Prospective Clinical Study of Zirconia-Based Posterior Four-Unit Fixed Dental Prostheses: Four-Year Follow-up

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Purpose: The aim of this prospective study was to evaluate the clinical performance of zirconia-based posterior four-unit fixed dental prostheses (FDPs) after 4 years of clinical observation. ***Materials and Methods:*** Between 2006 and 2010, 10 patients (5 women, 5 men; mean age: 52.8 years) received 17 posterior four-unit FDPs. Two calibrated examiners evaluated the FDPs independently 1 week (baseline), 6 months, and 1, 2, 3, and 4 years after placement using California Dental Association (CDA) criteria. Periodontal status was assessed on both the abutment and contralateral control teeth using Plaque Index, Gingival Index, probing attachment level, and Margin Index parameters. Statistical analysis was performed using descriptive statistics and the Wilcoxon signed-rank test. ***Results:*** Three restorations were lost because of fractures at their distal connectors after a mean clinical service of 25.3 months, and one abutment tooth was extracted because of vertical root fracture 23 months after cementation. Three FDPs presented chipping of a moderate size 1 week before framework fracture, and minor chipping was observed in 2 other FDPs 1 week and 36 months after cementation. After 4 years of clinical service, the cumulative survival rate of the posterior four-unit FDPs was 76.5%. No caries lesions were detected on the abutment teeth. The remaining restorations were judged to be satisfactory according to the CDA criteria. Periodontal parameters did not show significant differences between test and control teeth, but Gingival Index scores demonstrated a slight increase in inflammation in the distal abutments after 4 years ($P = .016$). ***Conclusions:*** The use of zirconia-based posterior four-unit FDPs should be restricted for patients with high esthetic demands, except in patients where at least 4 mm of height is available for connector thickness. *Int J Prosthodont 2012;25:403–409.*

Recently, interest in the replacement of missing teeth using fixed dental prostheses (FDPs) with ceramic frameworks has increased with the introduction of a great variety of all-ceramic systems in the dental market. Yet, metal-ceramic FDPs are still considered standard treatment modalities in dental practice. However, when missing posterior teeth are replaced with traditional metal-ceramic long-span FDPs, high failure rates have been reported.

In one meta-analysis, the evaluation of 4,118 metal-ceramic FDPs showed a survival rate of 74% after 15 years.[1] In another meta-analysis, while less than 15% of metal-ceramic FDPs were removed or replaced at 10 years, one-third of the FDPs were removed or replaced at 15 years.[2] Walton examined the survival rate of 515 metal-ceramic FDPs placed by one operator in a specialized prosthodontic practice and reported that tooth-supported FDPs have an estimated survival rate of 96%, 87%, and 85% at 5, 10, and 15 years, respectively.[3]

Since more data are available for metal-ceramic FDPs, the survival rates of all-ceramic systems should be compared to those of metal-ceramic ones. Unfortunately, long-term clinical data with all-ceramic systems are limited. Survival rates for In-Ceram Alumina FDPs (VITA) were reported to range between 83% and 90% after 3 to 5 years,[4–6] and those for IPS

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Empress 2 FDPs (Ivoclar Vivadent) ranged between 70% and 93% after only 2 to 5 years in service.[7–9] For this reason, dentists and the dental industry continuously work together to increase the physical and mechanical properties of dental ceramics to make them suitable materials for the restoration of long-span posterior FDPs with great durability. In that respect, the introduction of zirconia-based ceramics has generated considerable interest in the dental community. The mechanical properties of zirconia are the highest ever reported for any dental ceramic. This material was expected to allow substantial reduction in framework thicknesses of posterior FDPs.[10–12]

Clinical findings so far indicate two major drawbacks of zirconia restorations compared to metal-ceramic ones. The first is the high incidence of veneering ceramic fracture, manifesting clinically as chipping failures. Some clinical studies presented data up to 5 years reporting a high prevalence of chipping of the veneering ceramics for zirconia-supported FDPs.[13–15] A recent systematic review evaluated metal-ceramic FDPs versus zirconia ones and concluded that the frequency of veneer chipping was significantly higher in zirconia FDPs.[15] The second drawback of zirconia restorations is the inherent accelerated aging problem that has been indentified to occur in zirconia in the presence of water. This aging phenomenon is known as low-temperature degradation and decreases the physical properties of zirconia by spontaneous phase transformation of the zirconia crystals from the tetragonal phase to the weaker monoclinic phase. This phenomenon eventually places zirconia frameworks at risk of possible spontaneous catastrophic failure. However, fracture of the frameworks has been reported rarely to date. The fractures reported occurred mostly in the connectors of multiple-unit FDPs (≥ four units) or on second molar abutments.[15]

One other review reported biologic complications such as secondary caries, loss of vitality, abutment tooth fracture, and periodontal disease affecting the survival rate of zirconia FDPs.[16] The survival rates of zirconia FDPs in anterior and posterior regions range from 74% to 100% after 2 to 5 years of clinical service.[17] Therefore, more clinical studies are needed to determine whether zirconia FDPs could be indicated for long-span posterior FDPs.

