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Effect of Porcelain-Firing Cycles and Surface Finishing on the Marginal Discrepancy of Titanium Copings

Halemane C. Naveen, MDS,[1] Lekha K. Pillai, MDS,[3] Amit Porwal, MDS,[3] Ramesh K. Nadiger, MDS,[2] & Satyabodh S. Guttal, MDS, MFPT[2]

[1] Department of Prosthodontics, Vasant Dada Patil Dental College and Hospital, Sangli, Maharashtra, India
[2] Department of Prosthodontics, SDM College of Dental Sciences & Hospital, Dharwad, Karnataka, India
[3] Department of Prosthodontics, Pacific Dental College & Hospital, Udaipur, Rajasthan, India

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Correspondence
Satyabodh Guttal, SDM College of Dental Sciences & Hospital – Prosthodontics, Dhavalnagar Sattur, Dharwad, Karnataka 580009, India. E-mail: drsatyabodh@yahoo.co.in

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Abstract

Purpose: The aim of the study was to evaluate the effect of simulated porcelain firing cycles and surface finishing on the marginal fit of commercially pure titanium (Cp Ti) copings.

Materials and Methods: A machined stainless steel die system with standard 0.5-mm copings was fabricated. Wax patterns were prepared by pouring the molten wax on a two-part stainless steel die. Thirty specimens were cast in Cp Ti. These were divided into three groups with ten specimens in each group. Group 1 was treated with conventional cold working and later oxidized. Group 2 specimens were oxidized initially and then cold worked. Group 3 was heat treated in its original investment and later treated as in group 1. All specimens were later subjected to sequential simulated porcelain firing cycles, that is, oxidation, bonder, opaque, body, and glaze firing. Following the completion of each firing cycle, marginal discrepancy was measured in μm using a traveling microscope. The obtained data were subjected to one-way analysis of variance (ANOVA) and Student's t-test. The statistical level of significance was set at 1%.

Results: The results showed that the mean and SD values (in μm) were 55 ± 2.6, 43 ± 3.0, and 68 ± 4.0 after oxidation for groups 1, 2, and 3, respectively. Mean and SD values (in μm) after glaze firing were 76 ± 3.9, 64 ± 4.1, and 89 ± 4.3 for groups 1, 2, and 3, respectively. The mean marginal opening was largest for group 3 specimens. One-way ANOVA showed the difference within the three groups was highly significant after oxidation (F-value 149.37 at p-value 0.0000) and glaze firing (F-value 82.43 at p-value 0.0000).

Conclusions: (1) The Student's t-test values demonstrated that increased marginal openings of the specimens resulted after the sequential simulated porcelain firing cycles. (2) Marginal discrepancy values improved when the specimens were thermocycled prior to cold working.

Porcelain-fused-to-metal (PFM) restorations are commonly used in fixed prosthodontics because of their casting accuracies, the high-strength properties of the metal, and the cosmetic appearance of porcelain. Metals used for this purpose should be biocompatible, as crown margins are often subgingival, where biologic considerations are of great concern. In this respect, titanium may prove to be an attractive alternative to popular base metal alloys containing known allergens.

The introduction of Ti casting by the lost-wax technique has made possible the use of a material with high biologic compatibility, high modulus of elasticity, low density, high mechanical strength, and high resistance to corrosion, at a cost that is not as high as that of traditional gold alloys.[1] Thus, a growing trend involves the use of Ti as an economical and biocompatible replacement for existing alloys, despite the sophisticated technology needed for accurate casting.[2]

Marginal fit of a metal ceramic crown has been a critical prerequisite for a successful artificial crown.[3,4] The crevice, or gap, in the crown margin can be viewed as physical roughness and as such is considered adverse to optimal gingival and periodontal health in the same way that calculus or a poorly finished amalgam margin would be judged.[5-7] It has been widely observed that the "as-cast" fit of a metal ceramic restoration deteriorates during the high temperature firing cycles used for porcelain veneer application and that the marginal discrepancy of PFM crowns increases after porcelain firing.[8-11]

On the basis of theoretical calculations of clinically tolerable marginal openings, Brockhurst et al[12] proposed a value of 50 μm as clinically acceptable; however, there are controversial opinions in the literature regarding how large a gap in marginal openings is considered clinically acceptable. Leong et al[13] considered a marginal discrepancy of 120 μm to be the maximum limit of clinically tolerable margin opening. Christensen[14] showed that marginal discrepancies along the gingival margin varied from 34 to 119 μm and were considered as clinically acceptable by ten experienced restorative dentists.

