Three-Year Split-Mouth Randomized Clinical Comparison Between Crowns Fabricated in a Titanium-Zirconium and a Gold-Palladium Alloy

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Purpose: The aim of this study was to compare the clinical performance of metal-ceramic crowns made with an experimental alloy prepared by the Nordic Institute of Dental Materials, containing 15% zirconium and 85% titanium (Ti-15% Zr), and a high noble gold-palladium alloy (Mattikraft). ***Materials and Methods:*** Twenty patients who satisfied the inclusion criteria were selected sequentially from the departmental waiting list. Each patient received 2 crowns in the premolar or molar region. Which tooth was to receive a crown based on gold-palladium alloy or Ti-15% Zr alloy was randomly decided. A number of aspects indicating the clinical performance of the crowns were recorded at baseline and after 1, 2, and 3 years. ***Results:*** No statistically significant differences between the 2 types of crowns were demonstrated regarding overall technical evaluation, occurrence of plaque, bleeding on probing, or patient satisfaction. Periodontal pocket measurements around Ti-15% Zr crowns were significantly higher than those around gold alloy crowns. However, a similar difference also existed at baseline. Periodontal pocket measurements increased and patient satisfaction improved significantly over time. ***Conclusions:*** Within the limitations of this study, the results indicate that there is no difference in the clinical performance of crowns based on Ti-15% Zr or gold-palladium alloy. *Int J Prosthodont 2008;21:312–318.*

Restorations made with metal-ceramic alloys have mechanical properties exceeding those of the all-ceramic alternatives.[1] Despite recent improvements and widened indications, all prosthodontic problems cannot be solved by all-ceramic restorations. Metal-ceramic alloys are thus still indicated for cases where mechanical strength and high durability is an issue, such as for severely damaged teeth[2] and multiple-tooth fixed partial dentures (FPDs),[3] and will likely remain so in the foreseeable future.

In consequence, at least in Scandinavia, the vast majority of prosthodontic restorations are made in metal-ceramics. In industrial countries, such restorations are often made with a gold alloy, but some may be fabricated with commercially pure (CP) titanium. Clinically, both materials function satisfactorily in most cases. However, there are some disadvantages associated with each. On a population basis, positive epicutane test reactions to gold have been recorded in nearly 8% of subjects.[4] When the same test was performed in a population with subjectively or objectively reported adverse reactions toward dental biomaterials, 25% were found to have positive reactions to gold alloys.[5] Such test reactions alone offer insufficient evidence of hypersensitivity and have limited clinical significance. Nevertheless, they still indicate that some patients may have adverse reactions to gold alloys. In

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addition, the cost of gold alloys is considerable, particularly in larger reconstructions where the health gain is the greatest.

CP titanium has been used clinically in fixed prostheses for 20 years,[6,7] mainly because of its favorable biocompatibility, but also because it is inexpensive.[8] To some extent, failures may occur with fixed prostheses regardless of which material is used.[9] Nevertheless, anecdotally, mechanical failures appear to occur somewhat more frequently on crowns and FPDs made with CP titanium than on those made with conventional gold alloys,[8,10] but few scientific studies comparing the clinical behavior of the 2 materials have been performed.[11,12]

One possible reason for a higher failure rate of restorations made with CP titanium may be that the mechanical properties for this material are only equivalent to those of a type III gold alloy, whereas a conventional metal-ceramic gold alloy normally satisfies the requirements for type IV.[13] Moreover, the lower mechanical properties of CP titanium limits the clinical use of this material to reconstructions where mechanical requirements are not too great—usually single crowns or short-span FPDs. Also, some failures with CP titanium might be caused by the special ceramic veneer, which some authors report is more susceptible to fractures than the medium fused ceramics normally used in crowns made with conventional metal-ceramic alloys.[8] However, these observations may be outdated because the ceramic materials used for CP titanium restorations are subject to continual development and improvement.

A strong dental casting alloy that retains the biocompatibility of pure titanium is needed if the use of titanium is to extend beyond smaller restorations, particularly in cases where sufficient stiffness of the construction is otherwise difficult to obtain. Such an alloy, containing 15% zirconium and 85% titanium (Ti-15% Zr), has been prepared by the Nordic Institute of Dental Materials (NIOM). Zirconium is the element with chemical properties closest to titanium. Titanium-zirconium–based alloys containing a small amount of niobium have previously been investigated to evaluate their possible general use as biomedical materials,[14] but have so far not been used in dentistry.

