A Preliminary Prospective Evaluation of All-Ceramic Crown-Retained and Inlay-Retained Fixed Partial Dentures

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Purpose: The purpose of this preliminary prospective study was to evaluate the clinical outcome of crown-retained and inlay-retained fixed partial dentures (FPDs) made from a new lithium-disilicate glass-ceramic (IPS e.max Press, Ivoclar Vivadent). ***Materials and Methods:*** Eighty-one 3-unit FPDs were placed in 68 patients. The FPDs replaced teeth in the anterior (8%) and posterior region (92%). All teeth were prepared according to a standardized protocol. The size of the proximal connector of the FPDs was 12 mm^2 (anterior) or 16 mm^2 (posterior), respectively. Crown-retained FPDs were cemented either with glass ionomer (n = 20) or resin composite (n = 16), while all inlay-retained FPDs (n = 45) were cemented with resin composite. Initial follow-up was performed at 6 and 12 months and annually thereafter. ***Results:*** The mean observation periods were 48 months (for crown-retained FPDs) and 37 months (for inlay-retained FPDs). None of the crown-retained FPDs failed during the observation period, while 6 inlay-retained FPDs (13%) had to be replaced. Six cases failed because of debonding (n = 3) or a combination of debonding and fracture (n = 3). During the observation period, 2 patients died and the status of another 5 patients is unknown. The 4-year survival rate according to Kaplan-Meier was 100% for crown-retained FPDs and 89% for inlay-retained FPDs. The differences between the groups were statistically significant. ***Conclusion:*** Crown-retained 3-unit FPDs made from a new glass-ceramic have a significantly better outcome up to 5 years than inlay-retained 3-unit FPDs over the observation period. *Int J Prosthodont 2005;18:497–505.*

The use of all-ceramic materials for fixed restorations in dentistry has become more and more important for patients and clinicians in recent decades. Since the cementation of the first feldspathic crown in 1886,[1] recent progress in material technology and manufacturing procedures has extended the indications for these materials. In 1990,[2] the IPS Empress System (Ivoclar Vivadent) was introduced to the dental community and became a popular all-ceramic system for pressed glass-ceramic inlay and onlay restorations. The estimated survival rate for this type of restoration was 95.6% after an observation time up to 4.5 years (mean 37 months).[3] But for crowns in the posterior region, the survival rate dropped to 86.7% after the same observation period.[3] The properties of this ceramic material have limited its use for crowns to the anterior region (survival rate: 99%).[3]

In recent years, however, growing interest in biocompatible and esthetically attractive restorations has stimulated further development in this field. To increase the mechanical strength of all-ceramic restorations, different core materials were used. They were made either from pure alumina ceramic (Procera, Nobel Biocare)[4] or glass-infiltrated alumina ceramic (In-Ceram Alumina, Vident). For In-Ceram Alumina, successful long-term outcome of short-span fixed partial

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Table 1 Distribution by Location of 81 Crown-Retained and Inlay-Retained FPDs

Location	Type of FPD	
	Crown retained	Inlay retained
Right maxilla		
Lateral incisor	2	–
Canine	1	–
First premolar	3	–
Second premolar	1	4
First molar	6	7
Left maxilla		
Central incisor	1	–
Lateral incisor	2	–
Second premolar	1	–
First molar	8	12
Left mandible		
Second premolar	1	1
First molar	4	10
Right mandible		
Second premolar	1	3
First molar	5	8

dentures (FPDs) was reported in a prospective[5] (observation time at least 5 years) and a retrospective[6] (observation time up to 9 years, mean 76 months) clinical study. To the best of our knowledge, no other well-designed study has shown a successful long-term outcome of short-span all-ceramic FPDs. For IPS Empress 2 (Ivoclar Vivadent), a lithium-disilicate based glass ceramic, which is also used as core material, only short-term results have been published to date. Laboratory tests reported a similar fracture strength of 3-unit FPDs compared to In-Ceram Alumina.[7,8] Clinical evaluations showed a failure rate of 3.2% after 1 year for posterior 3-unit FPDs[9] and 10% after 9 months for inlay-retained 3-unit FPDs.[10] Regardles of which type of ceramic the clinicians use, crown preparation is always a risk to pulp vitality and may lead to pulpal reactions in the long term.[11]

Approximately 63% to 73% of the coronal tooth structure is removed when teeth are prepared for all-ceramic crowns.[12] With these facts in mind, it seemed desirable to adapt the type of abutment preparation to the extent of sound tooth structure after caries removal, not only for a single-tooth restoration but also for FPD abutment preparations.