Various factors, including alloy type, creep at high temperatures, release of induced stresses from casting and cold working, and different coefficients of thermal expansion of alloy and porcelain, have been suggested as the reason for metal distortion during porcelain firing.[15] Fonseca et al[16] evaluated the stress relieving and simulated porcelain firing cycles' influence on marginal fit of Cp Ti and titanium-aluminium-vanadium alloy copings. They found that the porcelain-firing protocol for copings increased the marginal misfit significantly. The stress-relieving treatment was not effective for improving the marginal fit in Ti copings.

The marginal fit of Ti copings depends on a multitude of factors. Numerous studies have studied the effect of various factors on the accuracy of fit. But the literature is sparse on the effect of porcelain-firing cycle and surface finishing on the marginal accuracy of Ti ceramic restorations. Therefore, this study evaluated the effect of simulated porcelain firing cycles and surface finishing on the marginal discrepancy of Cp Ti copings with a hypothesis that, even though there is considerable difference in the melting temperature of the Ti and the porcelain-firing temperature that should prevent thermally activated creep, there is an increase in the marginal distortion of Ti copings after porcelain-firing cycles and surface finishing.

Materials and methods

A machined stainless steel die system (die and counterpart) to create a 0.5-mm standardized coping was fabricated. The master die had two parts (base, sub-base). The first part of the die was the base, which was square, having length and width of 5.0 cm and a height of about 2.0 cm. Two vertical projections on the base were made with a 5-mm width and 1.5-cm height and were placed diagonally, to guide the counterpart. The sub-base was kept circular with a diameter of 1.5 cm and height of 1.5 mm (Fig 1). A crown preparation was simulated on the sub-base with 6° axial taper. The height of the crown and its base was 8 mm, its occlusal diameter was 6 mm, and the finish line was heavy chamfer (1-mm width) (Fig 2). A counterpart that fit the base accurately on the sub-base of the die was made. On the base of the former, two holes were made diagonally to receive vertical projections of the die. A Y-shaped groove was designed on the occlusal surface of the die to help in reseating of the copings. A uniform layer of die spacer was applied 1 mm short of the margin.

The wax patterns were fabricated directly on the master die to avoid errors due to impression making and die stone expansion on the die. Thirty wax patterns were fabricated. The die lube

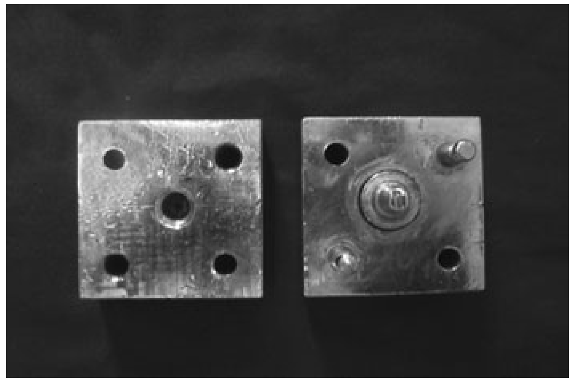

Figure 1 Stainless steel metal die (die and counterpart).

(Dentaurum, Ispringen, Germany) was applied on the die, to avoid the wax patterns sticking to the die. This was repeated each time the wax pattern was fabricated. The hard wax (Schuler inlay wax blue; Schuler Dental, GmbH, Ulm, Germany) was then melted into the counterpart with an electric wax knife (Dentaurum) through the 2-mm hole, which was present at the top of the counterpart of the die. Remarginations of the patterns were done with the soft wax.