The mechanical properties of Ti-15% Zr are improved significantly compared to CP titanium and more than satisfy the requirements of a type IV metal-ceramic alloy. Preclinical standard tests of this alloy according to International Organization for Standardization standards 6872 and 9693 were performed to assure that the mechanical and cytotoxicity criteria are satisfied (NIOM, personal communication, 2002). However, preclinical laboratory tests, although necessary, are not sufficient by themselves and must be validated by clinical studies before the material can be recommended for clinical use. Furthermore, the clinical behavior of a metal-ceramic crown is dependent not only on its core metal, but also on its ceramic veneer.

The aim of this study was to compare the clinical behavior of single metal-ceramic crowns made with this new Ti-15% Zr alloy with that of crowns made with a conventional gold-palladium alloy. The working hypothesis was that no such difference could be discerned.

Materials and Methods

Patient Sample

The patient sample consisted of 20 informed subjects who were willing to participate in this study. Patients were recruited sequentially from the departmental waiting list, and when this was exhausted, from new patients in need of crown treatment. The age range at baseline was 28 to 74 years. Only abutments with opposing dentition and tooth damage precluding satisfactory intradental filling restorations were included. None of the patients suffered from inadequately controlled general diseases or from untreated periodontitis, and all abutments had more than two-thirds remaining periodontal attachment. Further inclusion criteria were as follows:

1. Patients requiring at least 2 metal-ceramic crowns (premolars or molars, or one of either kind) localized in different quadrants of the mouth.
2. Teeth in such a condition that they could be restored with standard methods. This requirement entailed exclusion if the teeth were extensively damaged by caries or loss of tooth substance so that uncomplicated procedures could not be employed. Thus abutments requiring procedures such as crown lengthening, hemisection, extrapulpal pins, etc, were excluded, whereas nonvital teeth requiring post-retained cores were accepted.
3. Patients who resided within a 1-hour travel time from the dental school. This criterion was established to reduce dropouts from the follow-up recordings.

The project was approved by the Norwegian Committee for Medical Research Ethics, Health Region West.

Alloys

For each patient, 1 of the 2 metal-ceramic crowns was made with a type IV high noble gold-palladium alloy (Mattikraft M, Cookson Precious; composition: Au 51.6%, Pd 38.4%, In 8%, Ga 2%), and the other was made with the Ti-15% Zr alloy prepared by NIOM, in a split-mouth design. The mechanical properties of the

Table 1 Distribution of Crown Type in Relation to Arch and Abutment Teeth

Alloy/arch	Molar	Premolar	Total
Gold-palladium			
Maxilla	3	3	6
Mandible	14	–	14
Ti-15% Zr			
Maxilla	4	4	8
Mandible	12	–	12

latter alloy exceeded the requirements of a type IV alloy. The Ti-15% Zr alloy had the following physical characteristics: composition: Ti 84.8%, Zr 15.2%; melting point/range: 1540°C to 1640°C; hardness (HV 5/30): 257 (–35, +60); density: 471 ± 1, 0.2%; proof stress: 621 ± 4 MPa; ultimate tensile strength: 721 ± 25 MPa; elongation to fracture: 12.5% ± 4; thermal expansion coefficient: 25°C to 500°C (10^{-6}°C).

The gold-palladium alloy was chosen because it had approximately the same color as the Ti-15% Zr alloy. Which alloy was used for each crown was blinded for the operator (second author) as well as for the patient. The code was stored in a safe and broken only after the observation time of 3 years and after all recordings had been performed.

Randomization

The project leader (first author) randomized (by tossing a coin) which of the 2 teeth would receive a gold alloy or a Ti-15% Zr alloy metal-ceramic crown, and informed the dental laboratory producing the crown accordingly. The distribution of crown type in relation to arch and abutment teeth is shown in Table 1.