The aim of the present study was to investigate whether a new lithium-disilicate glass-ceramic is satisfactory for use in inlay-retained and crown-retained 3-unit FPDs when adopted with a standardized protocol concerning preparation technique and restoration design. The hypothesis was that the survival rate of inlay-retained and crown-retained FPDs does not differ when identical connector dimensions are used.

Materials and Methods

Study Design

Patients referred to the Department of Prosthodontics of the University at Kiel, Germany with a need for 3-unit FPDs were selected for the study. All participants were healthy and had an almost complete dentition. Informed consent was obtained from all subjects on a written form approved by the Ethical Committee of the Medical Faculty of the University at Kiel.

All restorations were constructed as 3-unit FPDs. No cantilever FPDs were provided. The edentulous space had to be equal to or smaller than the width of a molar. The bone level of the vital abutment teeth had to correspond to at least two thirds the root length, with no signs of active bone resorption or periapical pathology. Oral hygiene had to be good and caries activity low. Maximum tooth mobility of grade 1 was accepted.[13] Further, patients with probing depths greater than 4 mm, vertical bone pockets around the abutment teeth, extreme bruxism, or a conspicuous medical or psychological history were not accepted. Patients were informed about the risks of and alternatives to the proposed therapy. Depending on the extent of sound tooth structure after caries removal, a complete crown or an inlay preparation was carried out for the abutment teeth.

Patients

Sixty-eight patients were included in the study and gave their written consent. Altogether, 36 complete crown-retained and 45 inlay-retained FPDs were incorporated. Fifty-five patients received 1 restoration. Thirteen patients received 2 restorations, and 3 of these received both types of restorations. The patients were distributed to both groups as follows: Twenty-nine patients received crown-retained FPDs (17 women with a mean age of 47.9 years, range 32 to 64 years; 12 men with a mean age of 46.2 years, range 25 to 68 years). Forty-two patients received inlay-retained FPDs (21 women with a mean age of 36.1 years, range 20 to 61 years; 21 men with a mean age of 42.0 years, range 24 to 67 years). The distribution of the replaced teeth in both groups is shown in Table 1.

Clinicians

Eighteen clinicians performed the patients' treatment. Thirteen of them were involved in the treatment of crown-retained FPDs and 15 in the treatment of inlay-retained FPDs. The operators´ experience varied between 1 and 5 years. The mean vocational experience of the clinicians was 3.0 ± 1.0 years for the full crown-

retained FPDs and 2.9 ± 1.0 years for the inlay-retained FPDs. Every clinician performed between 1 and 6 restorations. All clinical work was supervised and inspected by 2 dentists with a specialization in prosthodontics (approved by the German Society for Prosthodontics and Dental Materials Science [DGZPW]). A calibration of all clinicians was performed, considering the following treatment modalities.

Prosthodontic Procedures

For crown abutments, an occlusal reduction of at least 1.5 mm was prepared, followed by a circular 1.2-mm-wide rounded shoulder preparation. The finished crown preparation resulted in an abutment height that was between 3 and 6 mm. Abutment teeth with minor defects were prepared with a mesio-occlusal, occlusodistal, or mesio-occlusodistal inlay cavity, respectively. Inlay preparation procedures were performed in accordance with general principles for ceramic inlay restorations. Box-shaped inlay cavities were prepared with fine (30 to 40 μm grain) diamond instruments. The finishing line was a shoulder; no bevels were used. All preparations were finished by rounding sharp angles.

After abutment preparation, impressions were made with a simultaneous, dual-mix technique using polyether material Permadyne (3M/Espe). In the laboratory, the impressions were cast with Type IV gypsum (GC-Fuji Rock EP), and a die spacer was applied to each master die (Vita In-Ceram Distanzlack, Vita). The FPDs were made from an experimental heat-pressed lithium disilicate glass-ceramic (Ivoclar Vivadent), following the manufacturer's instructions. This ceramic is now available under the trade name IPS e.max Press (Ivoclar Vivadent).

For the fabrication of the FPDs, the wax patterns were fabricated and invested with a special investment material (IPS-Empress 2 Speed, Ivoclar Vivadent). All FPDs were pressed in 1 piece; no additional veneering was conducted. After the pressing process, minor adjustments to seat the castings on their dies were completed under a light microscope (magnification ×20) if necessary. The use of additional ceramic was performed only in cases where small ceramic corrections were necessary (ie, pontic area, esthetic form correction of the FPD). The individualization of the color was achieved with universal intensive stains (Universal Stains Kit, Ivoclar Vivadent).

