Five-Year Clinical Results of Zirconia Frameworks for Posterior Fixed Partial Dentures

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Purpose: The aim of this prospective clinical cohort study was to determine the success rate of 3- to 5-unit zirconia frameworks for posterior fixed partial dentures (FPDs) after 5 years of clinical observation. ***Materials and Methods:*** Forty-five patients who needed at least 1 FPD to replace 1 to 3 posterior teeth were included in the study. Fifty-seven 3- to 5-unit FPDs with zirconia frameworks were cemented with 1 of 2 resin cements (Variolink or Panavia TC). The following parameters were evaluated at baseline, after 6 months, and 1 to 5 years after cementation at test (abutments) and control (contralateral) teeth: probing pocket depth, probing attachment level, Plaque Index, bleeding on probing, and tooth vitality. Intraoral radiographs of the FPDs were taken. Statistical analysis was performed using descriptive statistics, Kaplan-Meier survival analysis, and the McNemar test. ***Results:*** Twenty-seven patients with 33 zirconia FPDs were examined after a mean observation period of 53.4 ± 13 months. Eleven patients with 17 FPDs were lost to follow-up. After the 3-year recall visit, 7 FPDs in 7 patients were replaced because they were not clinically acceptable due to biologic or technical complications. After 5 years of clinical observation, 12 FPDs in 12 patients had to be replaced. One 5-unit FPD fractured as a result of trauma after 38 months. The success rate of the zirconia frameworks was 97.8%; however, the survival rate was 73.9% due to other complications. Secondary caries was found in 21.7% of the FPDs, and chipping of the veneering ceramic in 15.2%. There were no significant differences between the periodontal parameters of the test and control teeth. ***Conclusions:*** Zirconia offers sufficient stability as a framework material for 3- and 4-unit posterior FPDs. The fit of the frameworks and veneering ceramics, however, should be improved. *Int J Prosthodont 2007;20:383–388.*

In recent years, there has been increasing interest in the replacement of missing teeth using fixed partial dentures (FPDs) with ceramic frameworks.[1,2] However, when posterior teeth were replaced with all-ceramic FPDs, high failure rates were reported.[1,2] So far, only 2 studies are available presenting 5-year results of all-ceramic FPDs.[3,4] Both studies analyzed In-Ceram Alumina FPDs, with one reporting a 10% failure rate[3] and the other a 12% failure rate.[4]

In contrast, 2 meta-analyses observed much lower failure rates for metal-ceramic FPDs.[5,6] After 10 years, the failure rates were 8%[6] and 10%.[5] Based on these data, metallic frameworks veneered with tooth-colored ceramics still represent the standard for posterior FPDs.

Regarding all-ceramic FPDs, the most frequent reason for failure is fracture of the ceramic framework.[4] Analysis of the location of the fractures revealed that the connector area represented the *locus minoris resistentiae.* Studies using finite-element analysis demonstrated that during occlusal loading the highest stress within FPDs was located at the gingival side of the connector area.[7–9] This stress occurred in the form of tension. Since ceramics are brittle, their resistance

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to tension is low.[8–10] During clinical function, bending forces lead to tension at the gingival side of the connector area, thus promoting cracks and subsequent fracture. In an effort to overcome these shortcomings and the associated high failure rates, ceramics with superior bending strength and fracture toughness have been developed.

The bending strength of the glass-ceramic Empress 1 (Ivoclar Vivadent) is 182 MPa, and the fracture toughness is 1.77 MPa $m^{1/2}$.[11] In contrast, the bending strength (547 MPa) and fracture toughness (3.55 MPa $m^{1/2}$) of alumina are much higher.[11] Zirconia exhibits the highest bending strength (900 MPa) and fracture toughness (9 MPa $m^{1/2}$) of all presently available ceramic materials.[12]

When using traditional ceramics for FPD frameworks, the cross section of the connector must be enlarged to increase the stability of the framework. However, this enlargement, which is not necessary for connectors of metal-ceramic FPDs, may cause periodontal and esthetic problems.

As the result of recently developed computer-aided design/computer-assisted manufacturing (CAD/CAM) technologies, the production of frameworks made of high-strength ceramic zirconia has become possible. Furthermore, the most recent technological progress has made it possible to process zirconia in its presintered, “soft” condition, thus permitting new clinical and technical options.

The successful application of zirconia in orthopedics (hip replacement)[13] and dentistry (root posts, implant abutments),[14,15] along with refined processing techniques, encourage its use as a material for FPD frameworks. Unfortunately, no clinical long-term data on reconstructions with zirconia frameworks are presently available. The aim of this prospective clinical trial was to assess the long-term survival and success of zirconia frameworks for posterior FPDs.