The aim of this prospective study was to evaluate the clinical performance of zirconia-based posterior four-unit FDPs after 4 years of clinical observation. The null hypothesis tested was that there would be no mechanical or biologic complications during the clinical observation period.

Materials and Methods

Between 2006 and 2010, 10 patients (5 women, 5 men; mean age: 52.8 years) in need of posterior maxillary or mandibular four-unit FDPs were consecutively enrolled in this study to comprise a convenience study sample. Before treatment, patients were informed about the objective of the study, clinical procedures, materials used, advantages and possible risks of the ceramic material, and other therapeutic alternatives.

Exclusion criteria were as follows: unacceptable oral hygiene, active caries, periodontal disease, and severe bruxism. Patients who had removable or removable and fixed prostheses in the opposing arch were also excluded. Prior to the study, ethical approval was obtained, and each patient signed a declaration of informed consent.

Clinical and Laboratory Procedures

Before tooth preparation, impressions were taken to fabricate indirect provisional FDPs during the manufacturing period of the prosthesis. Two experienced clinicians performed the clinical treatment. The abutment teeth had a chamfer preparation of 0.8 to 1.0 mm, a buccal/lingual/approximate reduction of 1.0 to 1.5 mm, and an occlusal reduction between 1.5 and 2.0 mm. A 10- to 15-degree angle of convergence was achieved for axial preparations.

Impressions were made with the two-stage putty-wash technique using polyvinyl siloxane impression materials (Express Penta Putty and Express Body Light, 3M ESPE). Impressions of opposing arches were made with an irreversible hydrocolloid impression material (CA37, Cavex Holland). Master casts were then obtained using type IV plaster (Fujirock, GC) and were sent to the laboratory mounted in a semiadjustable articulator (Articulator ARH, Dentatus).

Zirconia frameworks of the FDPs were made using the Lava system (3M ESPE). All FDPs were fabricated according to the manufacturer's recommendations, with a connector cross-sectional area of a minimum of 9 mm^2 (abutment-pontic) or 12 mm^2 (pontic-pontic) and a framework thickness of 0.5 mm (Fig 1). The zirconia frameworks were then veneered with the corresponding veneering ceramic (Lava Ceram, 3M ESPE).

Provisional FDPs were cemented using eugenol-free cement (Temp RelyX NE, 3M ESPE). For the final cementation, self-adhesive resin cement (RelyX Unicem, 3M ESPE) was used according to the manufacturer's instructions.

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Fig 1 Representative zirconia framework with abutment teeth at the maxillary right first premolar and second molar positions fabricated according to the manufacturer's recommendations with a connector cross-sectional area of a minimum of 9 mm^2 between the abutment and pontic and 12 mm^2 between the pontic and pontic.

Evaluation Procedure

Two calibrated examiners evaluated the FDPs independently 1 week (baseline, t_0), 6 months (t_1), and 1 (t_2), 2 (t_3), 3 (t_4), and 4 years (t_5) after completion of treatment. Calibration was initially performed on phantom casts involving zirconia FDPs. The presence of caries in the abutment teeth was examined by means of a mirror and an explorer. Radiographs were taken using a photostimulable phosphor image plate system (Digora Optime, Soredex) and a dental radiography machine (Oralix AC Densomat, Gendex). The periodontal situation was examined using the Plaque Index, Gingival Index, probing attachment level, and Margin Index.[18–20] These parameters were evaluated in the abutment and control teeth (the contralateral teeth not restored with crowns). Both examiners evaluated the quality of the surface, color, anatomical form, and marginal integrity of FDPs according to the criteria described by the California Dental Association (CDA).[21]

Statistical Analysis

Statistical analysis was performed using a statistical software package (SAS 9.1, SAS Institute). The Wilcoxon signed-rank test was used for matched pairs to calculate significant differences between t_0 and t_5 considering the periodontal parameters and CDA ratings. The level of significance was set at 5%.