The minimum occlusal ceramic thickness for inlays and crowns was 1.5 mm. For the proximal connector, the minimum dimensions were 4 mm in height and 4 mm in width (16 mm^2) for posterior teeth and 4 mm in height and 3 mm in width (12 mm^2) for anterior teeth.

The marginal fit of the abutments was checked intraorally with a silicone indicator paste (Fit Checker, GC) and an explorer. Adjustments were made if necessary. The marginal fit of the restorations was accepted when the silicon indicator paste showed a thin and homogeneous thickness.

To avoid creating microcracks in the ceramic material, no temporary cementation was performed. Twenty of the crown-retained FPDs (abutment height of more than 3 mm at both abutments) were cemented with Ketac Cem (3M/Espe) following the manufacturer's instructions. The other 16 crown-retained FPDs (abutment height of only 3 mm at 1 or both abutments) and all inlay-retained FPDs were cemented adhesively: The surfaces of the inlay retainer were conditioned by etching with hydrofluoric acid 5% (ceramic etchant, Ivoclar Vivadent) and silane coating (Monobond S, Ivoclar Vivadent). Then the FPDs were bonded to the abutment teeth with standard adhesive luting techniques using the dentin adhesive Syntac Classic and the bonding resin Variolink II (both Ivoclar Vivadent). Rubber dam was used during adhesive cementation. After cementation of the FPD a radiograph of the restoration and its abutment teeth was obtained. Using this clinical protocol, the medians of the marginal discrepancies after cementation were 130 μm for crown-retained FPDs and 92 μm for inlay-retained FDPs.[14]

Follow-up Clinical Examinations

The patients were scheduled for a final evaluation 1 to 3 weeks after cementation. Follow-up examinations were performed after 6 months, after 12 months, and then annually.

The gingival conditions (probing depth) were recorded at 4 sites for the abutment teeth and their contralaterals. Bleeding on probing was diagnosed as present (1) or not present (0) by gentle moving of a blunt periodontal probe in the marginal part of the gingival sulcus. Tooth mobility was classified in 3 grades[13]: grade 1 = 0.2 to 1 mm mobility in the horizontal direction; grade 2 = more than 1 mm in the horizontal direction; grade 3 = same as grade 2 with additional movement in the vertical direction. Occlusal contacts were assessed with 8-μm shimstock foils (Hanel, Roeko).[15] Marginal integrity was inspected visually and with a probe. Furthermore, marginal integrity was classified in 3 categories following the inspection with the probe: 1 = the margins of the restorations are not detectable with the probe (excellent); 2 = small positive or negative steps are detectable (acceptable); 3 = marginal integrity has strong overlaps or negative steps or the probe can penetrate the margins (not acceptable). Marginal discolorations were classified into 2 categories: 1 = no visible discoloration, and 2 = discoloration/staining on the margin between the restoration and tooth structure.

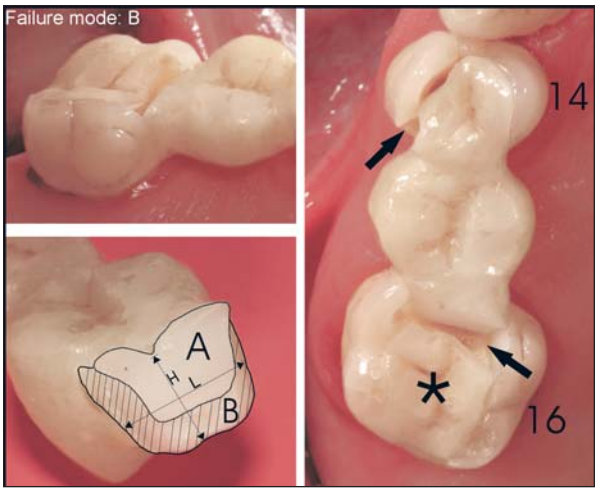

Fig 1 Example of an FPD that experienced failure mode B (patient no. 8 in Table 3). One inlay retainer (maxillary right first premolar/tooth 14) is debonded and the other inlay retainer (maxillary right molar/tooth 16) is fractured at its most fragile part, while the occlusal part (*) of the inlay is still in function. The fracture (surface A) occurred in combination with debonding of the proximal part of the inlay (surface B). Lines L and H show the area that corresponds with the connector size of 16 mm^2 between the inlay retainer and the pontic. Arrows indicate missing pieces of enamel and ceramic.

All patients who did not show up at the follow-up examination were contacted by telephone. They were asked 2 standardized questions: (*1*) Is the FPD still in situ? and (*2*) Do you have any problems with your teeth in general and especially with the FPD?