Materials and Methods

Patients and Reconstructions

Forty-five patients (18 women, 27 men) in need of at least one FPD in the posterior region of the maxilla or mandible were included in this study. The requirements of the Helsinki Declaration were fulfilled and the patients provided informed consent.

In accordance with the requirements for conventional metal-ceramic reconstructions, the prospective abutment teeth had to fulfill several clinical criteria: periodontally healthy, vital or lege artis endodontically treated, proper positioning in the dental arch, favorable maxillomandibular relationship, and sufficient amount of dentin.

Fifty-seven 3- to 5-unit posterior FPDs replacing premolars and molars were inserted. Forty-seven FPDs were 3-unit, 8 were 4-unit, and 2 were 5-unit.

Prosthodontic Procedures

Most of the clinical treatments were performed by experienced clinicians. Five FPDs were carried out by undergraduate students under strict guidance by graduated dental clinicians. The clinical and technical procedures were published in detail elsewhere and will therefore only be summarized here.[16]

The preprosthetic and prosthetic treatments were similar to the techniques normally applied for metal-ceramic reconstructions. The only difference was the adaptation of the preparation to the guidelines required for computerized framework production. The abutment teeth were prepared as follows:

- Margin: circumferentially rounded shoulder/chamfer (1.2 mm)
- Minimal chamfer radius: 0.65 mm
- Tapering angle: 6 to 8 degrees for both molars and premolars
- Occlusal reduction: 1.5 to 2.0 mm

All frameworks were produced by the direct ceramic machining (DCM) technique,[8,9] the prototype of a presently available system (Cercon, DeguDent).

First, the frameworks were manually fabricated on master casts out of light-curing resin composite (Targis, Ivoclar). The shape of the resin frameworks was mechanically captured and digitized, and the data were enlarged by 25%. Next, the frameworks were milled out of presintered zirconia blanks. The enlarged frameworks were sintered to full density at a temperature of 1,500°C, thus shrinking them to the dimensions of the original resin frameworks. For veneering, a newly developed prototype veneering ceramic (thermal expansion coefficient adjusted to zirconia) was applied. After sandblasting with aluminum oxide (grain size: 110 µm, pressure: 2.5 bar) and degreasing (alcohol) of the internal parts, the reconstructions were adhesively cemented with 1 of 2 resin cements (Variolink, Ivoclar; Panavia TC, Kuraray). In situations where the occlusion required adjustment, the reshaped surfaces were meticulously polished.

Baseline Examination

Probing pocket depth (PPD) of the restored teeth was assessed at 4 sites per tooth immediately following cementation of the reconstructions. Radiographs of the abutment teeth and clinical photographs of the reconstructions were taken. Pulp vitality of the abutment teeth was tested using carbon dioxide.

Table 1 Failed FPDs with No. of Units, Clinical Service Time, Sealing Cement, and Reason for Failure

FPD no.	Units	Service time (mo)	Cement	Reason for failure
1	3	21.2	Panavia	Fracture of abutment tooth
2	4	23.3	Panavia	Secondary caries
3	5	33.0	Panavia	Secondary caries
4	4	33.3	Variolink	Loss of retention
5	5	38.0	Panavia	Fracture of reconstruction
6	4	38.3	Panavia	Chipping of veneering
7	3	42.0	Variolink	Endodontic problems
8	3	44.1	Panavia	Cementation error, secondary caries
9	3	53.7	Panavia	Fracture of abutment tooth
10	4	54.9	Panavia	Secondary caries
11	3	60.4	Variolink	Secondary caries
12	3	70.2	Panavia	Secondary caries

Follow-up Examination

Five years following incorporation, the reconstructions were examined for technical and biologic failures and complications. The following technical parameters were assessed: framework fracture, fracture of the veneering material, and marginal discrepancies. The following periodontal parameters were assessed at abutment (test) and control teeth (analogous, contralateral, noncrowned teeth): PPD, probing attachment level (PAL), Plaque Index (PI), bleeding on probing (BOP), and tooth mobility. Furthermore, pulp vitality was tested at abutment and control teeth using carbon dioxide. Occlusal and functional relationships between FPDs and opposing arches were noted. Radiographs and clinical photographs were taken. Alginate impressions of the maxilla and mandible were taken to fabricate study casts.

Finally, patients were asked whether they were satisfied with the esthetic outcome and occlusal function of their reconstructions via yes or no questions.

