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Evaluation of Zirconium-Oxide-Based Ceramic Single-Unit Posterior Fixed Dental Prostheses (FDPs) Generated with Two CAD/CAM Systems Compared to Porcelain-Fused-to-Metal Single-Unit Posterior FDPs: A 5-Year Clinical Prospective Study

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Abstract

Purpose: The purpose of this prospective clinical study was to determine the success rate of single-unit posterior fixed dental prostheses (FDPs) with zirconia copings generated with two CAD/CAM systems, compared to porcelain-fused-to-metal (PFM) single-unit posterior FDPs after 5 years of function.

Materials and Methods: From 2005 to 2006, 60 patients who needed a single-unit FDP on a first molar in the mandibular jaw (left or right) in a private office setting were included in this study. The 60 first mandibular molars were randomly divided into three groups (n = 20): in the control group (group C), 20 PFM FDPs were included. In the other two groups CAD/CAM technology was used for the fabrication of the zirconium-oxide copings: 20 single-unit posterior FDPs with zirconia copings were generated with the Procera system (group P, Nobel Biocare); 20 single-unit posterior FDPs with zirconia copings were generated with the Lava system (group L, 3M ESPE). For the ANOVA follow-up data, the clinical life table method was applied. The statistical analysis was performed using two nonparametric tests, the log-rank test for k-groups and the Fisher exact test.

Results: No statistically significant difference in the clinical outcome of zirconia–ceramic FDPs of both groups (P and L) evaluated together and metal–ceramic posterior single FDPs was found at 5 years of function; however, clinical data showed that technical problems, such as extended fracture of the veneering ceramic, tended to occur more frequently in the zirconia–ceramic FDP groups. The difference in the frequency of failure was statistically significant only in the comparison of groups C and P.

Conclusions: Even if no statistically significant difference in the clinical outcome of zirconia–ceramic FDPs of both groups (P and L) considered together and metal–ceramic posterior single FDPs was found at 5 years of function, clinical data showed that the two zirconia–ceramic FDP groups tended to have more frequent clinical problems: for this reason all the clinical and technical variables related to the use of zirconia–ceramic FDPs generated with CAD/CAM systems should be carefully considered prior to all treatment procedures.

Thanks to their growing awareness of esthetics and biocompatibility, patients increasingly request metal-free solutions.[1] Due to the successful use of all-ceramic crowns both in the anterior and posterior segments,[2-6] and with the introduction of advanced dental technology and high-strength ceramic materials, all-ceramic systems may become a viable treatment option. Such restorative all-ceramic systems must fulfill biomechanical requirements and provide longevity similar to metal–ceramic restorations[7-10] while providing enhanced esthetics.[11] Zirconia, which is a polycrystalline material without a glassy matrix and is partly stabilized by yttrium oxide (approximately 3 mol%), is a valid metal-free option. The use of zirconia has been

facilitated by the advent of computer-aided design/computer-aided manufacturing (CAD/CAM) systems.[12-18]

Conventional metal frameworks veneered with tooth-colored ceramics are regarded as the gold standard for posterior FDPs because of their low failure rate (8–10% after 10 years).[19-20] Recent studies have tested whether FDPs with zirconia frameworks exhibited similar survival rates and technical and biological outcomes to those with metal frameworks. Some authors showed that zirconia ceramic FDPs exhibited a similar survival rate to metal ceramic FDPs after a few years of function,[21-22] even if chipping of the ceramic veneer occurred in 13% of restorations. [22]

The purpose of this prospective clinical study was to determine the success rate of single-unit posterior FDPs with zirconia copings generated with two CAD/CAM systems, compared to porcelain-fused-to-metal (PFM) single-unit posterior FDPs after 5 years of function. The null hypothesis of this study was that posterior FDPs with zirconia copings exhibit similar survival rates to those with metal copings.