Outcome

According to Walton,[16] treatment outcomes were allocated to 1 of 6 fields:

1. *Successful.* Review of documentation and patient examination revealed no evidence of or no need for retreatment other than maintenance procedures, which include prophylaxis and minor occlusal or contour adjustments.
2. *Surviving.* The patient could not be examined directly, but the patient and examination of the patient's records confirmed via telephone interview that there had been no retreatment other than that described for a successful outcome.
3. *Unknown.* The patient could not be traced or reached by telephone.
4. *Dead.* The patient had passed away during the observation period. In these cases the FPD(s) were rated successful until death.
5. *Repaired.* The original marginal integrity of all the retainers and abutment teeth was maintained irrespective of other retreatments/modifications. Occlusal perforation of a retainer for access to perform endodontic therapy was not considered a repair.
6. *Failed.* Any retainer or its original marginal interface with its respective abutment tooth had been lost. All types of failure that occurred during the observation time could be assigned to the following 2 subcategories: (*1*) a restoration had to be replaced because of retention loss (failure mode A); (*2*) a restoration had to be replaced because of a combination of both debonding and fracture of the inlay (failure mode B; Fig 1).

Patient Satisfaction Scores

On the latest follow-up examination the patients were interviewed regarding their satisfaction with the ceramic FPDs using a visual analogue scale (VAS) of 100 mm with the endpoints "extremely satisfied" (0) and "extremely dissatisfied" (100).

Statistical Evaluation

Because the data were not normally distributed (Kolmogorov-Smirnov test), statistical analyses were performed with the Wilcoxon rank sum test to determine differences between the 2 groups (crown- versus inlay-retained FPDs). Kaplan-Meier survival curves[17] were used to demonstrate cumulative survival rates and timing for FPDs. Survival time was calculated from the cementation date to the end of the latest follow-up visit (September 2004) for the successful, surviving, and repaired categories; to the latest date of known status for the dead and unknown categories; and to the date of failure for the failed category. All hypothesis testing was conducted at a 95% level of confidence.

Results

The age of the subjects was significantly higher ($P \leq .05$) in the crown-retained group (mean age: 47.8 $\pm$ 12 years) than in the inlay-retained group (mean age: 39 $\pm$ 12 years).

Outcome of FPDs

The following results include all restorations (36 crown-retained and 45 inlay-retained FPDs). Table 2 shows the distribution of all FPDs to the different outcome categories. Table 3 gives detailed information about all failures and endodontic treatments that occurred during the observation period.

The mean observation time for crown-retained FPDs was 48 months (range 30 to 55 months) (Figs 2a and

Table 2 Outcome of FPDs (n = 81)

Outcome	Type of FPD	
	Crown retained	Inlay retained
Successful	28	32
Surviving	1	5
Unknown	3	2
Dead	3	0
Repaired	1	0
Failed	0	6
Total	36	45

Table 3 Descriptive Analysis of Failures/Endodontic Problems That Occurred in 36 Crown-Retained and 45 Inlay-Retained FPDs

Patient no. and category	Gender	Age (y)	Replaced tooth	Time to failure (mo)	Failure mode (Fig 1)	Other abutment	Clinician no.[a]	Restoration type
1: Successful	F	43	16	9	Endo of 17; still in situ at 54 mo		2 (1 y, n = 4)	CR
2: Successful	F	45	26	14	Endo of 25; still in situ at 48 mo		7 (4 y, n = 9)	CR
3: Successful	F	38	45	18	Endo of 44; still in situ at 60 mo		1 (5 y, n = 7)	IR
4: Repaired	F	34	21	34	Repair of 21; chipping on tooth 21; still in situ at 54 mo		1 (4 y, n = 7)	CR
5: Failed	M	34	46	53	Mode A at 45; luting cement mostly on FPD	No retention loss on abutment tooth 47	5 (2 y, n = 5)	IR
6: Failed	F	61	46	6	Mode A at 47; luting cement mostly on abutment tooth	No retention loss on abutment tooth 45	2 (1 y, n = 4)	IR
7: Failed	M	30	16	22	Mode A at 17; luting cement mostly on abutment tooth	No retention loss on abutment tooth 15	4 (5 y, n = 4)	IR
8: Failed	M	61	15	4	Mode B at 16; luting cement mostly on abutment tooth	Retention loss on abutment tooth 14	16 (2 y, n = 5)	IR
9: Failed	M	31	46	3	Mode B at 47; luting cement mostly on abutment tooth	No retention loss on abutment tooth 45	16 (2 y, n = 5)	IR
10: Failed	F	27	26	21	Mode B at 27; luting cement mostly on abutment tooth	Retention loss on abutment tooth 25	16 (2 y, n = 5)	IR

[a]Identification no. of the clinician, his/her vocational experience (in years), and total no. of restorations performed in the study.
CR = crown-retained FPD; IR = inlay-retained FPD.
Tooth numbers shown are FDI.

