Original Research

Mechanical Retention of Low-fusing Porcelain to Cast Titanium

Watanabe Ikuya, DDS, PhD, Atsuta Mitsuru*, DDS, PhD and Liu Jie**, DDS, PhD

Department of Biomaterials Science, Baylor College of Dentistry,

Texas A&M University System Health Science Center

**Department of Developmental and Reconstructive Medicine,*

Nagasaki University Graduate School of Biomedical Sciences

***Department of Histology and Cell Biology,*

Nagasaki University Graduate School of Biomedical Sciences

Clinical significance

This study examined the bond strength of porcelain to cast titanium surfaces modified by incorporating several sizes of retention beads into the framework patterns. The results suggested that the use of 150 μm or 200 μm -sized retention beads is appropriate for making clinically reliable titanium ceramic prostheses.

ABSTRACT

Purpose : This study used a three-point bending test to measure the bond strength of porcelain to cast titanium and examined the effect on bond strength of one means of mechanical retention.

Materials and Methods : Retention beads (150, 200, 600 μm) were applied on the central portion of the pattern surface. After molds prepared from the patterns were cast with commercially pure (CP) titanium, the cast surfaces were air-abraded with 50 μm alumina powder. To investigate the effect of air-particle abrasion, cast titanium plates without retention beads were prepared and air-abraded with different alumina particle sizes (50, 125, 250 μm). Cast gold alloy plates air-abraded with 50 μm alumina were also prepared as references with and without 200 μm retention beads. Porcelain was applied on an area in the center of each cast metal plate. The three-point bending test was conducted at a crosshead speed of 1.5 mm/min. Fracture forces (F_f : N) and deflections (D_f : mm) at fracture were recorded. The data (n=5) were statistically analyzed.

Results : There were no statistical differences ($p>0.05$) in the F_f and D_f values of specimens air-abraded using different alumina particle sizes. Increasing the size of the retention beads significantly increased the F_f and D_f values of the specimens. The calculated bond strengths of porcelain to cast titanium were significantly ($p<0.05$) lower than to gold alloy.

Conclusion : The application of retention beads significantly improved the three-point bending strength of porcelain to cast titanium.

Key words

titanium, porcelain, three-point bending strength, retention bead, air-abrasion

Corresponding author : Watanabe Ikuya

3302 Gaston Ave., Dallas, TX 75246, USA

Tel : +1-214-828-8356, Fax : +1-214-828-8458

E-mail : iwatanabe@tamcd.edu

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INTRODUCTION

Metal-ceramic restorations have been widely used in prosthodontics. However, the porcelain/metal interface is an area that is prone to mechanical failure. Clinically, such failures often begin as porcelain fractures. The success of a porcelain-fused-to-metal restoration acutely depends on the success of the bonding between the porcelain and the metal substructure^{1,2}. Titanium offers many advantages as a dental prosthetic material because of its good corrosion resistance, excellent biocompatibility and low weight³⁻⁵. However, since titanium has a high melting temperature and high chemical reactivity at high temperatures, it is difficult to obtain sufficient bonding of porcelain to cast titanium. Cast titanium-ceramic prostheses fracture more frequently compared to other metal-ceramic restorations made from gold alloys or base metal alloys. Titanium casting can be carried out by special machines under argon gas atmosphere to avoid oxidation of the metal^{6,7}, which is generally believed to proceed through an inward lattice diffusion of oxygen with a new oxide forming at the oxide-metal interface. At 882°C, titanium undergoes a phase change from α Ti to β Ti⁸⁻¹⁰. Titanium requires low-fusing porcelains (under 800°C) because it produces increasingly thick oxidation layers at temperatures above 800°C. The use of low-fusing porcelain on cast titanium has increased during the past decade⁸⁻¹⁵.

Various pattern designs can be used to mechanically enhance the attachment of the resin to the metal frameworks in resin-bonded prostheses. These designs incorporate features such as struts, loops, mesh, and beads into the metal frameworks. Retention beads are the smallest design variation that allows for thickening of the resin layers. Air-particle abrasion is also a

method that contributes to the mechanical enhancement of bond strength between resin and cast metal¹⁶. The mechanical retention principles for resin-metal restoration might be applied to enhance the bonding between cast titanium and low-fusing porcelain for metal-ceramic prostheses. Therefore, this study examined the bond strength of porcelain to cast titanium surfaces modified by air-abrasion with various alumina particle sizes and by incorporating several sizes of retention beads into the framework patterns.

MATERIALS AND METHODS

The metals used in this study were commercially pure titanium (CP Ti, Grade II, Selec, Osaka, Japan) and a high gold-containing alloy (Degudent Universal®, Degussa AG, Hanau, Germany) for metal-ceramic restorations. The porcelains employed were a low-fusing porcelain (Super Porcelain Titan®, Noritake, Nagoya, Japan) for titanium and a conventional porcelain (Vita Omega 900®, Vita Zahnfabrik, Bad Sackingen, Germany) for gold alloy.