Statistical Analysis

Descriptive statistics were applied to the data. Several events, as well as the times of those events, were considered: loss of the reconstruction, chipping of the veneering ceramic, and caries. In addition, caries was separately analyzed as a reason for loss of FPDs. Patients lost to follow-up were excluded. Differences in survival of the Variolink- and Panavia-cemented FPDs were tested for statistical significance using the log rank test. The comparisons of PPD, PI, and BOP between test and control teeth were carried out using the McNemar test. Correlation analysis was performed for caries and marginal deficiency and for PI and BOP.[17]

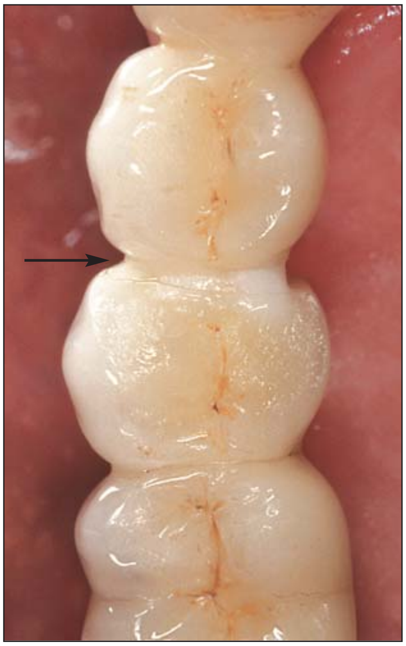
Results

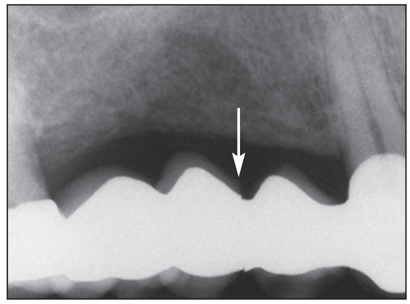
Twenty-seven patients (11 women, 16 men) with 33 FPDs were examined after a mean observation period of 53.4 (± 13) months. The mean age of the patients was 48.3 ± 10 years. Twenty-seven reconstructions were 3-unit and 6 were 4-unit. In all but one 3-unit cantilever FPD, the pontics were located between the abutments. Twenty FPDs were located in the mandible and 13 in the maxilla.

Of the 45 originally treated patients, 11 patients with 17 three-unit FPDs dropped out of the study before the 5-year recall because they either moved away or were no longer interested in participating in the study. Seven FPDs in 7 patients were replaced after the 3-year recall because they were not clinically acceptable due to biologic or technical complications. Therefore, 33 FPDs remained for further analysis at the 5-year recall.

After 5 years of observation, 12 FPDs (26.1%) in 12 patients had to be replaced (Table 1). One framework fracture was observed after a clinical service time of 38 months; this 5-unit framework broke through the connector area when the patient accidentally bit on a stone in a piece of bread (Figs 1a to 1c). Therefore, the success rate for the zirconia frameworks in the 5-year follow-up was 97.8%; the remaining 11 failed FPDs were lost because of biologic or technical complications (Table 1).

Eleven additional FPDs were lost because of biologic or technical complications. In one case, loss of retention occurred in one 4-unit FPD cemented with Variolink after a clinical service time of 33.3 months. In another patient, a 3-unit FPD had not been properly cemented initially, and the marginal areas remained unsealed. The FPD had to be replaced after 44.1 months as a result of secondary caries in this region.





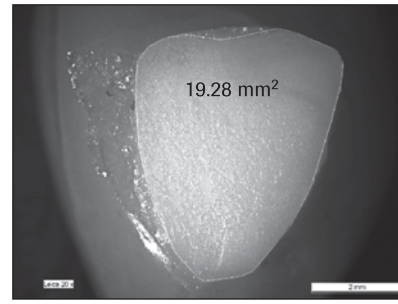


Fig 1a *(left)* Fracture of the framework of a 5-unit maxillary FPD after 38 months of clinical service. The framework fractured between the pontics at the first and second premolar sites.
Fig 1b *(center)* Radiograph of the fractured reconstruction.
Fig 1c *(right)* Since the connectors were adequately dimensioned, trauma was judged to be the primary reason for failure.

