In Vivo Wear of Enamel by a Lithia Disilicate–Based Core Ceramic Used for Posterior Fixed Partial Dentures: First-Year Results

Josephine F. Esquivel-Upshaw, DMD, MS[a]/Henry Young, DDS[b]/Jack Jones, DMD[c]/
Mark Yang, PhD[d]/Kenneth J. Anusavice, PhD, DMD[e]

Purpose: This study aimed *(1)* to test the hypothesis that no significant relationship exists between the magnitude of occlusal clenching force and wear rates of enamel opposing a new core ceramic (e.max Press, Ivoclar Vivadent) used in posterior fixed partial dentures (FPDs); and *(2)* to test the hypothesis that mean annual enamel wear by an experimental core ceramic is comparable to the mean annual enamel wear by enamel of 38 μm. ***Materials and Methods:*** Baseline data were obtained for patients in addition to preliminary impressions of maxillary and mandibular teeth. Thirty ceramic FPDs were processed from a new core ceramic (e.max Press) that was hot pressed and glazed. Patients were recalled 1 year after cementation and evaluated using clinical criteria that included wear assessment of opposing teeth. Impressions were made of the opposing teeth with polyvinylsiloxane impression material and photographs were taken of intraoral occlusal contacts marked with articulating ribbon. Baseline casts and casts made at each recall exam of opposing dentitions were scanned using a 3-dimensional laser scanner (Laserscan 3D, Willytec) and evaluated for wear. A total of 21 occlusal surfaces were analyzed for the presence of wear. ***Results:*** Statistical analysis using a linear and quadratic model revealed no significant relationship between occlusal forces and wear rate assuming either a linear model (R^2 = 0.018) or a quadratic model (R^2 = 0.023). The maximum annual wear of enamel by the glazed core ceramic (e.max Press) was 88.3 μm, which is significantly greater than the annual enamel-by-enamel wear of 38 μm (P < .0001). ***Conclusion:*** Further analysis with a larger sample size is needed to determine the relationship between occlusal clenching force and wear rate and the influence of other factors that cause increased wear of enamel by opposing ceramic restorations. *Int J Prosthodont 2006;19:391–396.*

Wear is measured primarily in 1 dimension, usually along a vertical axis. The standard method adopted by the International Standards Organization and the American Dental Association for measuring wear is based on a pin-on-disk system in which a disk of enamel is abraded by a pin that is fabricated from the restorative material being investigated.[1] Although this is the simplest method for determining the amount of wear, it is not representative of the masticatory environment. Some investigators have proposed other wear machines that claim to adequately simulate the conditions of the oral environment.[2–5] Some have even introduced the concept of artificial saliva, as well as toothpaste, as a medium in wear testing.[6] The problem with these methods is that none of the claims for predicting clinical wear are validated for enamel wear by ceramics. The most complex issue is the method used to simulate masticatory movements, because the jaw moves in many different directions in addition to vertical and circular movements. Chewing patterns are very complex and can vary from individual to individual depending on the existence of joint pathology, occlusion, and muscle tone.[7]

[a]*Associate Professor, Department of Prosthodontics, University of Florida, Gainesville, Florida.*
[b]*Associate Professor, Department of Operative Dentistry, University of Florida, Gainesville, Florida.*
[c]*Assistant Professor, Department of Prosthodontics, University of Florida, Gainesville, Florida.*
[d]*Professor, Department of Biostatistics, University of Florida, Gainesville, Florida.*
[e]*Professor and Chairman, Department of Biomaterials, University of Florida, Gainesville, Florida.*

Correspondence to: *Dr Josephine Esquivel-Upshaw, Department of Prosthodontics, University of Florida, PO Box 100435, Gainesville, Florida 32610. Fax: 352 846 0248. E-mail: jesquivel@dental.ufl.edu*

Fig 1 Extensive enamel wear by an opposing porcelain restoration.

