Four-Year Clinical Performance of a Lithia Disilicate–Based Core Ceramic for Posterior Fixed Partial Dentures

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Purpose: The objective of this research was to test the hypothesis that 3-unit fixed partial dentures (FPDs) made from a moderately high-strength core ceramic will adequately resist fracture in posterior regions if fabricated with a minimal connector size of 4 mm. **Materials and Methods:** Thirty ceramic FPD core frameworks were prepared using a hot-pressing technique and a lithia disilicate–based core ceramic. The maximum occlusal force was measured for each patient prior to tooth preparation. Connector heights and widths were measured for each FPD. Patients were recalled annually after cementation for 4 years and evaluated using 11 clinical criteria. All FPDs were examined by 2 independent clinicians, and rankings for each criterion were made from 1 to 4 (4 = excellent; 1 = unacceptable). **Results:** The fracture rate was approximately 3% per year, and the proportion of good overall ratings in the nonfractured FPDs was reduced by more than 6% per year, where a good overall rating was defined to be a rank of 3 or 4 in all 11 criteria. There was little evidence that the use of either resin-reinforced glass-ionomer cement (Protec CEM) or dual-cure resin cement (Variolink II) made any difference in terms of fracture rate or overall rating (P = .30, .63, .97, and .71 for the 4 years, respectively). From a fracture resistance perspective, 4 of the 30 ceramic FPDs fractured within the 4-year evaluation period, representing an 86.7% success rate. Another FPD was replaced because of a caries lesion on 1 abutment tooth away from the margin. One FPD fracture was associated with the subject having the greatest occlusal force (1,031 N). The other 2 fractures were associated with FPDs that exhibited connector heights of less than 3 mm. All criteria were ranked good to excellent during the 4-year period for the remaining FPDs. **Conclusion:** Fractured FPDs were associated with a connector height of less than 4 mm; thus, the hypothesis was accepted. *Int J Prosthodont 2008;21:155–160.*

The increasing demand for esthetic restorations has led to increased acceptance of all-ceramic fixed partial dentures (FPDs) for use in posterior regions of the mouth. There are few reliable clinical studies documenting the longevity of these restorations. All-ceramic FPDs have several advantages compared to metal or metal-ceramic FPDs. Primarily, the esthetics obtained using all-ceramic restorations is unrivaled because of their increased translucency and light transmission.[1,2] Other advantages include biocompatibility, less tooth reduction,[3,4] low thermal conductivity,[5] less periodontal pathology because of supragingival placement of margins,[6–8] and ease of patient access for hygiene purposes.

Clinical studies of all-ceramic FPDs showed comparable longevity of 90% to 93% within a 5-year observation period.[9,10] This is lower than survival rates of 95% to 97.7% for metal-ceramic FPDs after 5 to 7.5 years.[11,12] Despite the slightly lower survival rate, ceramic FPDs are still indicated, primarily for esthetic reasons. With greater esthetic demands from the general population, it is easier to achieve esthetic results with ceramic prostheses with less tooth reduction (1.0 to 1.5 mm) compared with that of metal-ceramic prostheses for anterior restorations (1.2 to 1.7 mm).[1]

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Guidelines for the selection and design of all-ceramic FPDs are based on recommendations of manufacturers, which have not been validated by clinical research. A connector thickness of at least 4 mm is recommended for ceramic products with moderate strength and toughness, and a minimum thicknesss of 1.5 mm is recommended for the overall occlusal thickness of crowns.

Compared with metal-ceramic prostheses, the fracture susceptibility of some all-ceramic crowns and FPDs is greater because of several important factors: *(1)* relatively low tensile and flexure strength, *(2)* low to moderate fracture toughness, *(3)* susceptibility to crack initiation in the presence of microscopic flaws, and *(4)* sensitivity to tensile stress in the core structure. The veneering ceramics used for all-ceramic restorations are the most susceptible to fracture because of their low tensile strength and fracture toughness. For moderate-strength core ceramics, it is possible to reduce the fracture probability of all-ceramic crowns or FPDs by using only the core ceramic and no veneering ceramic.

