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SHORT COMMUNICATION

Metal–ceramic-fixed dental prosthesis with CAD/CAM-fabricated substructures: 6-year clinical results

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Abstract
Objectives The aim of this study was to evaluate the clinical performance of fixed dental prostheses (FDPs) with computer-aided design (CAD)/computer-aided manufacturing (CAM)-fabricated titanium substructures veneered with low-fusing porcelain after 6 years.
Materials and methods Thirty-one FDPs for 23 patients were fabricated. The frameworks were designed and milled using an early version of a dental CAD/CAM system. Checkups were performed annually.
Results Complications totaled ten porcelain fractures, one substructure fracture, and one biologic failure. The success rate was calculated at 58.6 % and the survival rate at 88 % (Kaplan–Meier analysis).
Conclusion The clinical performance of the described technique for FDPs with titanium substructures was poor. Therefore, the presented concept cannot be recommended.
Clinical relevance CAD/CAM-fabricated titanium substructures veneered with the powder build-up technique showed poor clinical outcome after 6 years.

Keywords CAD/CAM · Titanium–ceramic · FDP · Low-fusing porcelain

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Introduction

Titanium has desirable properties for dental restorations, such as good corrosion resistance, low specific gravity, good mechanical properties, high biocompatibility, and low cost [1]. Unfortunately, several problems are encountered in the casting and veneering of titanium [2, 3]. For example, in the lost wax technique, molten titanium reacts with the ingredients of the investment material. The marginal layer becomes severely embrittled and impure. This "α-case layer" reduces the bond strength between the veneering porcelain and the titanium substructure and affects the marginal accuracy [4].

Furthermore, veneering titanium is difficult owing to excessive oxidization of the metal during porcelain firing. This oxidization causes the formation of a darkened layer, which makes predictable esthetics challenging, and weakens the bond between the porcelain systems and titanium. Manufacturers have suggested the use of titanium–ceramic bonders to prevent spontaneous oxidization [5]. Titanium–ceramic fixed dental prostheses (FDPs) that use such bonders were evaluated in several clinical studies with promising clinical results [6–8]. Around the year 2000, dental computer-aided design (CAD)/computer-aided manufacturing (CAM) technology began to strongly influence the fabrication of dental restorations. One of the first metals to be used for dental CAD/CAM frameworks was titanium, owing to its biological and mechanical properties. Milling titanium produces excellent fitting, avoids the α-case layer, and decreases the fabrication costs in comparison to copy milling, spark erosion, and laser welding [9, 10]. A recently published review on the in vitro performance of titanium–ceramic restorations strongly supported this treatment option [11]. However, despite technological improvements, titanium has not yet reached a clinical breakthrough.

Moreover, insufficient data are available on the clinical performance of CAD/CAM-fabricated metal–ceramic FDPs with titanium substructures. Therefore, the purpose of this clinical observational study was to evaluate FDPs fabricated from CAD/CAM-milled titanium veneered with low-fusing porcelain. For a casted titanium substructure, the ceramic veneer after a clinical observation time of 6 years was reported to be completely intact in 84 % of the prostheses [7]. However, for high-gold alloy substructures, the veneering material demonstrated 98 % clinical success in the same study [7]. The working hypothesis is that FDPs fabricated with the proposed concept will provide clinical results comparable to those reported for casted titanium.