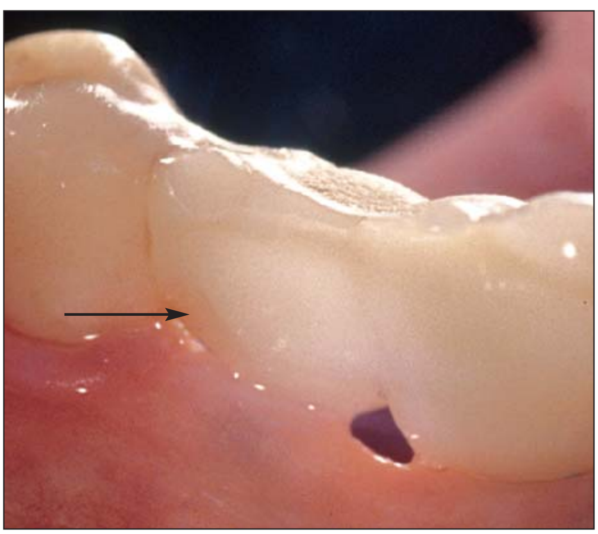


Fig 2 Fracture of veneering ceramic up to the zirconia framework on the lingual aspect of the pontic region in a mandibular 4-unit FPD.

Marginal discrepancy and resulting secondary caries were the reasons for the loss of one 5-unit, two 4-unit, and two 3-unit FPDs. One abutment tooth was extracted as a result of endodontic problems, and in 2 other patients abutments supporting 3-unit FPDs were removed because of root fractures. Both teeth had been endodontically treated with post-and-core buildups before the reconstruction was fabricated. In one 4-unit FPD, an extensive fracture of the veneering ceramic exposing the framework was the reason for replacement (Fig 2). Thus, after 5 years, the survival rate of the FPDs was 73.9%.

In 15.2% of cases ($n = 7$), chipping of the veneering ceramic occurred after a mean service time of 35.1 ($\pm$ 13.8) months. In 58.7% of the FPDs ($n = 27$), marginal gaps were evident. In 21.7% of the reconstructions ($n = 10$), secondary caries was observed in the marginal areas. A statistically significant association between the occurrence of marginal gaps and secondary caries was found ($P = .0046$, Fisher exact test), but because of the small sample size no statistical correlation between any of the complications and the type or span of reconstruction was observed. Regarding the periodontal parameters, no significant differences were found when PPD, PI, and BOP were compared between the test and control teeth.

Fourteen FPDs were luted with Variolink and 20 with Panavia TC. No differences were found in the overall survival or the occurrence of marginal discrepancies and caries when comparing the FPDs cemented with Variolink to those cemented with Panavia.

All patients were satisfied with the esthetics of the all-ceramic restorations, and 91.7% were satisfied with the functional aspects. Of the 3 patients not satisfied with the functional aspects, 1 complained about sensitivity to temperature. In this patient, the FPD had not been properly placed at the time of cementation, resulting in a marginal gap without a proper seal. The other 2 patients complained about supraocclusion of the reconstruction or sensitivity to pressure.

Discussion

The success rate of posterior FPDs with zirconia frameworks was 97.8% after 5 years. Only one 5-unit reconstruction fractured at 38 months because of trauma.

None of the 3- or 4-unit frameworks broke during the observation period. When zirconia was first introduced as a material for FPD frameworks, its excellent physical properties led to the assumption that it could be successfully used for the fabrication of all-ceramic reconstructions replacing molars and premolars. The present study provides encouraging data for the use of zirconia in these indications. The minimal incidence of framework fracture in this study is in clear contrast to the results of studies using ceramics other than zirconia.[1,2]

The connector area of 5-unit zirconia frameworks should be at least 11 mm^2 to withstand clinical loading.[8,9] Precise analysis of the failed FPD after removal revealed that the connector dimensions (18.49 to 19.28 mm^2) were adequate for the material and span of the restoration (Fig 2). Trauma was assumed to be the primary cause for failure. Another possible reason could be fatigue of the ceramic.

No framework fractures were reported in various studies on FPDs with zirconia frameworks.[18–21] Hence, this new ceramic material exhibits better clinical stability when used as a framework material compared to traditional ceramics. Only 2 ceramics were previously utilized for FPD frameworks: Empress 2 (Ivoclar Vivadent) and In-Ceram (VITA). In a prospective study of 3-unit anterior and posterior Empress 2 FPDs, the survival rate was 72.4% at 38 months of clinical service.[22] Complete fracture of the core occurred in 50% of the failed cases. Surprisingly, fractures only occurred in the anterior FPDs. Unfortunately, no long-term results exceeding 3 years of follow-up have been published on Empress 2 FPDs so far. Compared with Empress 2, In-Ceram FPDs showed better clinical results. This is probably a result of the superior material stability of In-Ceram. In a prospective study of 3-unit posterior In-Ceram FPDs, the survival rate was 90% after 5 years.[3] Fracture of the reconstruction was the only reason for failure, occurring in 10% of the reconstructions. In a retrospective analysis of anterior and posterior In-Ceram FPDs, 12% of the FPDs failed because of fracture at a mean observation period of 76 months.[4]

