, causing permanent grooves during sliding that lead to very small cracks. When a much higher contact pressure occurs because of the high concentration of stress in the contact area, the sliding action produces gross surface and subsurface cracking as well as plastic deformation.[13]

The natural wear that occurs in dental ceramic is adhesive and abrasive. Wear may occur when adhesion takes place across an interface between ceramic and enamel. If tangential motion results in fracture of the ceramic, adhesive wear has taken place. The fracture strength of 1 of the 2 surfaces must be less than that of the interfacial junction.

The complex wet environment of the oral cavity, which is impossible to reproduce in vitro, can impart positive surface charges on glass or ceramic, leading to loss of sodium ions to the interacting aqueous environment and thereby reducing surface hardness.[14–16] The microstructural components of different dental ceramics interact differently with the oral environment. This interaction may affect the behavior of the ceramics. Some in vitro studies questioned the effect of hardness on wear, finding that relatively soft ceramics exhibited more abrasive action against human enamel than harder ceramics.[17–20]

The results of this study showed that the ($>$ 70%) ratio of crystals included in a glassy matrix do not necessarily have a negative impact on the wear of enamel. Care must be taken when interpreting data from previous in vitro tests, because the wear behavior of a ceramic with fine crystal content may be characterized differently by different wear tests.

The outer layer and final surface finish of dental ceramic may affect the wear pattern. In this study, the ceramic surface was polished to the finest particle size and then glazed. In the first 6 months of clinical performance, the surface glazing layer was lost in the occlusal contact area, and some visible wear facets became macroscopically visible, especially with Procera AllCeram crowns. The fabrication of the experimental ceramic crown involved the lost wax process, which requires fabrication of a wax pattern and investment of the pattern for glass-casting procedures. During the glass-casting procedure, a distinct surface layer is produced. The newly formed layer consists of crystalline whiskers oriented perpendicular to the external surface of the glass ceramic. This surface layer may cause enamel abrasion and may be more resistant to abrasion itself. The finishing procedures in this study involved polishing and glazing, which eliminates the effect of this layer. The application of shading porcelain, however, reduced the abrasiveness of the surface layer by filling the microscopic surface irregularities. This layer helped reduce initial wear against enamel until it was worn away by the opposing enamel at the occlusal contact areas.

This study did not measure the wear of enamel against enamel. It has been shown that steady state enamel/enamel wear is in the range of 29 μm per year for molars and 15 μm per year for premolars.[21] In this study, Procera AllCeram wore 4 times as much as enamel. The experimental ceramic wore 1.25 times as much as enamel, and metal-ceramic wore at about the same rate as enamel. Each of these comparisons allows for steady-state wear to have been established after the first year.

Conclusions

The experimental ceramic material appeared to provide clinical performance that was superior to that of Procera AllCeram in terms of wear behavior. The experimental ceramic showed a friendly wear behavior on the opposing tooth enamel, and was more wear resistant than the Procera AllCeram system. The wear behavior of the experimental ceramic was comparable to the metal-ceramic crown.

Therefore, it is suggested that clinicians should consider the type of ceramic restorative materials used to maintain a stable occlusal relation. Further, the ceramic restorations should be sufficiently polished after any chairside adjustment of occlusal surface. Modification of ceramic materials is recommended to produce more durable ceramic in terms of wear resistance and to minimize the undesired effects—such as wear—of ceramic materials on antagonistic enamel.

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