Clinical Procedures

All clinical procedures were performed by a specialist in prosthodontics (second author), while the technical procedures were performed by a commercial dental laboratory (Dentalstøp). The preparations were made with a high-speed contra-angle handpiece. Whenever possible, the crown margins were placed supragingivally. The exception was when caries, surface defects, or existing fillings necessitated subgingival coverage. There were 3 nonvital abutments, 2 of which were restored with cast gold alloy posts. The impressions were made with a polyvinyl siloxane impression material (Afinis putty soft and regular, Coltene). No crowns were placed unless they conformed to satisfactory standards in terms of marginal adaptation, emergence profile, color, occlusal form, and function. All crowns were cemented with phosphate cement (PhosphaCEM IC, Ivoclar Vivadent).

Technical Procedures

The metal cores of the Ti-15% Zr alloy crowns were invested with Titavest (J. Morita MFG) and cast in an argon atmosphere using a Neutrodyn Easyti centrifugal casting machine (Manfredi). The crowns were veneered with Triceram (Dentaurum). The metal cores of the gold alloy crowns were invested with GC Fujivest Super (GC). The veneer used for these crowns was Finesse (Dentsply De Trey).

Recording Times

Baseline recordings of the 2 types of crowns were made approximately 2 weeks after the crowns were cemented and again after 1, 2, and 3 years.

Clinical Parameters

The overall quality of the crowns was assessed on the basis of evaluation of the color, the occurrence of any defects (ceramic status), and possible wear of the ceramic veneer. A modified California Dental Assocation (CDA) grading[15] was used to assess these subcriteria. Each was classified into 4 possible categories: *(1)* Romeo, without defects; *(2)* Sierra, with minor defects; *(3)* Tango, with major defects; and *(4)* Victor, unacceptable.

The color of the crown was compared to that of its neighboring teeth. If the ceramic veneer of the crown was considered 1 step off in terms of chroma or hue on a Classical Vita shade guide, it was rated Sierra. If it differed by 2 steps but the deviation was not of such a nature that it indicated a remake of the crown, it was rated Tango. Similarly, in cases of an intact veneer with minor, superficial cracks, the ceramic status was rated Sierra. If the veneer exhibited deep cracks and/or loss of substance but the defect was such that it could be adjusted without unacceptable loss of function or esthetics, it was rated Tango. Finally, minor but discernable wear of the crown was rated Sierra, whereas significant wear of the crown that did not completely compromise its clinical function or esthetics was rated Tango.

The overall rating of a crown was equal to the lowest quality rating of its color, defects, or wear. Thus, if a crown was rated Romeo on 2 of the 3 criteria, but Tango on 1, the overall rating of the crown was Tango.

These evaluations were made on the basis of clinical photographic prints. For each crown and time of recording, 3 digital photographs were taken from the facial, occlusal, and lingual sides (the latter by means of a mirror). A close-up lens was used so that each frame depicted only the experimental tooth and its neighboring teeth on either side. The prints were enlarged to 20 × 15 cm. Attempts were made to standardize the exposures. The photographs were all taken with the same digital camera and ring flash throughout the study.

All evaluations of the technical quality of the crowns were performed after the study period on prints that were randomly ordered. Two calibrated examiners (the first and second authors) independently rated the recordings. Agreement between the examiners was found in 79%, 95%, and 99% of observations in assessment of color, ceramic status, and wear, respectively. In cases where the ratings differed, the examiners reexamined the recording together and arrived at a consensus.

Biologic Parameters

Plaque was recorded (third author) as the percentage of sites on the tooth where plaque was found. The percentage of the sites with bleeding on probing (BOP)[16] and the probing depth of the periodontal pockets were also recorded. Caries and periodontal disease were controlled for at each of the recording times after baseline.

Patient Satisfaction

Patient satisfaction was recorded according to the patient's response to the question: To what extent are you satisfied with your crown? The responses were categorized into the preselected categories "Very satisfied," "Satisfied," "Not quite satisfied," and "Dissatisfied."[17] Both the recordings of biologic variables and patient satisfaction were made by a registered dental hygienist (third author).

Statistical Analysis

For all variables except probing depth of the periodontal pockets, the Friedman test was used to test for possible changes during the follow-up period for each crown type, and the Wilcoxon signed rank test was used to test for possible differences between the crown types at each time of recording. Probing depth of the periodontal pockets, which is a continuous variable, was analyzed by means of repeated-measures analysis of variance with 2 factors (time and crown type). A paired *t* test was applied at each recording time.