Most methods of wear measurement in vivo are made on replicas of restorations on which a reference plane is selected (eg, 3 or more points along a ditched margin). If no reliable reference plane exists, one must be created in the form of 3 reference points. This involves the creation of reference depressions by drilling the intact tooth structure to create a plane based on relocatable markers, which the surface-scanning device can use for calibration and orientation during subsequent measurements with a measuring microscope or a profilometer. A profilometer is used to scan the teeth surfaces and estimate the amount of lost structure based on the reference points.

A 3-dimensional (3D) laser scanner (Laserscan 3D, Willytec) has been developed that can be used to measure wear on replicas to an accuracy of ± 20 µm. The 3D laser scanner[8–10] uses a laser beam projected through a special optic system onto the surface being studied. The reflection of the beam is observed at a defined angle (25 degrees) by a high-resolution charge-coupled device camera based on the principle of the light-slit microscope. After scanning, it allows for 3D superimposition of the images by means of the selection of at least 3 reference points or areas that are not subjected to wear, and it then locates and quantifies the spatial differences between the 2 images, thereby measuring the amount of wear. It can also measure wear in 3 dimensions, thereby giving a more realistic view of the clinical characteristics of wear and the potential mechanisms involved.

Dental ceramics can cause extensive wear of enamel under certain conditions. Figure 1 shows extensive wear of mandibular teeth by the feldspathic porcelain veneer of a metal-ceramic fixed partial denture (FPD). Numerous studies have confirmed the wear potential of ceramics as opposed to other restorative materials.[11–16] However, an esthetics-conscious society has encouraged the development and use of dental ceramics for anterior and posterior restorations. The ultimate goal of ceramic development is the creation of a fracture-resistant, wear-friendly ceramic that exhibits superb esthetic results. Hot-pressed lithia disilicate–based ceramics such as IPS Empress 2 (Ivoclar Vivadent) are used as core frameworks for posterior FPDs in low- to moderate-stress sites. The hot-pressed ceramic system uses the lost-wax technique, in which the FPD pattern is waxed to its proper shape and contour and then invested in a special flask with a special type of investment material. The desired shade of a precerammed ceramic cylinder is plasticized at 1,100°C, pressed under vacuum, and pressure into the mold of the investment.[17] For optimal fracture resistance, FPDs can be made completely from the lithia disilicate–based core ceramic, because of its higher fracture toughness (3.3 $MPam^{1/2}$)[18] and translucency, rather than being veneered with a predominantly glass-phase ceramic. Because of its higher volume fraction of crystalline phase compared with the glaze layer and many veneering ceramics, it is likely that in the event the surface glaze layer (~100 µm) is lost, the core ceramic may cause more wear of opposing enamel than typical veneering ceramics. However, a new lithia disilicate–based core ceramic was used with a homogeneous distribution of smaller crystals (compared with Empress 2 core ceramic) that may increase fracture resistance and cause less wear of opposing enamel.

The objectives of this study were: *(1)* to test the hypothesis that there is no positive correlation between the magnitude of occlusal clenching force and the wear rate of enamel opposing a new lithia disilicate–based core ceramic used for posterior FPDs; and *(2)* to test the hypothesis that the wear of enamel by the core ceramic is comparable to the mean wear rate of enamel by enamel (38 µm annually) during the initial 1-year period.[19]

Materials and Methods

The protocol for this study was part of a previously published study.[20] A total of 30 FPDs were fabricated with the core ceramic for 21 patients, and all patients were recalled each year for 5 years. Three clinicians performed treatment and 1 technician performed all of the lab work using an in-house laboratory. Of the 21 patients, 18 were women and 3 were men, with ages ranging from 30 to 62 years. Exclusion criteria were medical contraindications to dental treatment, parafunctional habits, and uncertain residency in the area within the 5-year duration of the study. The 3-unit FPDs were located in the posterior area, with canines serving as the most anterior abutment and second molars as the most posterior abutment. All FPDs were opposed by natural dentition. Baseline data were collected to include preliminary impressions of the opposing dentition. Thirty all-ceramic FPDs were made using a heat-pressing technique and a new core ceramic (e.max Press, Ivoclar Vivadent) that contains lithia disilicate crystals. The clenching force for each subject was measured using a calibrated gnathodynamometer.[21] Each FPD was cemented with either a hybrid ionomer cement or a resin cement, the selection of which was determined from a random number table. Subjects were recalled 1 year after cementation and FPD performance was evaluated using the following 11 clinical criteria: tissue health, secondary caries, occlusion, sensitivity, proximal contact, margin integrity, color match, surface texture, wear of opposing enamel, anatomic contour, and fracture. FPDs were examined by 2 clinicians and scores given for each criterion, ranging from 1 (unacceptable) to 4 (excellent). Further, polyvinylsiloxane impressions were made of the opposing dentition at this time. Photographs were taken of intraoral occlusal contacts marked with articulating ribbon.