2b). In 2 cases endodontic treatment was necessary after 9 and 14 months, respectively. In 1 case a small piece of veneering ceramic in the pontic area fractured after 34 months. These 3 FPDs (10%) are still in function. None of the crown-retained FPDs failed during the observation period or had to be replaced.

The mean observation time for the inlay-retained FPDs was 37 months (range, 20 to 60 months) (Figs 2c and 2d). In 1 case an endodontic treatment was performed 18 months after cementation. The restoration (2%) is still in function. Six (13%) other inlay-retained FPDs had to be replaced because of retention loss (failure mode A) or because of a combination of both debonding and fracture of the inlay (failure mode B).

The Kaplan-Meier curve demonstrates the cumulative survival of the FPDs (Fig 3). After 4 years, the calculated survival rate was 100% for crown-retained FPDs and 89% for inlay-retained FPDs. The different failure episodes between crown-retained and inlay-retained FPDs were statistically significant ($P = .018$; log-rank test).

Follow-up Clinical Examinations

The following results include only the restorations of the category "successful" and "repaired," which were examined clinically throughout the last follow-up evaluation (29 crown-retained FPDs and 32 inlay-retained FPDs, respectively). In general, no significant differences in the following parameters were found between crown- and inlay-retained FPDs ($P > .05$):

- No caries were registered on any of the abutment teeth.

Figs 2a and 2b Examples of a crown-retained FPD (left) directly after cementation and (right) after 50 months' observation time.

Figs 2c and 2d Examples of an inlay-retained FPD (left) directly after cementation and (right) after 60 months' observation time.

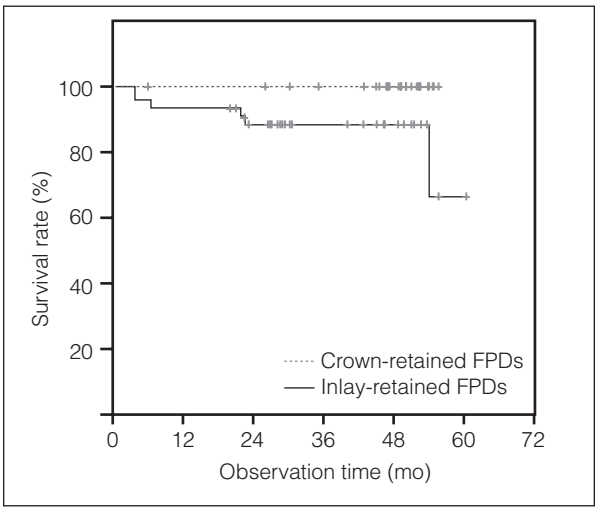

Fig 3 Kaplan-Meier curve demonstrating the cumulative survival for crown-retained FPDs (broken line) and inlay-retained FPDs (unbroken line). The difference in failure episodes between groups was statistically significant (P = .018, log rank test).

- The gingival conditions were generally sound.
- The median bleeding score on probing for all abutment sites was 1 (range, 0 to 4) compared to 0.5 (range 0 to 4) for the contralateral teeth.
- The median of all probing depths was 2.3 mm (range: 1 to 6 mm) for all abutment teeth and 2.6 mm (range: 2 to 7 mm) for the contralateral teeth.
- All abutment teeth exhibited low mobility (2 had mobility degree 1; 120 had degree 0).
- The marginal integrity was rated as excellent for 48 abutments (39%) and acceptable for 74 abutments (61%).
- One hundred seventy-one units (94%) had occlusal contacts at the 8-µm level, whereas the remaining 12 units (7%) had no occlusal contacts at this level.

Only for the parameter of marginal discoloration were significant differences shown between groups (P = .004); for the crown-retained FPDs, discoloration/staining was found in 4 cases (14%) and for inlay-retained FPDs discoloration/staining was seen in 18 cases (56%).

Patient Satisfaction

The median patient satisfaction ratings were very high: chewing comfort: crown-retained = 5, inlay-retained = 3; color: crown-retained = 3, inlay-retained = 3; willingness to try the same technique again: crown-retained = 3, inlay-retained = 2. Furthermore, the patients did not notice any kind of color changes at the FPDs. No statistically significant differences were shown between both types of restorations ($P > .05$).

Discussion

In studies similar to the present one, patients were treated by 4 or only by 1 clinician.[5,6] The small number of clinicians gave the investigations a consistency in the quality of the treatment because of the high number of incorporated restorations for each clinician.