Results

A total of 10 patients received 17 posterior zirconia-based four-unit FDPs. Of the 17 FDPs, 10 were placed in the maxilla and 7 in the mandible. In the maxilla, 6 FDPs were between the first or second premolar and first or second molar (5 on the right side, 1 on the left) and 4 were between the canine and first molar (all on the left side). In the mandible, all 7 FDPs were between the first or second premolar and second and third molar (4 on the right, 3 on the left). No FDP involved canines as abutments in the mandible. Distribution of the abutments, pontics, and location of the FDPs is presented in Tables 1 and 2.

Four (12%) abutment teeth were treated endodontically, and the others were vital. In all patients, cemented FDPs had an antagonist of either all-ceramic or metal-ceramic FDPs or natural teeth. After 4 years of clinical observation, no caries were found in the abutment teeth.

During up to 4 years of follow-up, four FDPs in four different patients had to be replaced. Table 3 shows the clinical service time and reasons for failures. Of the four replaced FDPs, three failed as a result of framework fracture and one because of vertical fracture of an endodontically treated posterior abutment (Fig 2). To determine the failure origins, scanning electronic microscopy (SEM) images were taken of the fractured FDPs after removal. All three framework fractures occurred at the distal connector area starting from the gingival surfaces (Figs 3a and 3b). Connector heights of the retrieved FDPs were measured to be 3.5, 3.5, and 3.6 mm.

Three FDPs presented chipping of a moderate size 1 week before framework fracture on the occlusal surfaces of the FDPs, and two FDPs showed minor chipping 1 week and 36 months after cementation: one at the cervical margin of an abutment and the other on the incisal surface. They were only polished. Thus, after 4 years of clinical service, the overall survival rate of zirconia FDPs was 76.5%.

With respect to the periodontal parameters, statistically significant differences were not observed between abutment and control teeth. Statistical comparisons of periodontal parameters and the CDA criteria of the surviving FDPs at the baseline (t_0) and 4-year observations (t_5) are presented in Tables 4 and 5. The Wilcoxon signed-rank test showed no statistically significant differences with regard to CDA scores and periodontal indices except for Gingival Index in posterior abutments ($P = .016$).

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Table 1 Distribution of Abutments, Pontics, and Location of Zirconia FDPs in the Maxilla

	Tooth no.*															
FDP no.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
1		O	X	X	O											
2		O	X	X	O											
3		O	X	X	O											
4		O	X	X	O											
5		O	X	X	O											
6											O	X	X	O		
7											O	X	X	O		
8											O	X	X	O		
9											O	X	X	O		
10													O	X	X	O

O = abutment tooth; X = pontic.
*FDI tooth-numbering system.

Table 2 Distribution of Abutments, Pontics, and Location of Zirconia FDPs in the Mandible

	Tooth no.*															
FDP no.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
11		O	X	X	O											
12		O	X	X	O											
13	O	X	X	O												
14	O	X	X	O												
15												O	X	X	O	
16												O	X	X	O	
17												O	X	X	O	

O = abutment tooth; X = pontic.
*FDI tooth-numbering system.

Table 3 FDP Failures Regarding Clinical Service Time Until Failure and Reason for Failure

FDP no.	Clinical service time (mo)	Reason for failure
2	23	Framework fracture
8	28	Framework fracture
10	25	Framework fracture
11	23	Fracture of abutment tooth

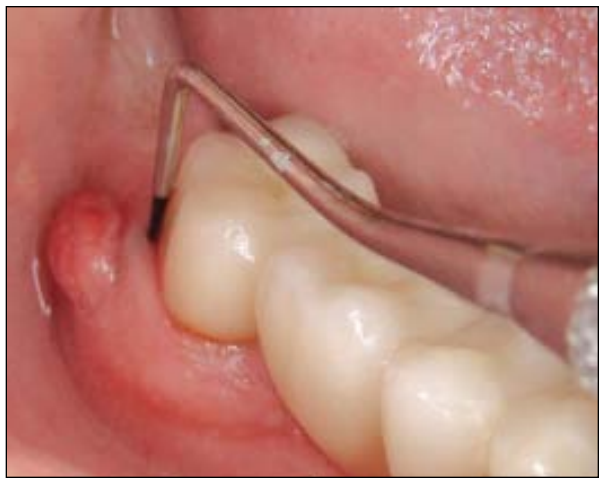

Fig 2 Probing of the vertical fracture at the distal abutment of FDP no. 11. The fracture was noted after 23 months of clinical service.