Baseline scans were taken from white type IV gypsum casts made from preliminary impressions during the initial examination of the 21 patients. Quantitative wear measurements were made with a 3D laser scanner on white gypsum casts (GC FujiRock) poured in polyvinylsiloxane impression material (Extrude, Kerr). Mean wear depths were calculated from the data provided by the scanner software as the difference in distance along the z-axis between the cast surfaces at 1 year and at baseline. A total of 21 occlusal surfaces were analyzed for the presence of wear.

Data were analyzed using linear and quadratic models and the *t* test.

Results

The mean occlusal wear of enamel opposing ceramic was 88.4 µm for premolars and 88.3 µm for molars after 1 year, with a range of 29 to 255 µm (Table 1). This is significantly higher than the wear rate of enamel opposing enamel of 18 µm annually ($P < .0001$) for premolars and 38 µm annually ($P < .0001$) for molars.[19]

In several cases, the laser-scan images revealed significant wear of enamel (Figs 2 to 4) by the core ceramic. The qualitative visual estimate of wear based on clinician ratings was unreliable, since 97% of wear ratings were judged to be excellent.

Statistical analysis based on linear and quadratic models of force and tooth type revealed that force was not a statistically significant factor ($P = .85$); nor were tooth type ($P = .35$) or the force–tooth type interaction ($P = .31$). The clenching force in the study ranged from 156 to 1,032 N (35 to 232 lb).

Table 1 Wear Rates for Premolar and Molar Teeth

Tooth*	Occlusal force (MPa)	Wear (µm)
Premolars		
14	98	48.16
34	50	149.39
35	50	148.50
24	82	54.76
25	82	44.07
25	82	45.60
45	116	159.08
45	142	48.00
45	142	50.00
43	82	181.00
44	82	116.00
45	82	56.00
45	82	48.00
Average		88.35
Molars		
16	98	29.55
17	98	255.31
26	82	51.22
26	82	34.42
26	81	27.72
47	116	124.76
47	116	123.27
46	142	60.00
Average		88.28

*FDI tooth-numbering system.

Discussion

The mechanism of tooth surface wear has challenged many dental scientists. Wear affects health in several ways, including effects on supporting structures of the teeth, loss of vertical dimension, tooth sensitivity, esthetics, and overall masticatory function. Unfortunately, there is very little understanding of the wear patterns, wear occurrence, and the amount of wear for any particular individual.

This results of this study suggest that the mean occlusal wear of enamel opposing the lithia disilicate–based core ceramic is significantly higher than the measured wear rate of mature enamel. A clinical study of enamel wear by Lambrechts et al[19] focused on an initial period of wear within the first year, which is usually 38 µm for molars and 18 µm for premolars. This is followed by a steady-state period in which balance is achieved in the occlusion and the enamel wear rate decreases. The steady-state wear for molars was 29 µm per year and 15 µm per year for premolars.

This study also suggests that there was no significant relationship between occlusal force and wear rate. Theoretically, frictional forces and localized impact forces affect the magnitude of the localized and generalized stresses that are generated. Higher frictional forces are generated under increasing clenching or masticatory forces.[22]

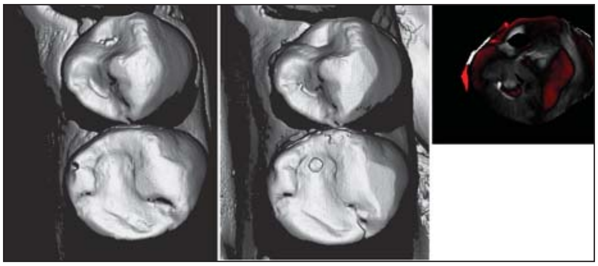

Fig 2 Significant wear of the buccal cusp by ceramic. The premolar displayed the highest vertical wear rate (255 μm).