A 5% significance level was chosen for the analyses. However, when comparing the crown types, each variable was subject to 4 tests, 1 for each of the 4 measurement times. The significance level used for each of these tests was therefore adjusted by dividing with the number of comparisons according to the method of Bonferroni.

Of the 1,280 recordings of a complete data matrix (64 variables × 20 subjects), 48 were missing. The missing data were related to 2 patients. One patient failed to appear at the 2-year control but attended the 3-year control. Another patient did not appear after the 1-year control. For the purpose of the analyses, the missing data were replaced with the median value of the variable in question.

The analyses were performed using SPSS 13.0 for Windows (SPSS).

Results

Complications

Pulpitis developed in 1 of the abutments with a Ti-15% Zr crown. The tooth in question was later extracted, since the endodontic intervention was unsuccessful. Furthermore, 1 Ti-15% Zr molar crown had to be remade prior to cementation because the ceramic veneer fractured during try-in. Apart from these cases, no adverse reactions or technical complications necessitating intervention were recorded.

Evaluations of Crowns

The ranking of overall evaluation of the crowns did not change significantly during the follow-up period for either of the crown types (Fig 1, Table 2), nor could any significant differences between the crowns be discerned in this respect at any of the recording times (Table 3). Similarly, none of the rankings of the subcriteria color, ceramic status, and wear of the ceramic veneer changed significantly over time (Table 2), and no significant differences were found between the crown types for any of the same variables at any recording time (Table 3).

Plaque Recordings

The proportion of sites where plaque was recorded did not change significantly for either of the crown types during the follow-up period (Fig 2, Table 2). There were no significant differences between the crown types regarding plaque for any of the recording times (Table 3).

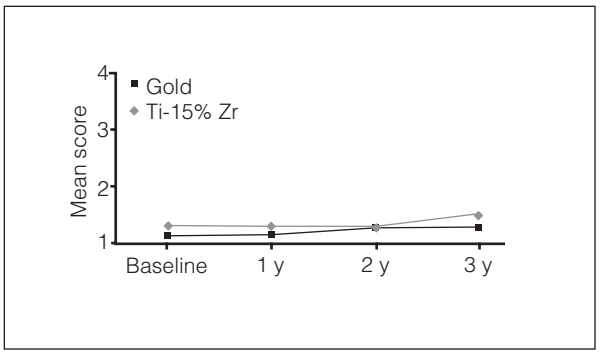

Fig 1 Changes occurring over time in overall evaluation of metal-ceramic crowns based on Ti-15% Zr or gold-palladium alloy. 1 = without defects; 2 = with minor defects; 3 = with major defects; 4 = unacceptable.

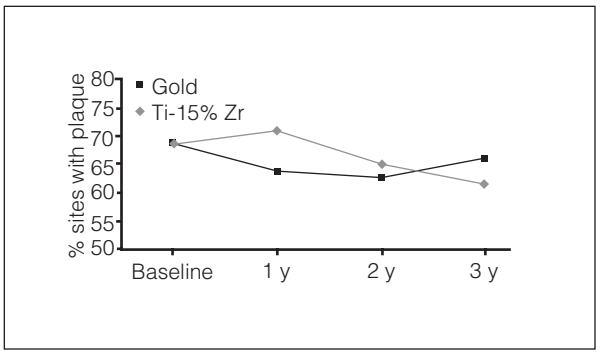

Fig 2 Changes occurring over time in plaque recordings of metal-ceramic crowns based on Ti-15% Zr or gold-palladium alloy.

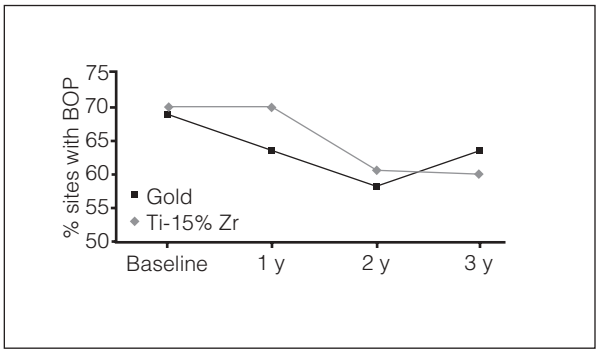

Fig 3 Changes occurring over time in bleeding on probing (BOP) with metal-ceramic crowns based on Ti-15% Zr or gold-palladium alloy.