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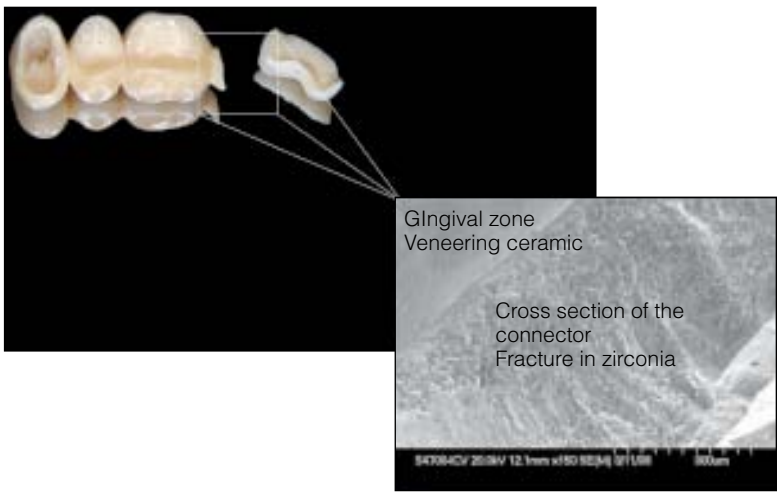

Fig 3a SEM image of clinically failed FDP no. 2. Note that the fracture initiated at the gingival connector area into the veneering ceramic. The height of the connector was measured to be 3.5 mm (original magnification ×150).

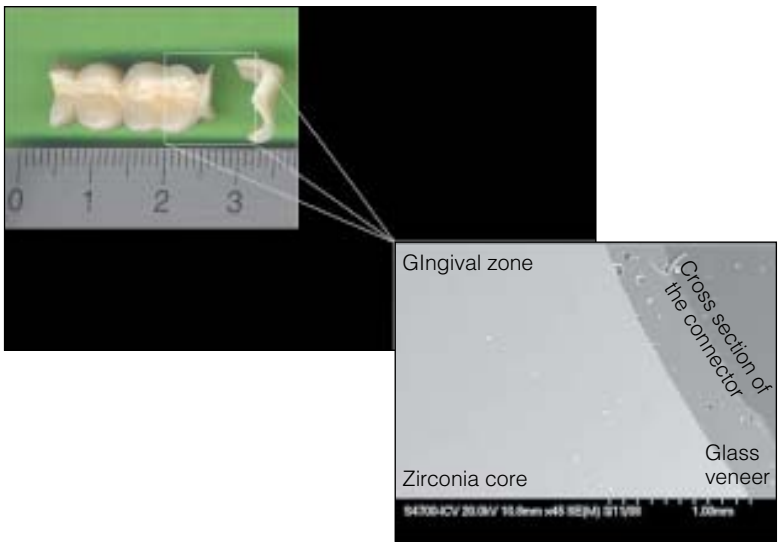

Fig 3b SEM image of clinically failed FDP no. 8. Note that the fracture initiated at the gingival connector area, and some porosities were visible in the veneering ceramic at the framework-veneer interface. The height of the connector was measured to be 3.5 mm (original magnification ×45).

Table 4 Statistical Comparisons of Periodontal Parameters of the Surviving FDPs at Baseline (t_0) and 4 Years (t_5)

Periodontal parameter	Anterior abutment (t_0 vs t_5)	Posterior abutment (t_0 vs t_5)
Plaque Index	.844	.063
Gingival Index	.094	.016*
Probing attachment level	> .999	> .999
Margin Index	.219	.125

*P < .05.

Table 5 Statistical Comparisons of CDA Criteria of the Surviving FDPs at Baseline (t_0) and 4 Years (t_5)

	t_0 vs t_5
Surface and color	.125
Anatomical form	.500
Marginal integrity	.625

Discussion

In this study, the survival rate of zirconia-based posterior four-unit FDPs was 76.5% after 4 years. Four FDPs were lost because of biologic or mechanical complications. The null hypothesis was rejected.

When zirconia was first introduced as a material for FDP 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.[14] Some studies provided encouraging data for the use of zirconia in the

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posterior region.[13,14] The incidence of framework fractures in this study is in clear contrast to the results of other clinical studies of zirconia-based FDPs. In a systematic review, it was reported that less than 1% of zirconia FDPs presented fracture of the framework.[15] It is important to indicate that the present study focused exclusively on posterior four-unit FDPs, while the majority of the FDPs reviewed in other studies were three units,[10,22] which may have influenced the fracture rate.