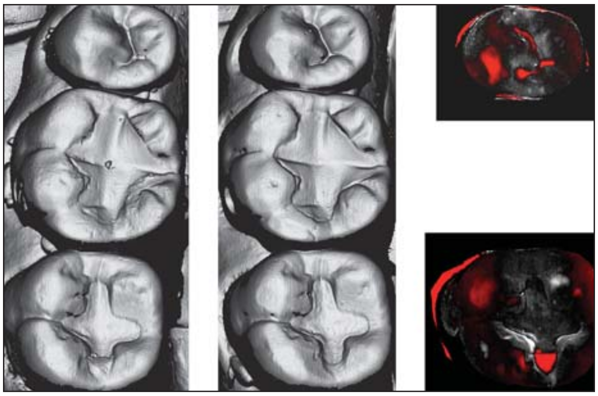

Fig 3 Significant wear of the buccal cusp regions by ceramic. Baseline image of 3 opposing teeth *(left)*. Image after 10 months of service *(middle)*. Differential image indicating the highest areas of enamel wear *(right, in red)*.

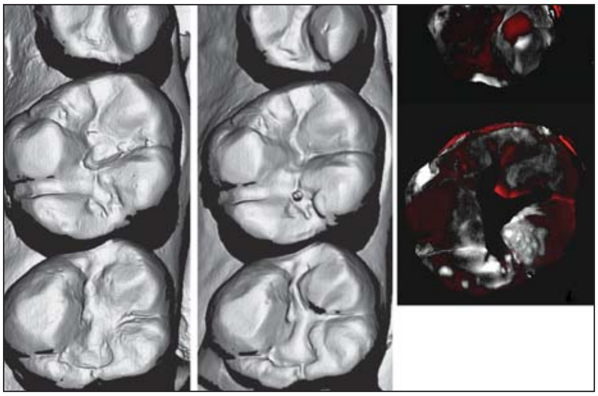

Fig 4 Maximum wear of 150 μm occurred along the occlusal surface of the premolar cusp tip. The red areas produced by the laser scanning software represent enamel abraded by the core ceramic over a 12-month period.

To determine whether wear is related to the force or tooth type, a regression model using wear as the response variable and force and tooth type as independent variables was used. Included in the model were the linear and quadratic terms for force and the force–tooth type interaction. The wear values were also compared using logarithmic function, and the conclusions were almost identical to the nontransformed data. The original data were therefore used for simpler interpretation and comparison.

Presently, the new lithia disilicate–based core ceramic is the strongest and toughest ceramic in the Empress line. Its predecessor, Empress 2, has been indicated for all-ceramic FPDs in the anterior and posterior regions of the mouth up to the second premolar. This new core ceramic has a finer crystal structure than Empress 2 with a slightly higher flexural strength and toughness.[23] Studies comparing IPS Empress, Empress 2, and e.max Press revealed mean biaxial strengths of 175 ± 32 MPa, 407 ± 45 MPa, and 440 ± 55 MPa, respectively.[24] Empress 2 and e.max Press have also demonstrated lower hardness values compared with IPS Empress, which makes IPS Empress more suitable for clinical and long-term use.[25] There are limited data available on e.max Press ceramic, although it is similar in composition to Empress 2, which consists of an interlocking microstructure with a relatively high content (~70 vol%) of lithium disilicate crystals ($Li_2Si_2O_5$).[26] Scanning electronic microscopy (SEM) revealed the presence of 2 crystal phases: phase 1 consisted of lithium disilicate crystals measuring 0.5 to 4 μm in length and represented the majority of the crystal phase; phase 2 consisted of lithium orthophosphate (Li_3PO_4) crystals, measuring 0.1 to 0.3 μm in diameter, which were dispersed uniformly throughout the glassy matrix and on the surface of the lithium disilicate crystals.[26] After hot pressing, the crystal phase comprised 70 ± 5 vol% of the glass-ceramic structure. An in vivo study was performed to measure the wear characteristics of the Empress 2 core ceramic opposed by enamel and showed enamel cusp wear of 125 μm after 1 year.[27] Impressions were made of teeth opposing an all-ceramic FPD at baseline, 6 months, and 12 months, and casts were profiled using the MTS Tooth Profiling System. Results at 6 months revealed that half of the natural antagonists were wear-free, whereas 40% of the ceramic surfaces had wear facets, showing that the ceramic is wear friendly.