Materials and methods

This prospective clinical trial was designed according to the recommendations of the Consolidated Standards of Reporting Trials for improving the quality of clinical trials. The requirements of the Helsinki declaration were fulfilled and approved by the Ethical Committee of the University Halle-Wittenberg (no. 05032004). Thirty-one FDPs for 23 patients were fabricated. Further, 22, 4, 4, and 1 six-unit FDPs (a total of 108 units) were placed. Ten FDPs were supported by a canine; all other units were placed in the posterior region. Preparation was done according to the manufacturer's recommendations, and all impressions were made with polyether (Impregum, 3 M ESPE, Seefeld, Germany). Master casts, fabricated with scannable type-IV gypsum (opti-rock; Whipmix, Dortmund, Germany), were digitized using a white-light projector scanner (Everest Scan, KaVo, Biberach, Germany). The preparation margins were automatically detected (Everest Scan Software, Everest Design Sherpa, each from KaVo), and the substructures were designed with the software of the CAD/CAM system (Everest CAM, KaVo). The abutments were milled with a uniform thickness of 0.5 mm; the software was unable to offer intelligent substructure designs for abutments or pontics. The cross-sectional area of the connectors was set to at least 5 mm^2. Data were transferred to the five-axis milling CAM unit of the used system (Everest Engine, KaVo). FPD frameworks were milled from grade 2 titanium blanks (Everest T-Blank, KaVo). All FDPs were veneered with low-fusing porcelain (Vita Titanium Porcelain, VITA Zahnfabrik Bad Säckingen, Germany) according to the firing protocol and recommendations of the manufacturer. To increase the adhesive bond strength between titanium and the veneering porcelain, a titanium bonder was applied (Vita Bonder, VITA Zahnfabrik Bad Säckingen, Germany). After fitting and adjusting the occlusal and proximal contacts, the restorations underwent an additional firing if adjustments on the veneering surface were made. The FDPs were cemented using zinc phosphate cement (Harvard Cement, Harvard Dental International GmbH, Hoppegarten, Germany). The patients were called back annually after cementation to evaluate the restorations. Technical and biological complications, as well as pocket probing depths (PPDs), were recorded.

An FDP was categorized as a "success" if it was free of any mechanical complications, whereas it was categorized as "survival" if it was not replaced, but functioning in place with or without mechanical complication(s).

Statistical analyses were performed using SPSS 17.0 for Windows (SPSS Inc., Chicago, IL, USA). The level of significance was set to 5 % ($p<0.05$). The success and survival rates were estimated by Kaplan–Meier analysis with 95 % confidence intervals. Friedman's test was used to detect differences in the mean PPD across the investigation period.

Results

Although four patients missed the 3-year checkup, information on all inserted restorations was recorded after 6 years. Two patients were unable to attend the final checkup procedure at Halle University. However, their dentist performed the final examination and sent the files and pictures. This resulted in a response rate of 100 %. Ten veneering porcelain fractures occurred on nine FPDs (six cohesive and four adhesive fractures), resulting in replacement of one FPD due to loss of function. Seven fractures were found at the abutments, and three, at the pontics. One framework fracture of a six-unit FDP was observed after a clinical service of 60 months. The restoration fractured between the mesial abutment [International Dental Federation (FDI) position 23] and the first pontic (FDI position 24). The connector showed a cross-sectional area of 5.5 mm^2. Two endodontically treated teeth were extracted, owing to recurrent apical periodontitis. Briefly, three FDPs were replaced because of mechanical or biological complications. Therefore, the Kaplan–Meier cumulative success rate with regard to mechanical complications was 58.6 % (Fig. 1). The Kaplan–Meier cumulative survival rate of CAD/CAM titanium–ceramic FPDs with regard to function was 88 % (Fig. 2). The mean PPD increased significantly from 2.1 to 3.0 mm during the period of investigation (Friedman's test, $p<0.001$) (Table 1).

Discussion

Contrary to expectations of the working hypothesis, the present study revealed a low clinical success rate for FPDs with a CAD/CAM-fabricated titanium substructure. Compared to the 3-year results of this study, the cumulative success rate with regard to mechanical complications decreased from 76.4 to 58.6 %, and the cumulative survival