Materials and methods

From 2005 to 2006, 60 patients who needed a single-unit FDP on a first molar in the mandibular jaw (left or right) in a private office setting were included in this study. The study was approved by the Clinical Medical Ethical Committee of the University of Padova, Institute of Clinical Dentistry, Padova, Italy. The patients' ages ranged from 19 to 55 years (mean: 32), with good oral hygiene and without periodontal disease. All teeth were vital and properly positioned in the dental arch; they had a sufficient amount of dentin for the retention of the FDP and were opposed to natural dentition. All clinical procedures were provided by the same prosthodontist. All abutment teeth were prepared in a standard manner as described in previous studies:[15] occlusal reduction of 1.5 mm; axial reduction of 1–1.5 mm with 10° taper; 1.0 mm wide, 360° rounded shoulder located 0.5 mm subgingivally on the facial aspect for esthetic reasons and supragingivally on the lingual aspect on a sound tooth structure; all internal line angles carefully rounded. An interim prosthesis was fabricated with polymethyl methacrylate (Jet; Lang Dental Mfg. Co., Wheeling, IL) and cemented using eugenol-free provisional cement (Temp Bond NE; Kerr Italia, Scafati, Salerno, Italy). For the impression phase, 2 mm thick custom impression trays were fabricated with Palatray LC resin (Heraeus Kulzer, Wehrheim, Germany), mixed in accordance with the manufacturer's instructions. The impression material (Impregum Penta; 3M ESPE, Seefeld, Germany) was machine mixed (Pentamix; 3M ESPE), and part of it was meticulously syringed all around the tooth to ensure complete coverage of the tooth itself. Five minutes were allowed for setting of the impression material. The impression was then removed from the patient's mouth and poured with an American Dental Association (ADA) type IV artificial stone (New Fujirock; GC Corporation, Tokyo, Japan) following the manufacturer's instructions. The definitive and opposing casts were mounted in a semiadjustable articulator (Whip Mix Corp, Louisville, KY).

The patient consent was obtained prior to FDP delivery. According to a list of randomization,[23] the first 60 mandibular molars (right and left) were randomly divided into three groups (n = 20). All technical procedures were accomplished by the same experienced dental technician.

Group C: in the control group, 20 regular PFM definitive crowns with porcelain occlusal surfaces were fabricated. A noble alloy (Valcambi, Balerna, Switzerland) was used for the metal copings, and porcelain (Noritake EX-3; Noritake, Nagoya, Japan) was applied in layers to them.

In the other two groups CAD/CAM technology was used for the fabrication of the zirconium-oxide copings. **Group P**: 20 single-unit posterior FDPs with zirconia copings were generated with the Procera system (group P, Nobel Biocare, Göteborg, Sweden). The layering ceramic was NobelRondo Zirconia (Nobel Biocare). **Group L**: 20 single-unit posterior FDPs with zirconia copings were generated with the Lava system (group L, 3M ESPE). The layering ceramic was Lava Ceram (3M ESPE).

All copings from groups C and L were 0.5 mm thick. All copings from group P were 0.6 mm thick. This allowed maintenance of a comparable amount of porcelain overlaying for all single-unit posterior FDPs. All occlusal adjustments were accomplished before final cementation at the porcelain try-in appointment. All FDPs from the three groups were cemented with glass-ionomer cement (Ketac-Cem, 3M ESPE) following the manufacturer's instructions.

Immediately following cementation of all FDPs, radiographs were obtained, and clinical photographs were taken. Occlusal and functional relationships between FDPs and opposing arches were recorded. At 6 months, 1, 2, 3, 4, and 5 years after delivery, all restorations were examined by a dentist who was not involved in the restorative treatment for technical or biological failures or complications. Radiographs of all crowned teeth and clinical photographs of the reconstructions were taken. For the evaluation of the technical performance of the FDPs, United States Public Health Service (USPHS) criteria were used (Table 1), as in a previous study.[22] An outcome was rated Alfa (A) when no problem occurred, Bravo (B) when small but clinically acceptable defects were found, Charlie (C) when the defects reached a level no longer clinically acceptable, and Delta (D) when the FDP had to be replaced due to the defect. All patients were informed about the clinical status of their FDPs.

For the ANOVA follow-up data, the clinical life table method was applied. Statistical analysis was performed using two nonparametric tests, the log-rank test for k-groups and Fisher's exact test. The null hypothesis stated that there was no real difference in the frequency of prosthetic crown failures in the three groups. The significance level was set at 5% ($p < 0.05$).

In the first part of the analysis, the frequency of failures was defined as the sum of the number of crowns needing replacement (classified as C and D); however, in the second part, the frequency of failures was defined as the addition of the number of crowns needing replacement together with the number of crowns damaged by small but clinically acceptable defect (classified as B, C, and D). The significance of the frequency of failures in the period of observation (5 years) was analyzed using the log-rank test. Fisher's exact test was applied to the difference in the groups at each interval. In the final part, the same tests were used for the comparison between the control group (the metal ceramic group C) and the groups of the zir-