The abrasive potential of ceramic is dependent on several factors, including fracture toughness, the presence of porosities, crystal size, and surface finish. Higher fracture toughness indicates a greater resistance to crack propagation, which can lessen the possibility of surface irregularities caused by chipping of the ceramic. An in vivo analysis of Empress 2 and

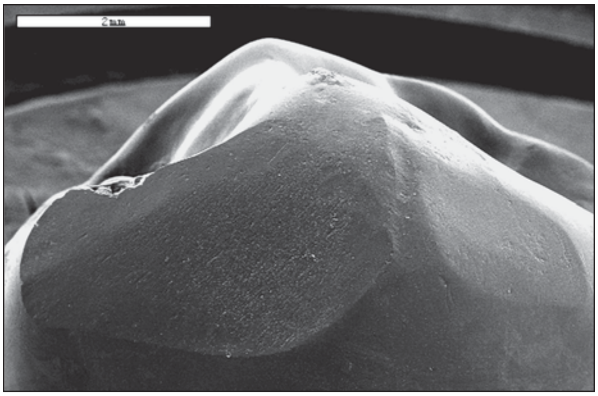

Fig 5 SEM image showing wear of a premolar opposing a ceramic FPD (×19 magnification).

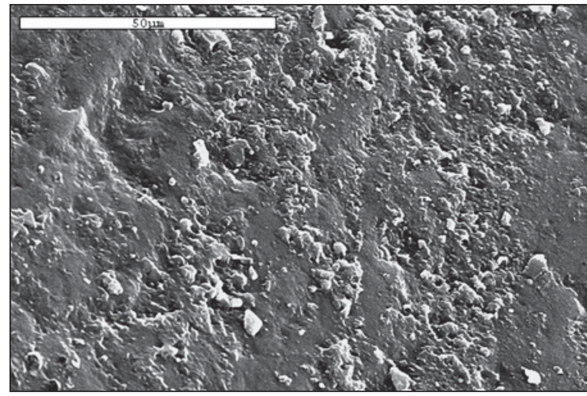

Fig 6 SEM image showing the surface of a premolar opposing a ceramic FPD (×1,000 magnification).

e.max Press reveals that both materials have a higher fracture toughness (3.1 ± 0.5 $MPam^{1/2}$ and 3.3 ± 0.6 $MPam^{1/2}$, respectively) and lower hardness (5.3 ± 0.2 GPa and 5.5 ± 0.2 GPa, respectively)[25] compared with IPS Empress. The abundance of porosities can cause a variety of problems, including reduced strength, poor esthetics, and the possibility of higher wear of the opposing enamel.[28] As porosities are exposed during wear, the irregularities produced on the surface cause more wear of the opposing dentition. The crystalline composition, which includes the type of crystals, content, morphology, and distribution of the crystal particles, also affects wear.[29] Perhaps the best explanation for the increased clinical enamel wear of the lithia disilicate–based core ceramic is associated with its surface roughness. Figure 5 is an SEM image that shows significant enamel wear on the surface of a premolar opposing an all-ceramic FPD. Figure 6 is an SEM analysis of the surface of the all-ceramic FPD opposing this worn premolar, which exhibited an extremely roughened surface causing significant wear and grooved areas on the opposing enamel (Fig 7). Frictional resistance increases with rougher surfaces and leads to a greater amount of wear. This could explain the excessive wear seen on the opposing enamel, which was as high as 255 μm in 1 case.