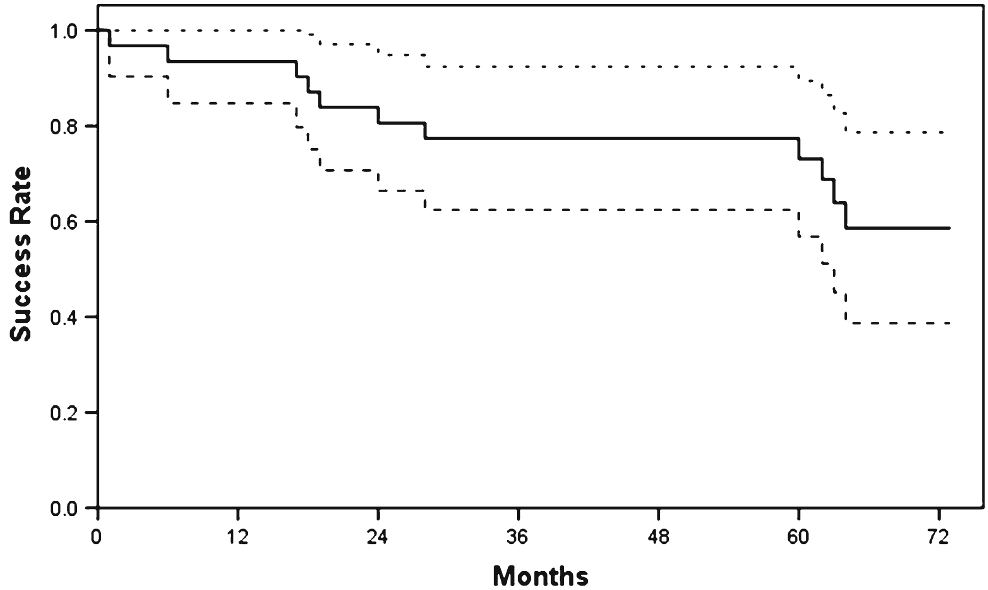

Fig. 1 Success rate of CAD/CAM titanium–ceramic FDPs over 6 years by Kaplan–Meier cumulative analysis with 95 % confidence intervals

rate with regard to function decreased from 96.8 % after 3 years to 88 % after 6 years [12]. Three of the 31 FDPs were replaced, owing to mechanical or biological complications (Table 2). Two root-filled teeth were extracted because of recurrent apical periodontitis, and one framework was broken. The fractured substructure was the six-unit FPD, which replaced two premolars and two molars in the maxilla. Long-span FDPs were reported to have a higher risk of failure than short-span FDPs [13]. Neither secondary caries nor loss of retention was detected during the 6-year observation period. This indicates that the marginal accuracy and internal fit of the titanium framework were acceptable [10]. The mean PPD increased over the observation period but remained within clinically acceptable limits. Similar results were reported in another study [8]. In sum, the low cumulative survival rate can be explained by the small sample size and the inclusion criteria of the investigation. Endodontically treated abutments and long-span FDPs represent a higher risk of clinical failure than short-span FDPs [14]. However, about one third (33 %) of the investigated FPDs showed fractures on the veneering porcelain. Six cohesive and four adhesive fractures were observed. During porcelain firing, titanium oxidizes excessively. The oxide layer compromises the quality of titanium–ceramic bonding and esthetics. A titanium–ceramic bonder is used to increase the bond strength between titanium and ceramics [15]. This bonder consists of kibbled glass powder, which seals or dissolves existing oxides on the titanium surface [5].

In addition to the α-case layer and spontaneous oxidation, titanium undergoes a phase transformation at 882 °C,