The patterns were sprayed with a surface-tension-reducing agent (True Blue; Renfert, Hilzingen, Germany) and allowed to air dry. A layer of moistened ceramic-based ring liner (Kera-Vlies; Dentaurum) was placed lining the investing ring and invested using Ti investment material (Titec investment; Orotig, Verona, Italy) according to manufacturer's instructions. Following the setting of the investment, burnout procedure was started at room temperature, with a gradual increase in temperature at a rate of 5°C/min, holding the temperature at 150°C for 30 minutes. Subsequently, the temperature was raised to 300°C for 60 minutes. Finally the temperature was raised to 950°C and held for 30 minutes. The mold was allowed to cool until a final casting temperature of 450°C was reached. The casting procedure was carried out in a semiautomatic pressure-type casting machine with one chamber (Titec- F_{210}M, Orotig) under 4-lbs argon pressure. Ten minutes later the casting ring was quenched for group 1 and 2 specimens.

The marginal discrepancy of the "as-cast" specimens was measured at four sites, representing the mid-buccal, mid-lingual, mid-distal, and mid-mesial areas of the metal die, which were equidistant to each other. At each site, the maximum marginal discrepancy was measured three times, and an average of the three discrepancies was recorded to reduce human error in recording the values. Later the mean of the three recordings for four sites was taken. The final mean for an individual crown was drawn from the above available mean of four sites. The procedure was repeated for all specimens.

The casting-induced distortions of a crown are bound to be present despite the casting being done according to standard techniques. Hence, to eliminate the casting-induced distortions, the "as-cast" measurements of the specimens were used as baseline values. When the specimens were subjected to simulated porcelain firing cycles, the marginal discrepancy resulting from the baseline value was regarded as the actual distortion of the

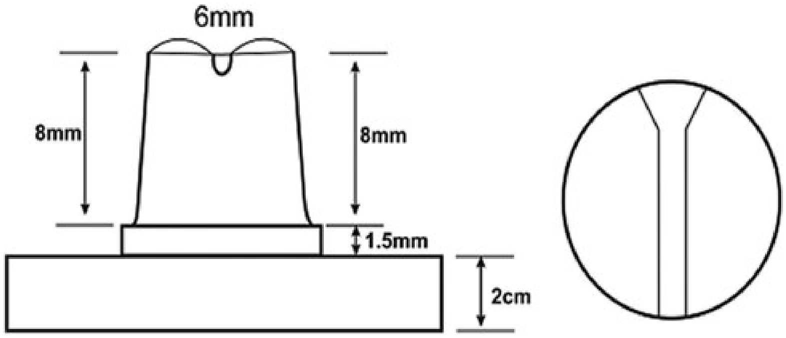

Figure 2 Schematic representation of metal die. Circle shows the "Y" index line.

specimen. So, irrespective of the "as-cast" values, the amount of change within a group and between groups is of importance.

The specimens were divided into three groups with ten specimens each as follows:

Group 1: specimens were finished sequentially with Ti finishing kit (Dentaurum). The specimens were then sandblasted with 50-μm aluminum oxide and later simulated porcelain firing was carried out.

Group 2: specimens were retrieved and oxidized thereafter with no manipulation of the casting surface; however, small nodules were removed with a round tungsten carbide bur (Dentaurum GmbH, Germany), and the copings with large nodules were discarded. Later, the castings were surface finished as in group 1 and again oxidized during simulated porcelain firing.

Group 3: specimens were not retrieved from the casting ring, and the ring was allowed to cool after casting. The casting in its original investment was again heated to 800°C at a rate of 15°C/min and sustained for 20 minutes. This helped to determine whether the distortion could be reduced by restraining the casting during the initial thermocycling (oxidation) process. The castings were then allowed to cool to room temperature and were divested and treated as in group 1.

Each of the specimens, on completion of the firing cycle, was seated on the die according to the "Y"-shaped index line, using a hydro press under a constant load of 500 grams on the occlusal surface for 5 minutes. The marginal discrepancy was measured in μm at four predetermined points using a traveling microscope with 50× magnification similar to the methodology followed for "as-cast" measurements. The specimen measurements of all groups were recorded following each simulated porcelain firing cycle (i.e., the oxidation, bonder, opaque, body, and glaze firing). The changes in marginal discrepancy noted from the "as-cast" values were subjected to statistical analysis using analysis of variance (ANOVA) and Student's *t*-test. The level of significance was set at 1%.