Conclusion

Initial analysis of a small sample size suggests that the wear rate of enamel opposing lithia disilicate–based core ceramic is not directly related to clenching force.

A larger sample size is needed to confirm whether enamel wear is related to clenching force under certain conditions. Since wear rate is also affected by other factors, such as occlusion, diet, and enamel thickness, it is also recommended that an examination of the contralateral dentition be performed in the future.

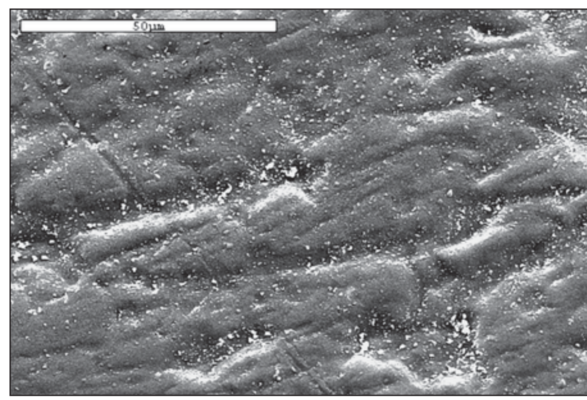

Fig 7 SEM image showing grooved surfaces of a premolar opposing a ceramic FPD (×1,000 magnification).

References

1. Suzuki S, Suzuki SH, Cox CF. Evaluating the antagonistic wear of restorative materials when placed against human enamel. J Am Dent Assoc 1996;127:74–80.
2. Ehrnford L, Derand T, Larsson LA, Svensson A. An abrasion test for composite resins. J Dent Res 1980;59:716–720.
3. Hacker C, Wagner W, Razzoog M. An in vitro investigation of the wear of enamel on porcelain and gold in saliva. J Prosthet Dent 1996;75:14–17.
4. Al-Hiyasat AS, Saunders WP, Sharkey S, Smith G, Gilmour WH. The abrasive effect of glazed, unglazed, and polished porcelain on the wear of human enamel, and the influence of carbonated soft drinks on the rate of wear. Int J Prosthodont 1997;10:269–282.
5. Seghi R, Rosenstiel S, Bauer P. Abrasion of human enamel by different dental ceramics in vitro. J Dent Res 1991;70:221–225.
6. Krejci I, Lutz F, Reimer M, Heinzmann JL. Wear of ceramic inlays, their enamel antagonists and luting cements. J Prosthet Dent 1993;69:425–430.
7. Okeson J. Management of Temporomandibular Disorders and Occlusion. St Louis, MO: Mosby, 1992:113.
8. Perry R, Kugel G, Kunzelmann K-H, Flessa H, Estafan D. Composite restoration wear analysis: Conventional methods vs three-dimensional laser digitizer. J Am Dent Assoc 2000;131:1472–1477.