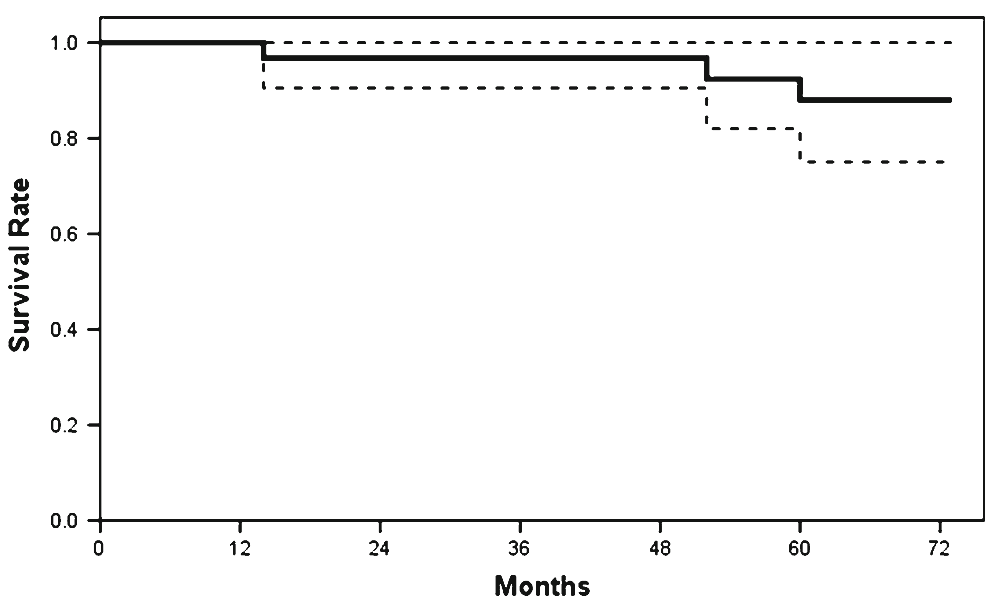

Fig. 2 Survival rate of CAD/CAM titanium–ceramic FDPs over 6 years by Kaplan–Meier cumulative analysis with 95 % confidence intervals

Table 1 Mean pocket probing depth (in millimeters) during the period of investigation

Baseline	12 months	24 months	36 months	72 months
2.1	2.4	2.8	2.8	3.0

during which bulking occurs in combination with intense embrittlement and contamination [16]. To avoid this phase transformation, the firing process of the veneering porcelain must not exceed 882 °C [11]. In addition, the coefficient of thermal expansion for titanium is very small. To achieve a low encapsulation temperature and a small coefficient of thermal expansion, the amount of alkali oxide metals is increased, and the fraction of alumina oxide and leucite is decreased in veneering porcelain for titanium compared to that for conventional metal–ceramic restorations. High fractions of leucite and alumina oxide result in higher flexural strength of the veneering porcelain. An increased amount of alkali oxide metals leads to higher inclusion of water in the ceramic. This effect will also decrease the mechanical strength of the titanium–ceramic [17, 18].

Furthermore, the uniform thickness of the substructures might have contributed to the high amount of veneering porcelain fractures because optimized substructure design increases the clinical performance of veneered dental restorations [19, 20]. Additionally, manufacturers recommend cooling fins to avoid stress cracking. These fins lead to consistent cooling after the veneering firings and should compensate for the low heat conductivity of titanium. Although the available CAD programs offer the possibility of smart substructure design, cooling fins are not yet implemented. Therefore, the

Table 2 Distribution of fixed dental prostheses, including location, possible failures, and clinical service time until failure

Number of restorations	Number of patients	Gender of the patient	Age of the patient	FDI position of abutments	FDI position of pontics	FDI position of fractured unit	Clinical service time until failure in months
1	1	F	50	25, 27	26		
2	1	F		35, 37	36	35, 37	52
3	2	F	70	35, 37	36		
4	3	F	66	34, 36	35		
5	4	F	33	15, 16	14		
6	4	F		25, 27	26		
7	4	F		34, 36, 38	35, 37		
8	5	F	55	23, 25, 27	24, 26	26	17
9	6	F	71	45, 47	46		
10	7	M	61	23, 25	24		
11	8	F	58	14, 16	15	16	18
12	9	M	58	13, 15, 17	14, 16	17	19
13	9	M		43, 45	42, 44		
14	10	F	52	35, 37	36		
15	11	F	65	44, 47	45, 46	46	60
16	12	M	52	13, 15	14	14	28
17	13	F	64	35, 37	36		
18	13	F		44, 46	45		
19	14	F	68	23, 25	24		
20	15	M	55	13, 16	14, 15		
21	16	F	60	25, 27	26		
22	16	F		35, 37	36		
23	17	F	63	23, 24, 27	25, 26	24	64
24	18	F	47	15, 16	14	15	6
25	18	F		45, 47	46		
26	19	F	56	45, 47	46		
27	20	M	56	44, 47	45, 46		
28	21	M	47	15, 17	16		
29	21	M		25, 27	26	25	24
30	22	M	69	23, 28	24, 25, 26, 27		60
31	23	F	65	23, 25	24		

titanium–ceramic concept might not give the same consistency as porcelain fused to conventional high-gold alloys [7].