The aims of this study were as follows:

1. To test the hypotheses that 3-unit posterior FPDs made from a high-strength core ceramic will exhibit good to excellent clinical performance (based on 11 evaluative criteria) and will adequately resist fracture in posterior regions (excluding third molars) if fabricated with the minimal connector size (4 × 4 mm).
2. To test the hypothesis that a reinforced glass-ionomer cement (ProTec CEM, Ivoclar Vivadent), when used to cement core ceramic crowns in posterior FPDs, will be associated with significantly lower marginal quality scores compared with the marginal quality associated with a dual-cure resin cement (Variolink II, Ivoclar Vivadent), while exhibiting similar fracture resistance.
3. To test the hypothesis that there is no significant difference in tooth sensitivity associated with FPDs cemented with glass-ionomer cement or dual-cure resin cement.

Materials and Methods

The protocol for this study was part of a previous study described in an earlier report.[13] All patient recruitment and treatments were performed in the Graduate Prosthodontic Clinic at the University of Florida College of Dentistry by prosthodontic faculty members. An Institutional Review Board approved the research protocol prior to commencement of patient treatment. Patients were initially screened to exclude individuals with medical contraindications to dental treatment, parafunctional habits, and inability to ensure residence in the area for the next 5 years. Inclusion criteria included a missing posterior tooth in a quadrant (first premolars through second molars) that could be restored with a 3-unit FPD, periodontal pockets of less than 4 mm for each abutment, no periodontal disease, vital abutment teeth, and a crown-root ratio of at least 1:1. A patient could have multiple FPDs placed as long as the aforementioned criteria were met. To obtain baseline data, the following procedures were carried out for each selected subject:

- General medical history and physical examination
- Primary casts made with irreversible hydrocolloid impression material
- Occlusal force measurement in Newtons made with a gnathodynamometer
- Pocket depths of abutment teeth
- Periapical radiographs of abutment teeth

The maximum occlusal force exerted by each subject was measured prior to treatment using a bite-force gauge previously described by Gibbs et al.[14] The purpose of these measurements was to analyze the influence of occlusal force on the survival of the FPDs. A total of 30 FPDs were fabricated for 21 patients with the core ceramic, and all patients were recalled each year for 4 years. Three clinicians performed treatment, and 1 technician, using an in-house laboratory, performed all of the lab work. Of the 21 patients, 18 were women and 3 were men, with ages ranging from 30 to 62 years. 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. Tooth reduction included at least 1 mm of axial reduction, 2 mm of occlusal reduction, and a shoulder or deep chamfer margin with rounded line angles. Final impressions were made using a dual impression technique with high- and low-viscosity polyvinyl siloxane in a stock tray. Provisional resin FPDs were fabricated and luted with provisional cement. FPDs were processed by hot pressing the core ceramic (e.Max Press, Ivoclar Vivadent) and applying stain and glaze as necessary. The heat-pressing ceramic system uses the lost wax technique, whereby the FPD is waxed to its proper shape and contour and 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 and pressed under vacuum and pressure into the mold of the investment.[15] The ceramic FPDs were inspected to ensure that the incisogingival height and curvature of the gingival embrasure of the connectors were adequate to minimize the risk of fracture when subjected to normal occlusal forces. The minimum connector width and height recommended for premolar FPDs (4 × 4 mm) and for molar FPDs (4 × 5 mm) were selected as "ideal dimensions" for each FPD to ensure optimal esthetics and gingival contour. Connector heights and widths were measured for each FPD using a Boley gauge. Each FPD was stained, and an overglaze was placed prior to cementation. FPDs were luted using either resin-reinforced glass-ionomer cement (Protec CEM, Ivoclar Vivadent) or a dual-cure resin cement (Variolink II, Ivoclar Vivadent). The cement used for each FPD was selected from a random number table of the numbers 1 and 2. Fourteen FPDs were cemented with the resin-reinforced glass-ionomer cement and 16 with the dual-cure resin cement using an adhesive (Syntac, Vivadent) under cotton roll isolation. Patients were recalled after cementation annually for 4 years and evaluated for the following clinical criteria:

1. Tissue health
2. Secondary caries
3. Occlusion
4. Proximal contact
5. Marginal integrity
6. Absence of sensitivity to percussion, heat, cold, and air
7. Color match
8. Surface texture
9. Absence of wear of opposing teeth
10. Anatomic contour
11. Cracks/chips or fracture

This evaluative system was derived from the California Dental Association quality assessment evaluation system.[16] FPDs were examined by 2 independent clinicians who did not prepare the teeth or cement the prostheses, and rankings of each criterion were made from 1 to 4, where 4 = excellent, 3 = good, 2 = unacceptable (needs repair or replacement in the near future), and 1 = unacceptable (needs immediate replacement). All clinicians/evaluators were trained in several calibration exercises that consisted of tabletop analysis of marginal openings as well as slide evaluations of different clinical situations.