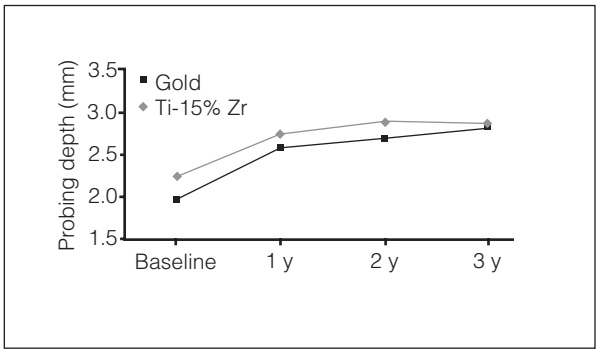

Fig 4 Changes occurring over time in probing depth of periodontal pockets with metal-ceramic crowns based on Ti-15% Zr or gold-palladium alloy.

Table 2 *P* Values for Changes Over Time ($\alpha = .05$)

	Ti-15% Zr	Gold-palladium
Overall evaluation	.415	.861
Color	.475	.724
Ceramic evaluation	.066	.194
Wear	1.000	1.000
Plaque	.441	.208
Bleeding on probing	.244	.451
Patient satisfaction	.347	.035*

*Significant.

Table 3 *P* Values for Comparisons Between Crown Types ($\alpha = .0125$)

	Baseline	1 y	2 y	3 y
Overall evaluation	.102	.257	1.000	.129
Color	.112	.257	1.000	.257
Ceramic evaluation	–	1.000	1.000	.317
Wear	–	1.000	1.000	1.000
Plaque	1.000	.014	.598	.344
Bleeding on probing	.851	.096	.305	.577
Patient satisfaction	1.000	.655	.317	.317

Bleeding on Probing

The proportion of sites with BOP did not change significantly for any of the crown types during the follow-up period (Fig 3, Table 2), nor could any significant differences be discerned between the crowns in this respect at any of the recording times (Table 3).

Probing Depth

There was no significant interaction between time and crown type ($P = .481$). However, time had a main effect that was significant beyond the 1% level ($P < .001$), indicating an increase in periodontal pocket measurement during the follow-up period (Fig 4). The crown type factor also had a main effect ($P = .012$), with a smaller mean periodontal pocket measurement for gold alloy crowns. At baseline, mean pocket depth was 1.98 mm for abutments with gold alloy crowns and 2.24 mm for abutments with Ti-15% Zr crowns. This difference was statistically significant ($P = .037$).

Patient Satisfaction

Patient satisfaction with the gold alloy crowns increased significantly during the follow-up period (Fig 5, Table 2). A similar tendency appeared to occur with the Ti-15% Zr crowns. However, this did not reach significance (Table 2). No significant difference between the crowns could be discerned at any recording time (Table 3).

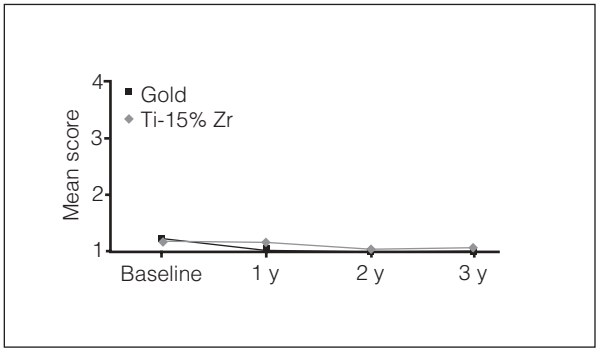

Fig 5 Changes occurring over time in patient satisfaction with metal-ceramic crowns based on Ti-15% Zr or gold-palladium alloy. 1 = very satisfied; 2 = satisfied; 3 = not quite satisfied; and 4 = dissatisfied.