However, some limitations of this study must be considered:

1. The limited number of restorations included in this study makes statistical analysis difficult.
2. Only one CAD/CAM system was used in this study. Other combinations of designing and manufacturing systems may lead to different results.
3. Only one type of veneering porcelain was used. The veneering material has a major impact on the clinical results.
4. The powder build-up technique was used by different ceramists to apply veneering porcelain. The ceramist also has a significant influence on the clinical result.

Conclusion

Within the limitations of the study, the presented protocol showed poor clinical results. Further, prospective clinical studies should be conducted by accounting for the latest improvements in CAD/CAM and veneering concepts.

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Conflict of interest None.

References

1. Wang RR, Fenton A (1996) Titanium for prosthodontics applications: a review of the literature. Quintessence Int 27:401–408
2. Kimura H, Horng CJ (1990) Oxidation effects on porcelain–titanium interface reactions and bond strength. Dent Mater J 9:91–99
3. Chai T, Stein R (1995) Porosity and accuracy of multiple-unit titanium casting. J Prosth Dent 73:534–541
4. Adachi M, Mackert JR Jr, Parry EE et al (1990) Oxide adherence and porcelain bonding to titanium and Ti-6Al-4 V alloy. J Dent Res 69:1230–1235
5. Al Hussaini I, Al Wazzan KA (2005) Effect of surface treatment on bond strength of low-fusing porcelain to commercially pure titanium. J Prosthet Dent 94:350–356
6. Chai J, McGivney GP, Munoz CA, Rubenstein JE (1997) A multicenter longitudinal clinical trial of a new system for restorations. J Prosthet Dent 77:1–11
7. Walter M, Reppel PD, Böning K, Freesmeyer WB (1999) Six-year follow-up of titanium and high-gold porcelain-fused-to-metal fixed partial dentures. J Oral Rehabil 26:91–96
8. Lövgren R, Andersson B, Carlsson GE, Odman P (2000) Prospective clinical 5-year study of ceramic-veneered titanium restorations with the Procera system. J Prosthet Dent 84:514–521
9. Shokry TE, Attia M, Mosleh I et al (2010) Effect of metal selection and porcelain firing on the marginal accuracy of titanium-based metal ceramic restorations. J Prosthet Dent 103:45–52
10. Witkowski S, Komine F, Gerds T (2006) Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. J Prosthet Dent 96:47–52
11. Haag P, Nilner K (2010) Bonding between titanium and dental porcelain: a systematic review. Acta Odontol Scand 68:154–164
12. Boeckler AF, Lee H, Psoch A, Setz JM (2010) Prospective observation of CAD/CAM titanium-ceramic-fixed partial dentures: 3-year follow-up. J Prosthodont 19:592–597
13. Sailer I, Fehér A, Filser F, Gauckler LJ, Lüthy H, Hämmerle CH (2007) Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. Int J Prosthodont 20:383–388
14. Eliasson A, Arnelund CF, Johansson A (2007) A clinical evaluation of cobalt-chromium metal-ceramic fixed partial dentures and crowns: a three- to seven-year retrospective study. J Prosthet Dent 98:6–16
15. Gilbert JL, Covey DA, Lautenschlager EP (1994) Bond characteristics of porcelain fused to milled titanium. Dent Mater J 10:134–140
16. Kvam K, Derand T, Austrheim EK (1995) Fracture toughness and flexural strength of dental ceramics for titanium. Biomaterials 16:73–76
17. Pröbster L, Maiwald U, Weber H (1996) Three-point bending test strength of ceramics fused to cast titanium. Eur J Oral Sci 104:313–319
18. Yilmaz H, Dincer C (1999) Comparison of the bond compatibility of titanium and an NiCr alloy to dental porcelain. J Dent 27:215–222
19. Rosentritt M, Steiger D, Behr M, Handel G, Kolbeck C (2009) Influence of substructure design and spacer settings on the in vitro performance of molar zirconia crowns. J Dent 37:978–983
20. Johansson M, Mosharraf S, Karlsson S, Carlsson GE (2000) A dental laboratory study of the dimensions of metal frameworks for fixed partial dentures. Eur J Prosthodont Restor Dent 8:75–78