Statistical analyses were based on a logistic regression analysis with SAS PROC CATMOD. The responses were dichotomized as "good to excellent" and "unacceptable." The independent variables were type of tooth, FPD connector height, occlusal force, marginal integrity, and cement.

Results

If the average scores for all 11 parameters were 3.0 or greater, the performance was considered good to excellent. Any fractured FPD or carious tooth abutment was considered as unacceptable (scores 1 or 2). Four of the 30 FPDs fractured, 3 of which had an undersized connector in the fracture site (Figs 1 to 4 and Table 1). One abutment tooth showed secondary caries. Good to excellent ratings in the nonfractured FPDs decreased, on average, by approximately 4% per year. Only 1 of the FPDs with a connector thickness of 4 mm or more fractured.

The overall performance of the FPDs decreased over time (Table 2). The percentages of good to excellent scores for the 30 FPDs were as follows (the P values indicate the level of significance when testing the equality of the performances of Protec-Cem and Varionlink II using the Fisher 2-sided exact test):

- One-year recall: 92.9% for Protec-Cem and 93.8% for Variolink II ($P = .99$)
- Two-year recall: 92.9% for Protec-Cem and 87.5% for Variolink II ($P = .99$)
- Three-year recall: 72.7% for Protec-Cem and 73.3% for Variolink II ($P = .99$)
- Four-year recall: 72.7% for Protec-Cem and 76.9% for Variolink II ($P = .99$)

There was no statistically or clinically significant difference between the mean performance scores for Protec-Cem and Variolink II cements in years 1, 2, 3, and 4 ($P = .30$, .63, .97, .71, respectively).

FPDs with a first or second molar abutment exhibited fracture rates of 21% (n = 14) and 20% (n = 5), respectively. There was no statistically significant difference between the 2 fracture percentages. If molar and premolar sites are separated, the molar fractures amounted to 21% (n = 19) of the total, and premolar fracture did not occur. As a result of the small sample size, the difference is not statistically significant ($P = .14$). The fracture resistance is related to the height of the connector. The shorter connector tended to induce more fracture ($P = .032$), but the occlusal force did not correlate well with the fracture rate ($P = .84$). There was no significant difference in mean marginal integrity ($P > .05$) and tooth sensitivity ($P = .961$) between Protec and Variolink II cements.

Discussion

The increased popularity of all-ceramic materials resulting from their superior esthetics has stimulated an increased interest in developing stronger, more fracture-resistant ceramic materials. Unfortunately, the strength of ceramics is predetermined by the existence of microcracks induced by grinding or other mechanical events.[17] These flaws determine the strength and survivability of the ceramic, along with factors such as the size and location of the cracks, which can lead to catastrophic failure.

After a 4-year follow-up period, the fracture of crowns in 4 of the 30 FPDs led to catastrophic failure of the prosthesis. One patient developed caries on one of the abut-

Fig 1 Baseline FPD in the patient with the highest occlusal force (distal connector: 3.5 × 6.3 mm; mesial connector: 4.0 × 5.1 mm).

Fig 2 Fractured connectors for the FPD in Fig 1. The distal connector fractured at 16.5 months. The mesial connector fractured 4 to 5 days after the distal connector.

Fig 3 FPD in the subject with the lowest occlusal force (373 N), which fractured at 24 months (distal connector: 2.9 × 5.2 mm; mesial connector: 3.4 × 6.0 mm).

Fig 4 Replacement FPD for the patient in Fig 3. The distal connector fractured at 24 months (distal connector: 3.0 × 6.2 mm; mesial connector: 2.6 × 5.5 mm).