9. Mehl A, Gloger W, Kunzelmann K-H, Hickel R. A new optical 3-D device for the detection of wear. J Dent Res 1997;76:1799–1807.
10. Folwaczny M, Mehl A, Kunzelmann KH, Hickel R. Determination of changes on tooth-colored cervical restorations in vivo using a three-dimensional laser scanning device. Eur J Oral Sci 2000;108:233–238.
11. DeLong R, Pintado MR, Douglas WH. The wear of enamel opposing shaded ceramic restorative materials: An in vitro study. J Prosthet Dent 1992;68:42–48.
12. Seghi RR, Rosenstiel SF, Bauer P. Abrasion of human enamel by different dental ceramics in vitro. J Dent Res 1991;70:221–225.
13. Palmer DS, Barco MT, Pelleu GB, McKinney JE. Wear of human enamel against a commercial castable ceramic restorative material. J Prosthet Dent 1991:65:192–195.
14. Ekfeldt A, Fransson B, Soderlund B, Oilo G. Wear resistance of some prosthodontic materials in vivo. Acta Odontol Scand 1993;51:99–107.
15. Ekfeldt A, Oilo G. Wear of prosthodontic materials—An in vivo study. J Oral Rehabil 1990;17:117–129.
16. Ekfeldt A, Oilo G. Occlusal contact wear of prosthodontic materials. An in vivo study. Acta Odontol Scand 1988;46:156–169.
17. Dong JK, Luthy H, Wohlwend A, Scharer P. Heat-pressed ceramics: Technology and strength. Int J Prosthodont 1992;5:9–16.
18. Olsson KG, Furst B, Andersson B, Carlsson GE. A long-term retrospective and clinical follow-up study of In-Ceram alumina FPDs. Int J Prosthodont 2003;16:150–156.
19. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. Quantitative in vivo wear of human enamel. J Dent Res 1989; 68:1752–1754.
20. Esquivel-Upshaw JF, Anusavice KJ, Young H, Jones J, Gibbs C. Clinical performance of a lithia-based core ceramic for 3-unit posterior FPDs. Int J Prosthodont 2004;17:469–475.
21. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosthet Dent 1986;56:226–229.
22. Pigno MA, Hatch JP, Rodrigues-Garcia RC, Sakai S, Rugh JD. Severity, distribution, and correlates of occlusal tooth wear in a sample of Mexican-American and European-American adults. Int J Prosthodont 2001;14:65–70.
23. Bona AD, Anusavice KJ, DeHoff PH. Weibull analysis and flexural strength of hot-pressed core and veneered ceramic structures. Dent Mater 2003;19:662–669.
24. Albakry M, Guazzato M, Swain MV. Biaxial flexural strength, elastic moduli, and x-ray diffraction characterization of three pressable all-ceramic materials. J Prosthet Dent 2003;89:374–380.
25. Albakry M, Guazzato M, Swain MV. Fracture toughness and hardness evaluation of three pressable all-ceramic dental materials. J Dent 2003;31:181–188.
26. Höland W, Schweiger M, Frank M, Rheinberger V. A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass ceramics. J Biomed Mater Res 2000;53:297–303.
27. Sorensen JA, Cruz MA, Berge H-X. In vivo measurement of antagonist tooth wear opposing ceramic bridges [abstract 232]. J Dent Res 2000;79:172.
28. Kelly JR, Campbell SD, Bowen HK. Fracture-surface analysis of dental ceramics. J Prosthet Dent 1989;62:536–541.
29. Oh W, DeLong R, Anusavice KJ. Factors affecting enamel and ceramic wear: A literature review. J Prosthet Dent 2002;87:451–459.

Literature Abstract

A clinical investigation of the fit of removable partial dental prosthesis clasp assemblies

This study evaluated the clasp assembly and the abutment tooth contact accuracy. Removable partial denture frameworks with conventional occlusal rest were evaluated. The spacing between the bottom 50 clasp assemblies and the corresponding rest seat were recorded with vinyl polysiloxane material. The fit of each rest was determined by measuring the thickness of the vinyl polysiloxane record between the rest and the bottom of the rest seat. The Kennedy classification was also recorded. A 2-sample t test was used to evaluate the difference in fit between tooth-tissue supported and tooth-supported designs. The average space between the rest and prepared rest seat was 193 ± 203 μm (range of 0 to 828 μm). Twenty tooth-tissue frameworks had an average space of 136 ± 160 μm and 30 tooth-supported frameworks had an average space of 230 ± 222 μm. No statistically significant difference for fit was noted between tooth-tissue supported and tooth-supported frameworks. Only 24% of rests had contact in the prepared rest seat. Removable partial denture frameworks are intricate castings commonly made of high-shrinkage base alloys. Partial denture design philosophies are all based on the assumption that various denture components fit well onto the abutment teeth. This study showed that a majority of rests evaluated did not contact the intended surfaces.

Dunham D, Brudvik JS, Morris WJ, Plummer KD, Cameron SM. *J Prosthet Dent* 2006;95:323–326. **References:** 9. **Reprints:** Dr Stephen M. Cameron, 1533 Clary Cut Rd, Appling, GA 30802. Fax: 706-787-7528—*Ansgar C. Cheng, Singapore*