Discussion

The present rating of overall evaluation of the crowns resembles the CDA system but differs notably in one respect: All assessments were carried out in a random order and simultaneously. Thus, there were no problems with changing levels of observation inherent in follow-up studies based on the CDA system.[18] Furthermore, probably because of the enlargement of the photographic prints and the polarizing effect of the ring flash, the few defects that were detected in the ceramic veneer could not be observed clinically. Whether the observed cracks would lead to eventual chipping or more substantial loss of ceramic substance remains to be seen, but they obviously represent a weakening of the material.

Despite this exacting method of evaluation, it is noteworthy that color, ceramic status, and wear did not deteriorate for either crown type over the course of the study period, nor could differences between them be discerned. This finding seems to be in contrast to previous reports, in which noble metal-ceramic crowns were compared with those based on CP titanium.[11,12] In these reports, the color stability and surface of the latter crowns were found to deteriorate significantly, both over time and compared to the other crown type.[12] Similar results have also been reported in several other follow-up studies of CP titanium crowns.[10,19,20] The strength of this change is illustrated by the fact that the deterioration was clearly apparent after only about 2 years of observation time, in small samples, such as in the present study, of no more than between 18 and 25 patients.[11,19,20]

Although the apparent deterioration of color over time in such crowns might be a consequence of possible changes in the observation level with the CDA system,[18] it does not explain the superiority of the conventional crown when the 2 crown types were compared, because the observations were performed at the same time.[11,12]

Even so, the present results merely offer an indication—but not sufficient evidence—that a metal-ceramic crown based on a Ti-15% Zr alloy is more favorable in terms of color, ceramic status, and wear than one based on CP titanium. The present observation time is only 3 years, which is considerably less than the expected lifetime of a metal-ceramic crown.[9] Furthermore, the color stability and surface quality of crowns depend on both the proficiency of the dental laboratory producing them and the type of ceramic. These undergo continual improvements, possibly making comparisons with previous reports invalid. Equally, the fact that the overall evaluations of the 2 crown types do not differ significantly does not prove unequivocally that no such difference might exist, only that none have been demonstrated in the present study.

Both alloys presently employed are among the most biocompatible dental materials used in dentistry. Accordingly, no difference between the crown types was expected regarding the biologic parameters. No differences were found for plaque or BOP. However, the overall mean probing depth of the periodontal pockets of the gold alloy crowns was significantly smaller than that of the Ti-15% Zr crowns ($P = .012$), even though the difference was too small to be of clinical relevance (Fig 4). In this context, it should be noted that the difference between the mean probing depths of the 2 crown types was manifest even at baseline, which may explain the apparent difference.

A probable explanation for why the probing measurements increased over time is that these patients were not under systematic periodontal maintenance. For that reason, probing measurements might be expected to increase somewhat from baseline, when there was no periodontal pathology, to the end of the 3-year follow-up period.

Patient satisfaction remained high throughout the follow-up period and even improved with time. The fact that this tendency was statistically significant only with the gold alloy crowns (Table 2) should not be assigned much importance, since both crown types showed

similar patterns (Fig 5), and no significant differences between them were found at any time of measurement (Table 3).

From a technical point of view, Ti-15% Zr alloy should be handled in the same manner as CP titanium, which is not particularly high-tech, although it entails casting under cover of argon gas in a casting machine specially designed for titanium casts. This requires, as with all new techniques, some habituation. Ceramic veneering, on the other hand, is basically handled much the same way as more conventional crown materials.

Conclusions

The major finding is that no clinically relevant differences in biologic or technical aspects could be discerned between crowns made with Ti-15% Zr or a conventional gold-palladium alloy. Within the limitations of this study, this indicates that the Ti-15% Zr alloy could represent a real alternative in the clinic. It is particularly suitable for patients with documented or suspected adverse reactions to other alloys. Furthermore, it is inexpensive compared with the noble metal alternatives. To date, the material has been tested only in single crowns. However, the mechanical properties of Ti-15% Zr are such that the alloy is most likely also suitable for extensive fixed partial dentures, although this must be confirmed by future studies.

Acknowledgments

This project was supported in part by the University of Bergen and by the Nordic Institute of Dental Materials. The valuable advice of John E. Tibballs, Stig Karlsson, and Nils Roar Gjerdet in the preparation of this paper is gratefully acknowledged.

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