Results

The mean and standard deviation values of "as-cast" specimens are displayed in Table 1. Mean and standard deviation values of total marginal discrepancy (in μm) of all experimental groups after sequential simulated porcelain firing cycles are shown in Table 2.

After oxidation, the smallest marginal gap was exhibited by group 2 and the largest gap by group 3. These recorded values were well within the clinically accepted marginal fit value of 120 μm. The specimens conventionally handled by cold working and then oxidized had significantly more distortion than the specimens oxidized before cold working.

Table 3 displays the statistical comparison (one-way ANOVA) of mean values of marginal discrepancy (in μm) of the test specimens of experimental groups 1, 2, and 3 after simulated porcelain firing cycles. The difference within the three groups was highly significant after oxidation (F-value 149.37 at p-value 0.0000) and glaze firing (F-value 82.43 at p-value 0.0000).

Table 4 depicts the results of Student's *t*-test between the groups. The values for oxidation and glaze firing suggest that there is an increase in the marginal opening of the specimens with sequential simulated porcelain firing cycles, indicating that subsequent firing cycles resulted in changes of increasing magnitude.

Table 1 Mean and standard deviation values of marginal discrepancy (μm) of all experimental groups before sequential simulated porcelain firing cycles (n = 10)

Initial	Mean	SD
Group 1	50	2.5
Group 2	40	2.8
Group3	60	4.6

Table 2 Mean and standard deviation values of the total marginal discrepancy (μm) of all experimental groups after sequential simulated porcelain firing cycles

Type of cycle	Oxidation	Bonder	Opaque	Body	Glaze
Group 1	55 (2.6)	61 (3.2)	66 (3.6)	71 (3.9)	76 (3.9)
Group 2	43 (3.0)	48 (3.7)	52 (3.5)	58 (3.7)	64 (4.1)
Group 3	68 (4.0)	73 (3.9)	77 (4.3)	85 (3.9)	89 (5.3)

Table 3 Statistical comparison (one-way ANOVA) of mean values of marginal discrepancy of test specimens of experimental groups 1, 2, and 3 after sequential simulated porcelain firing cycles

Oxidation		Bonder		Opaque		Body		Glaze	
F	*p*-Value	*F*	*p*-Value	*F*	*p*-Value	*F*	*p*-Value	*F*	*p*-Value
149.37	0.0000	120.36	0.0000	109.90	0.0000	120.90	0.0000	82.43	0.0000

Discussion

The marginal fit of a restoration to the prepared tooth surface is of paramount importance in the success of any restoration. Any deficiencies in the fit of the crown can result in damage to the tooth and its periodontal tissues.[17,18] Ideally, the cemented cast restoration margin should precisely meet the finish line of prepared teeth with nondetectable junctions. In reality, clinical perfection is difficult to achieve and difficult to verify. The reported literature on the marginal fit values of Ti were obtained without the effects of the porcelain-firing cycle, which is related to significant distortions in metallic restorations.[19,20] Although the deformation occurs during the porcelain-firing cycle, considerable controversy continues to exist with regard to the real cause of this deformation.[21]

In this study, conventionally cold-worked and oxidized group 1 specimens showed a mean marginal opening of 55 μm. Significant reductions in the marginal opening of group 2 specimens were seen, with 43 μm, when the oxidation was completed prior to surface finishing. Group 3 had more marginal distortion after oxidation (68 μm) compared to groups 1 and 2. The maximum value of the total marginal discrepancy of the specimens among all the groups after completion of the simulated porcelain firing cycles was 89 μm. The total discrepancy was a sum measure of "as-cast" values and the distortion resulting after completion of the simulated porcelain firing cycles. These values of marginal distortion are within the range of a clinically acceptable marginal gap (50-120 μm) as suggested in the literature.[12-14] The distortion of metal increased as porcelain firing progressed from oxidation to porcelain glaze. This finding was in agreement with the conclusions of other studies observing that most changes occur during the initial oxidation firing before porcelain application.[19,21-23]