In the present study, 18 clinicians altogether, each with a vocational experience between 1 and 5 years, treated the patients. Regarding our results for the crown-retained FPDs, the present study showed no clinician-related treatment sensitivity. This might be different for the inlay-retained FPDs. In these cases, a good command of the treatment procedures seems necessary to avoid handling errors, which for example could compromise the quality of the bonding when adhesive cementation is required.[18] An indication for that is the fact that 3 of the 6 failed FPDs had been cemented by the same clinician. This practitioner incorporated a total of 5 restorations, achieving a failure rate of 60% (Table 3). Further, it is noticeable that the vocational experience of the clinicians who caused total failures was low (as a rule, 1 to 2 years).

In the present study, patients were not randomized to 1 of the treatment options; rather, the amount of sound tooth structure determined the type of restoration that was performed. This might be the reason why there is a significant difference between the 2 groups concerning the age of patients. Because normally younger people have more sound tooth structure and less restorations than older people,[19,20] they were more often placed in the group of inlay-retained FPDs than in the group of crown-retained FPDs.

In the present study, the calculated survival rate was 100% for crown-retained FPDs and 89% for inlay-retained FPDs after 4 years. Among the very few long-term studies presented so far, 2 evaluated the survival rate of In-Ceram Alumina FPDs over an observation period of 5 years. One[5] reported 2 (8%) failures in 25 FPDs, and the other[6] reported 3 (7%) fractures of 42 FPDs. Meta-analyses of the outcome of conventional FPDs with metal frameworks have demonstrated a mean survival rate of 95% after 5 years.[21,22] Concerning the long-term results of inlay-retained FPDs, only a study that evaluated posterior resin-bonded FPDs with high noble alloy inlay retainers is available. After an observation time of 5 years, only 2 (4%) of 51 inlay-retained FPDs had lost retention.[23] A comparison between these studies and the current investigation must be done with caution, because the observation time in the current study is still shorter than those of the aforementioned studies. Nevertheless, the present results for crown-retained FPDs show that the replacement of single teeth with this new glass-ceramic involves no significant risks over the evaluated observation period. However, adequate evidence as to their long-term safety and efficacy is required before this material can be recommended as acceptable for general clinical practice. Concerning this, the inclusion criteria in 2 meta-analyses[21,22] included a minimum 5-year follow-up period. A shorter period was considered inadequate for assessing relevant clinical applications. Further, the present results for inlay-retained FPDs must be interpreted with caution.

In the literature, opinions on the clinical relevance of the size of the marginal discrepancies are controversial. Most authors agree that marginal discrepancies up to 100 µm seem to be clinically acceptable with regard to longevity of the restorations.[24–26] For other authors, marginal discrepancies up to 200 µm are still considered acceptable.[27] According to these studies, marginal discrepancies found with this new glass-ceramic (median between 92 and 130 µm)[14] are within biologically acceptable standards and largely comparable to results of some other in vivo studies of all-ceramic restorations.[28–30]

For glass-ceramic plates cemented with resin composite, a significant decrease in the fracture strength was observed only when cement thickness reached or exceeded 300 µm.[31] Therefore, the marginal discrepancies after cementation for inlay-retained FPDs (92 µm) do not seem to be an explanation for the failure rate of this restoration type in the present study.

Regarding the 6 total failures of the inlay-retained FPDs, the following can be stated. In 3 cases, the adhesive bonding of 1 abutment failed (failure mode A). In the other 3 cases, a combination of both debonding and fracture of an inlay occurred (failure mode B). In these cases the FPDs always fractured at the isthmus of 1 abutment, ie, the connection between the occlusal part and the proximal box of the inlay, which is the most fragile part of the restoration and presents its smallest diameter (Fig 1).

Further, it is obvious that in all 6 failures, debonding of 1 of the abutments was at least part of the problem, although a current dentin adhesive system and an adhesive cement were used that had been clinically tested and showed promising results.[32] Different factors may be responsible for this. First, the stress on the luting cement is very high because of different kinds of torsion

forces on the inlay retainers when the FPDs are loaded circumferentially. Second, because a connector that is 4 mm high was used, the boxes had to be prepared quite deep in the cervical direction of the abutment tooth. Therefore, often the bottom of the box was not surrounded by enamel anymore, or only very little enamel was left. In addition, the other inlay walls were mostly formed by dentin and not by enamel. Thus, most of the interface between the tooth and luting cement was between dentin and luting cement, instead of enamel and luting cement. Because the bond strength is much higher and more durable between luting cement and enamel than between luting cement and dentin,[33,34] loss of retention might have been hastened by this condition.