Table 1 USPHS criteria

	Alfa (A)	Bravo (B)	Charlie (C)	Delta (D)
Coping fracture	No fracture of coping			Fracture of coping
Veneering fracture	No fracture	Chipping, but polishing possible	Chipping down to the coping	New reconstruction is needed
Occlusal wear	No occlusal wear on reconstruction or on opposite teeth	Occlusal wear on reconstruction or on opposite teeth <2 mm	Occlusal wear on reconstruction or on opposite teeth >2 mm	New reconstruction is needed
Marginal adaptation	No probe catch	Slight probe catch, but no gap	Gap with some dentin or cement exposure	New reconstruction is needed
Anatomical form	Ideal anatomical shape, good proximal contact	Slightly over- or under-contoured, weak proximal contact	Highly over- or under-contoured, open proximal contact	New reconstruction is needed

conia ceramic generated with the Procera system (P) and the Lava system (L) taken together.

Results

Two patients, one from group C and one from group P, were lost to follow-up because they had moved to a different area of the country. The remaining 58 patients were all included in the 5-year follow-up. None of the FDP metal or zirconia copings fractured. Two crowns of group P and one of group L had to be replaced due to unrestorable delamination of the ceramic veneer. None of the group C crowns had to be replaced.

Comparison of the frequency of failures classified as C and D between the groups

The life table (Table 2) showed that the cumulative probability of survival to the end of the interval (5 years) was 95% in group C, 79% in group P, and 85% in group L. The probability of survival during a 2-year interval was less in group P (89%) than groups C (100%) and L (95%); however, none of the differences were statistically significant, and the null hypothesis was not rejected.

Comparison of the frequency of failures classified as B + C + D between the groups

The cumulative probability of survival to the end of the interval (5 years) was 84% in group C, 58% in group P, and 70% in group L (Table 3). The probability of survival during a 2-year interval was less in groups P (83%) and L (84%) than in group C (100%). At 4 years, groups C and P reached the lowest value of the probability of survival during the interval, 89% and 79%, respectively.

The risk of failure was significantly higher for group P than for group C. The log-rank test applied to the three groups gave a χ^2 equal to 4.613 (d.f. = 2). After that, the log-rank test for the two life tables of groups C and P produced a χ^2 of 2.98 (d.f. = 1). Both values were significant, and the level of significance was $p < 0.05$. Over the entire period of follow-up, group P had a failure rate (relative risk) 3.04 times higher than group C. In this comparison, the result led to a rejection of the null hypothesis. There was no difference between groups C and L, and L and P. Fisher's exact test revealed no significant values during the intervals in all groups.

Comparison of the frequency of failures (classified as B + C + D) between group C and groups P and L together

The cumulative probability of failure to the end of the 5-year interval was 16% for group C and 36% for groups L and P taken together (Table 4). The results of the statistical analysis were not significant.

Discussion

Within the limitations of this in vivo study, due to the small number of specimens tested, it was concluded that all three systems demonstrated a comparable clinical behavior. No statistically significant difference in the clinical outcome of zirconia ceramic FDPs from groups P and L considered together and metal ceramic posterior single FDPs was found at 5 years of function. Only when the comparison of the frequency of failures classified as B + C + D between the three groups was undertaken, was it perceived that the risk of failure was significantly higher for group P than for group C. Over the entire period of follow-up, group P had a failure rate (relative risk) 3.04 times higher than group C.

On the other hand, clinical data showed that technical problems, such as extended fracture of the veneering ceramic, tended to occur more frequently in the zirconia ceramic FDP groups. During the present observation period, clinically unacceptable major fractures of the veneering ceramic were found solely in zirconia ceramic FDPs. Two group P FDPs and one group L FDP had to be replaced, due to unrestorable delamination of the ceramic veneer: on these three, considerable delamination occurred on the facial aspects of the zirconia ceramic FDPs. No particular location was detected for the small porcelain chippings classified as B. None of group C's FDPs had to be replaced. The life table (Table 2) showed that the cumulative probability of survival to the end of the 5-year interval was 95% in group C, 79% in group P, and 85% in group L. The reason for the problems with zirconia veneering ceramic still remains to be clarified, as noted in previous studies.[21,24-30] A further

Table 2 Life table of the groups of the metal ceramic (C), zirconia ceramic generated with Procera system (P), and zirconia ceramic generated with the Lava system (L). The failures are the number of crowns needing replacement (C + D)