Fonseca et al[16] conducted a study on the stress relieving and porcelain-firing influence on marginal fit of Cp Ti, Ti alloy, and Pd-Ag alloy. They demonstrated that the "as-cast" Cp Ti and Ti-6Al-4V alloy copings not subjected to the porcelain-firing cycles had acceptable marginal fit values to bovine teeth, with 86 and 84 μm, respectively. The marginal fit values reported for machined and cast Ti restorations vary from 54 to 60 μm.[13] The values found in the present study are in a similar range for all the three groups. Hence, the hypothesis is accepted because the marginal discrepancy values of all the groups are within clinically acceptable limits.

The distortion of copings in group 1 specimens may be due to the release of the residual stresses from the casting and cold working (surface finishing).[24] The reduction of the marginal gap in group 2 specimens may be attributed to the stresses induced after cold working being eliminated, as thermocycling was completed prior to cold working. This finding is in accordance with Campbell et al,[25] who suggested that a fourfold improvement in marginal adaptation resulted when the initial thermocycling and cold working of the casting were completed as separate steps. The surface finishing may impart added stresses to an alloy surface. Surface finishing results in the storage of strain energy in the surface of an alloy.[26] Subsequent thermocycling allows the release of this stored energy, which may result in distortion.[26]

Other investigators[20,25] observed that a significant reduction in distortion was achieved in metal copings submitted to heat treatment when embedded or maintained in the original investment; however, in the present study, the stress-relieving treatment performed for group 3 specimens was not able to reduce the distortion. This finding is similar to the finding of Fonseca et al[16] who observed that the stress-relieving treatment in the investment was not effective for improving the marginal fit in Ti copings. It may be speculated that rather than restraining the distortion of the alloy, the investment may have been responsible for the pattern of distortion in group 3. The distortion may also have been influenced by the compressive strength of the investment—the higher the strength of the investment, the greater the distortion at a given temperature.[27]

Table 4 Statistical comparison (Student's *t*-test) of marginal discrepancy observed for the test specimens of all groups after sequential simulated porcelain firing cycles (n = 10)

	Oxidation		Bonder		Opaque		Body		Glaze	
Groups	*t*	*p*-Value	*t*	*p*-Value	*t*	*p*-Value	*t*	*p*-Value	*t*	*p*-Value
1*2	10.20	0.0000	8.73	0.0000	9.00	0.0000	7.39	0.0000	6.93	0.0000
1*3	−8.23	0.0000	−7.30	0.0000	−6.20	0.0000	−8.08	0.0000	−6.36	0.0000
2*3	−15.86	0.0000	−14.63	0.0000	−14.36	0.0000	−15.67	0.0000	−12.17	0.0000

Thus far, studies on the marginal gap of Ti copings are measured after a simulated porcelain firing without the application of actual porcelain. Some authors[28,29] have shown that porcelain application had no effect on the measured distortion of the castings. Hence, it may be an area for future research to measure the marginal gap of Ti copings with actual porcelain application.

Conclusion

The effect of simulated porcelain firing cycles and surface finishing on the marginal discrepancy of commercially pure titanium (Cp Ti) copings was examined. The test specimens were subjected to sequential simulated porcelain firing cycles. The marginal discrepancy was measured in μm using a traveling microscope. The following conclusions were drawn from this study:

1. All metal frameworks distorted significantly from casting and after completion of simulated porcelain firing cycles with mean values of 76, 64, and 89 μm for groups 1, 2, and 3, respectively.
2. Marginal discrepancy was seen in all test groups immediately after oxidation firing with mean values of 55, 43, and 68 μm for groups 1, 2, and 3, respectively.
3. Marginal discrepancy values seemed to improve when the specimens were thermocycled prior to cold working
4. Stress-relieving heat treatment of the castings by maintaining the copings in the investment was not effective for improving the marginal fit in Ti copings.

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