As a result of various biologic and technical problems, the overall survival rate of zirconia FPDs in this study was 73.9%. Marginal gaps leading to secondary caries were found in more than 20% of the cases. No gaps or caries were reported for Empress 2 and In-Ceram FPDs[3,4,22] or for zirconia FPDs[18–21] in previous studies. This difference in marginal accuracy is probably because a prototype DCM technique was used in the present study, whereas fully developed systems were used in the other studies. Furthermore, adapted preparation designs for the abutment teeth and new manufacturing methods were developed for this first investigation on the clinical application of zirconia as a framework material for FPDs. Refinements of this prototype DCM technique were carried out to improve the marginal accuracy to levels similar to those published for other CAD/CAM systems,[23] and have led to a system fulfilling these clinical requirements (Cercon).[19]

The most frequent technical problem in all studies of zirconia reconstructions is chipping or fracture of the veneering ceramic. In the present investigation, chipping was found in 15.2% of the cases. One reconstruction was replaced following extensive loss of the veneering. In another investigation, using a different prototype ceramic, chipping was found in 4.3% of FPDs as early as 18 months after insertion.[19] In a third study, chipping of the veneering occurred in 15% of the cases after 2 years.[21] Finally, a fourth study reported chipping in 6% of cases after 38 months of observation.[20]

Conventional feldspathic veneering ceramics for metal-ceramic reconstructions exhibit lower fracture rates than zirconia all-ceramic FPDs. Thus, in a clinical study of metal-ceramic FPDs, fracture of the porcelain veneering was reported in only 2.5% of the reconstructions after 5 years of clinical observation.[24] Furthermore, no chipping or fracture of the veneering was observed in In-Ceram FPDs after 5 years.[3,4] The high incidence of chipping of veneering for zirconia may be because new ceramics had to be developed for this purpose. Specifically, new low-fusing ceramics with a thermal expansion coefficient compatible with zirconia ($> 11 \times 10^{-6}\ K^{-1}$) were developed and are still under development. Similar problems have previously been reported for veneering ceramics developed for titanium frameworks. In a study comparing titanium and porcelain-fused-to-metal FPDs, significantly more defects of the veneering were found with the titanium reconstructions.[25]

It can be assumed that veneering ceramics for zirconia possess insufficient mechanical properties and that there is a strong need for refined veneering ceramics. On one hand, the ceramics themselves should be further developed and strengthened; on the other hand, the framework design should be adapted specifically to better support the veneering ceramics. One disadvantage of CAD/CAM framework fabrication techniques is that the uniform thickness of the virtually designed frameworks may not provide proper support for the veneering ceramic. The ideal proportions of the frameworks for sufficient support of the veneering material are either difficult or impossible to achieve.

In the present study, the frameworks were manually fabricated in a way that is comparable to traditional fabrication of metal frameworks. The frameworks were modeled according to the individual anatomic needs of each patient, following the requirements for metal-ceramic techniques. Still, a high rate of chipping was observed, indicating that new laboratory guidelines should be developed for the application of zirconia as a framework material. However, because of the multifactorial and complex nature of delamination, more in vivo and in vitro studies are required to better understand the findings and support new guidelines.

The periodontal parameters of the test and control teeth were not significantly different. This is in agreement with results reported in previous studies of FPDs with zirconia frameworks,[18–21] indicating adequate biologic integration of this new type of all-ceramic reconstruction.

Finally, patient satisfaction with both the function and esthetics of the zirconia reconstructions in this study was high and similar to earlier data.[20]

Conclusions

Based on the data of this 5-year study, the following conclusions can be drawn:

- Zirconia exhibits sufficient stability as a framework material for 3- and 4-unit posterior FPDs.
- Marginal discrepancies with this prototype system were regularly recorded. Further improvements of the marginal accuracy are necessary.
- Future research should be aimed at improving the clinical durability of the zirconia veneering.
- Zirconia can be utilized for the fabrication of all-ceramic FPDs for the replacement of molars and premolars.

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Erratum

In the *IJP* Issue 3, 2007 article "In Vitro Candida Colonization on Acrylic Resins and Denture Liners: Influence of Surface Free Energy, Roughness, Saliva, and Adhering Bacteria," the first author's name was incomplete. The correct name is Tatiana Pereira-Cenci.