Table 1 Position and Connector Widths of Each FPD and Maximum Occlusal Force of Each Patient*

FPD position (universal tooth no.)	Mesial connector (mm)	Distal connector (mm)	Maximum occlusal force (N)
11–13	4.1 × 5.0	4.0 × 6.1	284
12–14	4.5 × 5.4	4.0 × 5.7	155
27–29	4.5 × 3.8	4.2 × 4.4	781
13–15	4.7 × 7.2	4.3 × 8.2	781
18–20	4.0 × 4.9	3.9 × 6.2	781
12–14	4.5 × 7.0	4.5 × 6.8	382
12–14	3.4 × 6.4	4.3 × 6.4	266
4–6	4.3 × 5.4	4.3 × 6.5	266
19–21	2.9 × 5.2	3.4 × 6.0	**373 (759 d)**
12–14	3.4 × 7.3	3.8 × 8.3	373
19–21	3.6 × 5.5	3.0 × 6.2	**373 (764 d)**
4–6	5.4 × 4.5	4.8 × 5.3	364
11–13	5.4 × 5.9	5.3 × 6.6	N/A
11–13	5.1 × 5.4	4.8 × 6.5	222
3–4	3.8 × 7.2	4.2 × 7.7	515
11–13	4.2 × 5.4	4.8 × 6.0	N/A
4–6	6.0 × 5.1	5.1 × 5.6	N/A
4–6	5.6 × 5.8	4.9 × 6.6	564
28–30	4.0 × 5.1	3.5 × 6.3	**1,031 (528 d)**
28–30	3.9 × 4.6	5.2 × 5.6	**218 (1,190 d)**
4–6	5.7 × 6.8	4.7 × 7.7	204
27–29	4.4 × 5.2	4.9 × 6.0	204
20–22	4.4 × 5.2	5.1 × 5.9	204
3–4	4.7 × 5.5	4.9 × 7.1	719
13–15	5.2 × 5.8	5.2 × 6.7	719
28–30	3.0 × 5.7	4.5 × 6.7	N/A
28–30	5.5 × 4.2	5.4 × 4.8	435
3–4	4.3 × 5.0	4.0 × 5.7	795
18–20	4.3 × 5.7	4.3 × 6.2	364
3–4	4.9 × 5.7	4.6 × 5.9	631

*Failed FPDs in bold with number of days in service in parentheses.

ments that was not related to the FPD but nonetheless caused failure of the prosthesis. This explains the substantial decrease in good to excellent overall performance of the FPDs from 93.4% to 74.8% over 4 years. There were also ratings lower than 3 that were related to decreased marginal integrity and poor tissue health. These cracks are believed to have originated along the distal connector areas (Figs 5 and 6), and fracture of the distal connector caused a cantilever effect of the mesial connector, which led to a mesiocclusal connector failure.[13] This result is consistent with other studies that have documented the connector areas to be the weak link in prostheses.[18,19] The manufacturer recommended a minimum connector height of 4 mm, and studies[20–22]

Table 2 Clinical Performance of Surviving FPDs at 1- to 4-Year Recall Examinations

		Criteria										
Recall (y)	Ranking	1	2	3	4	5	6	7	8	9	10	11
1 (n = 29)	Excellent	23	29	28	25	19	27	21	28	29	18	28
	Good	5	0	1	4	10	2	8	1	0	11	1
2 (n = 28)	Excellent	24	28	28	24	15	24	15	27	27	26	28
	Good	4	0	0	4	13	3	13	1	1	2	0
3 (n = 24)	Excellent	16	24	24	18	15	23	11	21	23	14	23
	Good	7	0	0	6	8	1	13	3	1	10	0
	Needs repair	1	0	0	0	1	0	0	0	0	0	1
4 (n = 19)	Excellent	14	19	19	15	13	19	12	9	17	9	18
	Good	4	0	0	4	6	0	7	10	1	10	0
	Needs repair	1	0	0	0	0	0	0	0	1	0	1

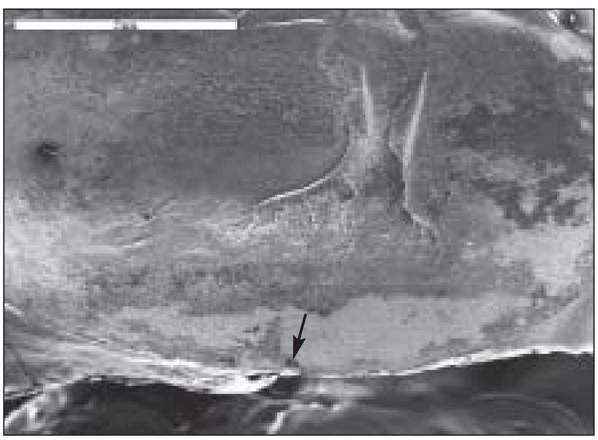

Fig 5 Critical flaw in gingival embrasure of the distal connector in Figs 1 and 2.