	Numbers entering interval			Failures during interval			Probability of failure during interval			Cumulative probability of failure by end of interval		
Interval	Group C	Group P	Group L	Group C	Group P	Group L	Group C	Group P	Group L	Group C	Group P	Group L
6 months	20	20	20	0	0	0	0	0	0	0	0	0
1 year	19	19	20	0	0	0	0	0	0	0	0	0
2 years	19	19	20	0	2	1	0	0.11	0.05	0.00	0.11	0.05
3 years	19	17	19	0	1	1	0	0.06	0.05	0.00	0.16	0.10
4 years	19	16	18	1	1	1	0.05	0.06	0.06	0.05	0.21	0.15
5 years	18	15	17	0	0	0	0	0	0	0.05	0.21	0.15

Table 3 Life table of groups of the metal ceramic (C), zirconia ceramic generated with the Procera system (P), and zirconia ceramic generated with the Lava system (L). The failures are the addition of the number of crowns needing replacement, together with crowns damaged by small but clinically acceptable defect (B + C + D)

	Numbers entering interval			Failures during interval			Probability of failure during interval			Cumulative probability of failure by end of interval		
Interval	Group C	Group P	Group L	Group C	Group P	Group L	Group C	Group P	Group L	Group C	Group P	Group L
6 months	20	20	20	0	0	1	0	0	0.05	0	0	0.05
1 year	19	19	19	1	1	0	0.05	0.05	0.00	0.05	0.05	0.05
2 years	18	18	19	0	3	3	0	0.17	0.16	0.05	0.21	0.20
3 years	18	15	16	0	1	1	0	0.07	0.06	0.05	0.26	0.25
4 years	18	14	15	2	3	1	0.11	0.21	0.07	0.16	0.42	0.30
5 years	16	11	14	0	0	0	0	0.00	0.00	0.16	0.42	0.30

Table 4 Life table of the metal ceramic (C) group and the groups of the zirconia ceramic generated with Procera system (P) and with the Lava system (L) together. The failures are the addition of the number of crowns needing replacement, together with crowns damaged by small but clinically acceptable defects (B + C + D)

	Numbers entering interval		Failures during interval		Probability of failure during interval		Cumulative probability of failure by end of interval	
Interval	Group C	Groups P and L	Group C	Groups P and L	Group C	Groups P and L	Group C	Groups P and L
6 months	20	40	0	1	0	0.03	0	0.03
1 year	19	38	1	1	0.05	0.03	0.05	0.05
2 years	18	37	0	6	0	0.16	0.05	0.20
3 years	18	31	0	2	0	0.06	0.05	0.26
4 years	18	29	2	4	0.11	0.14	0.16	0.36
5 years	16	25	0	0	0	0	0.16	0.36

clinical factor to consider with regard to risk of chipping of the veneering ceramic is the design of the framework, which ideally provides space for an even thickness of the veneering ceramic. In the present study, a CAM technique was used for fabrication of the zirconia copings. Therefore, for all three types of FDPs, the copings were modeled manually out of wax, respecting the anatomical situation of the patients. The support for the veneering ceramics was similar for both coping materials (metal and zirconia) and could not be considered a crucial factor for the greater extension of chipping in the zirconia ceramic group.

Another limitation of this study was that all restorations were inserted only with glass ionomer cement. No failures of cementation were observed in the present study; however, further clinical research should be conducted on the effect of cementation on zirconia FDPs.

Conclusion

Within the limitations of this medium-term test period, it may be concluded that even if no statistically significant difference in the clinical outcome of zirconia ceramic and metal ceramic posterior single FDPs was found at 5 years of function, from the clinical data, the zirconia ceramic FDP groups tended to have more frequent technical problems, such as extended fracture of

the veneering ceramic. For this reason, all clinical and technical variables related to the use of zirconia ceramic FDPs generated with CAD/CAM systems should be carefully considered prior to all treatment procedures.