The differences in bond strength to dentin and enamel are apparent when analyzing samples of failure mode B. In this mode, pieces of enamel fractured out of the tooth (Fig 1) and sometimes were still bonded to the FPD. This never happened to dentin. The third reason for debonding might be handling errors in the adhesive cementation procedures, as discussed above.

For other factors like gender, age, location (maxilla versus mandible), and molar or premolar region, the data were evaluated only descriptively because of the small number of failures. However, it is evident that total failure occurred more often in patients with a higher biting force (young and male patients) and in the parts of the dentition where the highest biting forces are performed (molar region). These trends underscore the theory that the failure of the FPDs was initiated by an overload of the FPD at its weakest point: the adhesive bonding and the connection between the occlusal part and the proximal box of the inlay.

In the current study, the dimensions of the FPDs were of an adequate and standardized size. Achieving these dimensions in crown-retained FPDs, however, requires more space than a comparable metal-ceramic FPD. Therefore, more sound tooth structure had to be removed, which might represent a risk for the vitality of the abutment teeth in the long term. Endodontic problems in abutment teeth occurred in 4% of complete crown-retained FPDs and 1% of inlay-retained FPDs. This difference might be explained by the differing amounts of tooth structure that had to be removed during preparation. This finding is in accordance with an earlier study, which showed that as more tooth substance had to be removed, the risk of pulp reactions increased in the long term.[11] Another clinical experimental study over 90 days demonstrated that the severity of pulp reactions depended more on the remaining dentin thickness than on the type of preparation.[35] However, the results of both groups are within the range known from the literature. After prosthodontic treatment, around 2% to 4%[16,36] of crowned teeth lost sensitivity within 1 to 10 years of clinical observation.

Conclusion

Full crown-retained FPDs made out of this new heat-pressed glass-ceramic showed a survival rate of 100% after a mean observation time of 48 months. For inlay-retained FPDs, this new ceramic material showed a cumulative survival rate of 89% after 48 months. The weakest points of the inlay-retained FPDs were the resin bond and the fracture resistance of the ceramic at the connection between the occlusal part and the proximal box of the inlay. Up to 5 years, crown-retained 3-unit FPDs had a significantly better outcome than inlay-retained 3-unit FPDs and therefore present a promising treatment modality.

Acknowledgments

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References

1. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent 1996;75:18–32.
2. Heinenberg BJ. Presentation of a new metal-free all-ceramic system. Quintessenz Zahntech 1990;16:809–812.
3. Fradeani M, Aquilano A, Bassein L. Longitudinal study of pressed glass-ceramic inlays for four and a half years. J Prosthet Dent 1997;78:346–353.
4. Andersson M, Odén A. A new all-ceramic crown. A dense-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand 1993;51:59–64.
5. Vult von Steyern P, Jonsson O, Nilner K. Five-year evaluation of posterior all-ceramic three-unit (In-Ceram) FPDs. Int J Prosthodont 2001;14:379–384.
6. 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.
7. Ludwig K, Kubick S. Fracture strength of 3-unit all-ceramic anterior fixed partial dentures. Dtsch Zahnärztl Z 1999;54:711–714.
8. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: A laboratory study. Int J Prosthodont 2001;14:231–238.
9. Pospiech P, Kistler S, Frasch C, Rammelsberg P. Clinical evaluation of posterior crowns and bridges of Empress 2: Preliminary results after one year [abstract #2714]. J Dent Res 1999;78:445.
10. Edelhoff D, Spiekermann H, Yildirim M. Metal-free inlay-retained fixed partial dentures. Quintessence Int 2001;32:269–281.
11. Bergenholtz G, Nyman S. Endodontic complications following periodontal and prosthetic treatment of patients with advanced periodontal disease. J Periodontol 1984;55:64–68.

12. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002;22:241–249.
13. Nyman S, Lindhe J. Examination of patients with periodontal disease. In Lindhe J, T Karring, Lang NP (eds). Clinical Periodontology and Implant Dentistry. Oxford: Blackwell Munksgaard, 2003:409–425.
14. Wolfart S, Wegner SM, Al-Halabi A, Kern M. Clinical evaluation of marginal fit of a new experimental all-ceramic system before and after cementation. Int J Prosthodont 2003;16:587–592.
15. Harper KA, Setchell DJ. The use of shimstock to assess occlusal contacts: A laboratory study. Int J Prosthodont 2002;15:347–352.
16. Walton TR. An up to 15-year longitudinal study of 515 metal-ceramic FPDs: Part 1. Outcome. Int J Prosthodont 2002;15:439–445.
17. L'Abbe KA, Detsky AS, O'Rourke K. Meta-analysis in clinical research. Ann Intern Med 1987;107:224–233.
18. Peschke A, Blunck U, Roulet JF. Influence of incorrect application of a water-based adhesive system on the marginal adaptation of Class V restorations. Am J Dent 2000;13:239–244.
19. Kerschbaum T, Micheelis W, Fischbach H, von Thun P. The prosthodontic treatment status in Germany. A representative epidemiological survey with subjects aged from 35 to 54 years. Dtsch Zahnärztl Z 1994;49:990–994.
20. Micheelis W, Reich E. Dritte Mundgesundheitsstudie (DMS III). Ergebnissse, Trends und Problemanalysen auf der Grundlage bevölkerungsrepräsentativer Stichproben in Deutschland 1997. Köln: Deutscher Ärzte-Verlag, 1999:1–530.
21. Creugers NHJ, Käyser AF, Van't Hof MA. A meta-analysis of durability data on conventional fixed bridges. Community Dent Oral Epidemiol 1994;22:448–452.
22. Scurria MS, Bader JD, Shugars DA. Meta-analysis of fixed partial denture survival: Prostheses and abutments. J Prosthet Dent 1998;79:459–464.
23. Stokholm R, Isidor F. Resin-bonded inlay retainer prostheses for posterior teeth. A 5-year clinical study. Int J Prosthodont 1996;9:161–166.
24. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107–111.
25. Fransson B, Øilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. Dent Mater 1985;1:197–199.
26. Boening KW, Walter MH, Reppel PD. Non-cast titanium restorations in fixed prosthodontics. J Oral Rehabil 1992;19:281–287.
27. Björn A-L, Björn H, Grkovic B. Marginal fit of restorations and its relation to periodontal bone level. Part II. Crowns. Odontol Revy 1970;21:337–346.
28. Krejci I, Krejci D, Lutz F. Clinical evaluation of a new pressed glass ceramic inlay material over 1.5 years. Quintessence Int 1992;23:181–186.
29. Molin M, Karlsson S. The fit of gold inlays and three ceramic inlay systems. A clinical and in vitro study. Acta Odontol Scand 1993;51:201–206.
30. Karlsson S. The fit of Procera titanium crowns. An in vitro and clinical study. Acta Odontol Scand 1993;51:129–134.
31. Scherrer SS, de Rijk WG, Belser UC, Meyer JM. Effect of cement film thickness on the fracture resistance of a machinable glass-ceramic. Dent Mater 1994;10:172–177.
32. Fehér A, Egger B, Lüthy H, Schumacher M, Loeffel O, Schärer P. Evaluation of different cements and a clinical investigation of ZrO2 post core. Acta Med Dent Helv 1999;4:201–209.
33. Kanca J. Improving bond strength through acid etching of dentin and bonding to wet dentin surfaces. J Am Dent Assoc 1992;123:35–43.
34. Yoshida K, Funaki K, Tanagawa M, Matsumura H, Tanaka T, Atsuta M. Mechanical properties and bond strength of commercially available adhesive resin cements to tooth substrates and precious dental alloys. J Jpn Dent Mater 1994;13:529–536.
35. Zöllner A, Gaengler P. Pulp reactions to different preparation techniques on teeth exhibiting periodontal disease. J Oral Rehabil 2000;27:93–102.
36. Jokstad A, Mjor IA. Ten years' clinical evaluation of three luting cements. J Dent 1996;24:309–315.

Literature Abstract

Long-term survival of endodontically treated molars without crown coverage: A retrospective cohort study

The purpose of this retrospective, observational study was to determine the survival rate of endodontically treated molars that had not been restored with crowns. A total of 203 subjects (with a total of 220 endodontically treated permanent molars) were identified and recalled for a clinical examination. The dependent variable was defined as a failure if negative findings in the condition of the tooth required a restoration, tooth repair, or extraction. Independent variables included patients' age, gender, location of endodontically treated molars, existence of opposing dentition and adjacent teeth, remaining tooth structure, and types of restorative material. A Kaplan-Meier survival analysis was used to calculate the survival probability, and a log-rank test was used to determine whether significant differences existed for each independent variable and survival outcome. The overall survival rate of molars without crowns at 1, 2, and 5 years were 96%, 88%, and 36% respectively. The survival of the tooth increased with greater amounts of remaining coronal tooth structure. Molars with only occlusal access cavity had a survival rate of 78% at 5 years. Restorations with direct composite (90%) had a better survival rate than amalgam (77%) or reinforced zinc oxide and eugenol with polymethacrylate (60%).

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