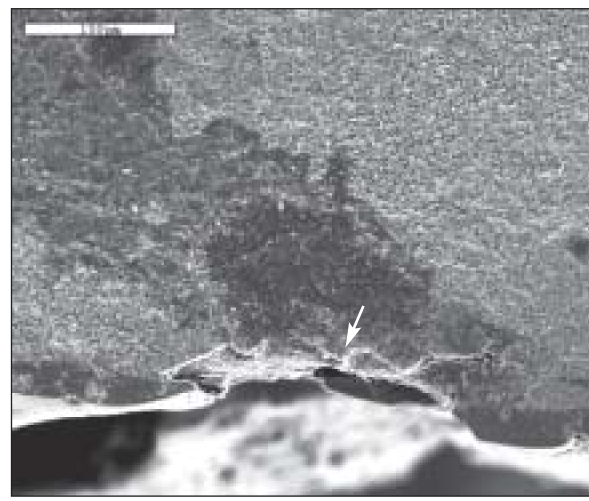

Fig 6 Enlarged view. Flaw is located in the gingival embrasure.

report a 40% to 50% stress reduction at this level compared with shorter connectors (3 mm). Finite element analysis has shown that shorter connectors and greater interdental distance in the connector areas resulted in up to a 4-fold increase in stress.[23] The connector heights of the failed FPDs ranged from 2.9 to 6.3 mm, which represents a realistic clinical application considering that connector height is also dictated by esthetics, cleansability, and embrasure contour and tends to become shorter in the posterior areas. This study clearly shows that there is a correlation between the fracture potential of the prosthesis and the connector height. Fractography studies related to crowns have documented fracture originating from the inner surface of ceramic crowns.[24–26] The survival rate of 86% in this study of all-ceramic prostheses is comparable to those seen in other studies at the 5-year observation period of 90% to 93%.[9,10] This is lower than the documented survival rate for metal-ceramic prostheses of 95% to 98% within a 5- to 7.5-year observation period.[11,12] It should be noted that experimental FPDs were used in this study. The official indication for e.Max Press is for anterior teeth and posterior teeth up through the second premolar.

There was no significant difference in the mean marginal integrity of the restorations or in the sensitivity of the teeth between resin-modifed glass-ionomer cement (Protec CEM) and resin cement (Variolink II). Clinical observation of the margins revealed some ditching along the margins sealed with glass-ionomer cement, although this did not seem to compromise the restorations. This was confirmed by previous studies that reported marginal breakdown, material loss, and eventual microleakage with increased roughness of restorations cemented with resin-modified glass-ionomer cement.[27–29] An impression should be made of the margins and analyzed using a microscope since clinical observation is not always sufficiently accurate. The linear expansion of approximately 0.36% caused by water absorption of Protec CEM hybrid ionomer appears to have a minimal effect on the fracture susceptibility of glass-ceramic crowns. This is in agreement with other research showing no significant difference in the fracture probability of ceramic crowns when cemented with resin-modified glass ionomer.[30,31] However, an in vitro study reported that the use of resin cements instead of glass-ionomer cements to lute all-ceramic crowns resulted in higher fracture resistance and better marginal adaptation.[32] There was also no difference in postoperative sensitivity between the 2 cements. This is confirmed by other clinical studies, which have shown that glass-ionomer cements even decrease the sensitivity of teeth.[29,33,34]

Conclusions

1. Proper treatment planning is needed to ensure an adequate connector height of 4 mm or more on all-ceramic prostheses made with a lithia disilicate–based core ceramic.
2. Although no significant difference was noted in the marginal integrity and postoperative sensitivity of prostheses cemented with resin and resin-modified glass-ionomer cements, submargination was observed in some cases. Therefore, it is recommended to use resin cements for all-ceramic prostheses as reported previously in the literature and validated clinically by this study.

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