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References

1. Reich S, Wichmann M, Nkenke E, et al: Clinical fit of all-ceramic three-unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci 2005;113:174-179.
2. Probster L: Four year clinical study of glass-infiltrated, sintered alumina crowns. J Oral Rehabil 1996;23:147-151.
3. Fradeani M, Redemagni M: An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. Quintessence Int 2002; 33:503-510.
4. Oden A, Andersson M, Krystek-Ondracek I, et al: Five-year clinical evaluation of Procera AllCeram crowns. J Prosthet Dent 1998; 80:450-456.
5. Odman P, Andersson B: Procera Allceram crowns followed for 5 to 10.5 years: a prospective clinical study. Int J Prosthodont 2001;14:504-509.
6. Fradeani M, D'Amelio M, Redemagni M, et al: Five-year follow-up with Procera all-ceramic crowns. Quintessence Int 2005;36:105-113.
7. Denry IL, Holloway JA, Rosenstiel SF: Effect of ion exchange on the microstructure, strength, and thermal expansion behavior of a leucite reinforced porcelain. J Dent Res 1998;77:583-588.
8. Walton TR: An up to 15-year longitudinal study of 515 metal-ceramic FPDs: part 1. Outcome. Int J Prosthodont 2002;15:439-445.
9. Drummond JL: Ceramic behavior under different environmental and loading conditions. In Eliades G, Eliades T, Brantley WA, et al (eds): Dental Materials In Vivo: Aging and Related Phenomena. Chicago, Quintessence, 2003, pp. 35–45.
10. Wolfart S, Eschbach S, Scherrer S, et al: Clinical outcome of three-unit lithium-disilicate glass-ceramic fixed dental prostheses: up to 8 years results. Dent Mater 2009;25:e63-e71.
11. Raigrodski AJ, Chiche GJ: The safety and efficacy of anterior ceramic fixed partial dentures: a review of the literature. J Prosthet Dent 2001;86:520-525.
12. Filser F, Kocher P, Weibel F, et al: Reliability and strength of all-ceramic dental restorations fabricated by direct ceramic machining. Int J Comput Dent 2001;2:89-103.
13. Mehl A, Hickel R: Current state of development and perspectives of machine-based production methods for dental restorations. Int J Comput Dent 1999;2:9-35.
14. Tinschert J, Natt G, Hassenpflug S, et al: Status of current CAD/CAM technology in dental medicine. Int J Comput Dent 2004;7:25-45.
15. Raigrodski AJ, Chiche GJ, Potiket N, et al: The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. J Prosthet Dent 2006;96:237-244.
16. Suttor D, Bunke K, Hoescheler S, et al: Lava—the system for all-ceramic ZrO2 crown and bridge frameworks. Int J Comput Dent 2001;3:195-206.
17. Vigolo P, Fonzi F: An "in vitro" evaluation of fit of zirconium-oxide based ceramic four-unit fixed partial dentures, generated with three different CAD/CAM systems, before and after porcelain firing cycles and after glaze cycles. J Prosthodont 2008;17:621-626.
18. Vigolo P, Motterle M: An in vitro evaluation of zirconia surface roughness caused by different scaling methods. J Prosthet Dent 2010;103:283-287.
19. Creugers NH, Käyser AF, van't Hof MA: A meta-analysis of durability data on conventional fixed bridges. Community Dent Oral Epidemiol 1994;22:448-452.
20. Scurria MS, Bader JD, Shugars DA: Meta-analysis of fixed partial denture survival: prostheses and abutments. J Prosthet Dent 1998;79:459-464.
21. Sailer I, Fehér A, Filser F, et al: Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. Quintessence Int 2006;37:685-693.
22. Sailer I, Gottnerb J, Kanelb S, et al: Randomized controlled clinical trial of zirconia-ceramic and metal-ceramic posterior fixed dental prostheses: a 3-year follow-up. Int J Prosthodont 2009;22:553-560.
23. Pocock SJ: Clinical Trials. A Practical Approach. Philadelphia, Wiley, 1984, pp. 73–80, pp. 221-224.
24. Aboushelib MN, deJager N, Kleverlaan CJ, et al: Microtensile bond strength of different components of core veneered all-ceramic restorations. Dent Mater 2005;21:984-991.
25. Fischer J, Stawarczyk B, Tornic M, et al: Effect of thermal misfit between different veneering ceramics and zirconia frameworks on in vitro fracture load of single crowns. Dent Mater J 2007;26:766-772.
26. Fischer J, Grohrnann P, Stawarczyk B: Effect of zirconia surface treatments on the shear strength of zirconia/veneering ceramic composites. Dent Mater J 2008;27:448-454.
27. Fischer J, Stawarczyk B, Härnrnerle CHF: Flexural strength of veneering ceramics for zirconia. J Dent 2008;36:316-321.
28. Luthardt RG, Sandkuhl O, Reitz B: Zirconia-TZP and alumina-advanced technologies for the manufacturing of single crowns. Eur J Prosthodont Restor Dent 1999;7: 113-119.
29. AI-Dohan HM, Yaman P, Dennison J, et al: Shear strength of core-veneer interface bi-layered ceramics. J Prosthet Dent 2004;91:349-355.
30. Aboushelib MN, Kleverlaan CJ, Feilzer N: Effect of zirconia type on its bond strength with different veneer ceramics. J Prosthodont 2008;17:401-408