In a previous study,[16] clinical survival of zirconia FDPs was reported to be 73.9% after 5 years. These results seem to be in accordance with the present study at first glance. However, the reasons for failure in that study comprised secondary caries, decementation, and chipping, with only one connector fracture of a five-unit FDP 38 months after insertion. The authors concluded that the cause of the failure was trauma. Schmitter et al[23] reported a core fracture at the base of the connector 29 days after cementation, probably caused by damage induced during fabrication. On the other hand, Beuer et al[24] reported a three-unit framework fracture that occurred after 30 months of service. Fractography analysis revealed a zirconia coping thickness of 0.3 mm at the origin of the fracture and occlusal contact on the framework in this area. In another study, Roediger et al[25] reported a core fracture at the vestibular margin caused by locally reduced framework thickness.

All framework fractures determined in this study were located at the connection area between the distal abutment and pontic. It is known that all-ceramic FDPs are susceptible to fracture under tensile or flexural loading and that high stresses can develop at the gingival aspect of the connector during occlusal loading.[22] Such failures can be prevented by fabricating connectors with sufficient height and width to reduce stress concentration areas.[26] Larsson et al[27] recommended a minimum diameter of 4.0 mm for long-span zirconia-based FDPs replacing molars. However, these dimensions may hinder the use of such restorations for substitution of the first or second molars since, in many occasions, the height of the clinical crown of the distal retainer is limited, restricting adequate placement of the connector. Analysis of the retrieved failed FDPs in this study revealed that the heights of the distal connectors were 3.5 to 3.6 mm, which is less than the recommended 4 mm. In fact, the manufacturer's recommendations for the zirconia used were followed in terms of cross-sectional areas at the abutment-pontic and pontic-pontic areas, primarily focusing on the cross section and less on the vertical height at the connector. However, the height of the failed restorations indicates that the height of the connectors may be more important than the width to achieve the recommended cross-sectional area. This aspect requires further clinical observation.

The most frequent technical problem in all studies of zirconia-based FDPs is chipping or fracture of the veneering ceramic.[15,16] In the present study, minor chipping was observed in 11.8% of FDPs and moderate chipping in 17.6% of restorations. Minor chipping was observed in one FDP at the margin (no. 15) and another on the occlusal surface (no. 6), both with partial exposure of the zirconia framework, which received no further treatment except polishing. Moderate chipping occurred on the occlusal surface prior to framework fracture (FDPs no. 2, 8, and 10). However, patients did not demonstrate discomfort until the fragments of the restoration were separated. Chipping prior to fracture was also reported previously.[22] Factors such as the coefficient of thermal expansion of the veneering and zirconia material, the low thermal conductivity of zirconia, and thickness of the veneer and core must be taken into account to reduce possible risk of veneer chipping.[15,28] Reasons for failure could be also attributed to material defects, manufacturing process error, and inappropriate handling in the laboratory. Interestingly, the FDPs presenting chipping subsequently failed in the framework. Since the number of incidences was small, failure of the zirconia frameworks could not be attributed to low-temperature degradation. Long-term observations will be made focusing on those FDPs that presented chipping. Although more force could be expected on the canines during lateral excursion of the mandible, only one framework fracture and one moderate chipping were observed in the maxilla where the canine served as an abutment. Nevertheless, considering all failures, the masticatory forces seem to be greater on the posterior segment than on the canines.

In this study, only one FDP was removed because of fracture of a distal abutment that previously underwent endodontic treatment. This problem was also reported previously.[15,29] Other biologic complications such as secondary caries, loss of vitality, and periodontal disease were not observed in this study. At the 4-year observation, the periodontal parameters demonstrated a slight increase on the abutment teeth. In spite of this, statistically significant differences were not observed, except for Gingival Index in posterior abutment teeth. According to CDA scores, there was a slight change from excellent to acceptable during the 4-year follow-up for all parameters examined, in agreement with a previous study.[30]

This study is limited by the relatively small sample size as well as by the fact that a control group for comparison with the current standard of care

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(metal-ceramic FDPs) did not exist. Studies with a larger sample size and an active control group would be better suited to answer the question of whether posterior four-unit zirconia FDPs can serve as an alternative to posterior four-unit metal-ceramic FDPs.

Conclusions

Within the limitations of this prospective clinical study, the results after 4 years of clinical observation indicate that the use of zirconia-based four-unit posterior FDPs should be restricted for patients with high esthetic demands, except in patients where at least 4 mm of height is available for the connector thickness. More long-term clinical observations are needed to clarify the aging phenomenon of zirconia FDPs.

Acknowledgments

This study was supported by grant no. 229-2006 from the University Complutense of Madrid. The authors would like to thank Dr Ricardo García, Centre of Data Processing and Computing Service for Research Support, University Complutense of Madrid, Madrid, Spain, for his assistance with the statistical analysis.

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