Plastic plate patterns $0.5 (d_M) \times 5.0 (W) \times 25.0 (I_M) \text{ mm}^3$ were prepared for the casting of CP Ti (Fig. 1). The retention beads used (average diameter) were 150 μm (Retention Beads 150®, Shofu, Kyoto, Japan), 200 μm (Retention Beads II®, GC, Tokyo, Japan) and 600 μm (Shofu Retention Beads Powder 10 g, Shofu). The beads were applied to a $5.0 (W) \times 8.0 (I_P) \text{ mm}^2$ area of the central portion of the $5.0 (W) \times 25.0 (I_M) \text{ mm}^2$ pattern surface. A thin layer of the adhesive for each brand of retention beads was applied to this area. The beads were then sprinkled evenly on the adhesive to make a thick layer. The excess beads were then blown away, leaving a uniform layer of beads on the surface. These patterns were invested in mold rings with a magnesia-based investment material (Selevest CB®, Selec). The

Fig. 1 Diagram of the three-point flexural test (Dimensions of the test configuration are : $I_M = 25$ mm, $I_P = 8$ mm, $I = 20$ mm, $d_M = 0.5$ mm, $d_P = 1$ mm, $W = 5$ mm)

invested molds were allowed to bench-set at room temperature for 60 minutes and were then placed in a burn-out furnace. The burn-out schedule before casting followed manufacturer's instructions. The CP Ti ingots were cast into the molds using a centrifugal casting machine (Ticast Super R®, Selec). After casting, the molds were bench-cooled to room temperature. Each cast specimen was then retrieved from the investments. All of the cast surfaces modified with retention beads were air-abraded with 50 μ m alumina powder.

To investigate the effect of air-particle abrasion, cast titanium plates without retention beads were prepared and air-abraded with 50 μ m (Hi Aluminas®, Shofu), 125 μ m (Powder WA 100®, Panasonic Heraeus Dental, Japan), and 250 μ m (Powder W®, Panasonic Heraeus Dental) alumina powders. Air-particle abrasion was applied perpendicularly to the surface of the cast Ti surface from a distance of 20 mm at pressure of 4 bars for 20 seconds. All the cast plates were examined radiographically with a dental unit (Coronis 90®, Asahi Roentgen Inc., Ltd., Kyoto, Japan) to determine whether there was any noticeable internal porosity. The 70 kVp x-ray source (current : 10 mA, exposure : 0.8 sec) was positioned perpendicular to the film at a

distance of 50 cm from the specimen. If there was any porosity in the cast plate, that specimen was excluded. The specimens were cleaned ultrasonically in acetone for 10 minutes. Cast gold alloy plates air-abraded with 50 μ m alumina were also prepared as references with and without the 200 μ m retention beads.

Two layers (totaling approximately 0.2 mm thick) of opaque porcelain were applied to both metals on the 8.0 (I_P) $\times$ 5.0 (W) mm² area located at the central portion of each cast metal plate. A bonding opaque porcelain was used for the first layer on the CP Ti. Two layers of body porcelain [8.0 (I_P) $\times$ 5.0 (W) $\times$ 1.0 (d_P) mm³] were then formed using a jig. The second layer of body porcelain compensated for the firing shrinkage of the porcelain. After fusing the porcelains, the 8.0 (I_P) $\times$ 5.0 (W) surface of the body porcelain was then polished and adjusted to a final thickness of 1.0 (d_P) mm. The degassing of metals and the porcelain fusing schedules followed each manufacturer's instructions.

The metal/porcelain specimens were subjected to a three-point bending test using a universal testing machine (AGS-10 KNG, Shimadzu, Kyoto, Japan) at a crosshead speed of 1.5 mm/min and a distance of 20 mm between the supporting rods. The specimens were loaded at the center of the metal, and fracture forces (F_f : N) were recorded. The deflections (D_f : mm) at fracture were also measured. For each experimental condition, five specimens were tested, and the means and standard deviations were calculated. From the fracture force of the specimens ($d_M = 0.5$, air-abraded with 50 μ m alumina) with no retention beads, the stress for the three-point bending strength was calculated according to a numerical method using data generated in a previous study¹⁷⁾. This method calculates the mean shear bond strength at the metal-porcelain interface as a function of the elastic modulus of the alloy, which was measured for each metal

according to ISO standard 6871. Three-point bending strength is defined as the mean shear bond strength, τ_b (MPa), at the force of fracture :

$$\tau_b = \sigma_{xy} \times F_f$$

where σ_{xy} is the mean shear stress under unit load $F=1$ N at the interface of a porcelain bonded to metal in the specimen geometry as described above. The value of σ_{xy} was taken from a previous publication by Schwarz et al.¹⁷⁾, and F_f is the force recorded at the failure of the veneer. Statistical analysis of the results of the three-point bend test for CP Ti was performed using a one-way analysis of variance (ANOVA) with a Tukey-Kramer HSD test at a significance level of $\alpha=0.05$ (SPSS, SPSS Inc., Chicago, IL, USA). The calculated bond strength between the CP Ti and gold alloy was compared using the Student-t test.

RESULTS

Table 1 presents the results of fracture force (F_f : MPa) and deflection (D_f : mm) at fracture for titanium that was air-abraded only or cast with retention beads. Although the specimens air-abraded with 50 μ m alumina showed higher F_f and D_f values compared to the specimens air-abraded with 250 μ m alumina, there were no statistical differences ($p>0.05$) among the groups of different alumina particle sizes. An increase in the size of the retention beads significantly increased the F_f and D_f values of the

specimen. However, there were no statistical differences in the deflection between the groups cast using the 150 μ m and 200 μ m-sized retention beads. When the specimens fractured, all those with retention beads showed cracks at the central portion of the porcelain, but did not separate from the metal surface. Most of the air-abraded specimens had extended cracks at the interface between the porcelain and metal.

The F_f values of the gold alloy specimens that were air-abraded (50 μ m) and cast with retention beads (200 μ m) were 17.3 (± 0.7) N and 28.9 (± 2.2) N, respectively (numbers in parentheses indicate one standard deviation). The D_f values [0.23 (± 0.01) mm for 50 μ m air-abraded and 0.37 (± 0.04) mm for 200 μ m retention beads] of the gold alloy specimens were greater than those of the titanium specimens [0.17 (± 0.01) mm for 50 μ m air-abraded and 0.21 (± 0.04) mm for 200 μ m retention beads]. The measured elastic moduli of the metals and calculated three-point flexure bond strengths are presented in Table 2. The calculated bond strengths of porcelain to titanium (49.6 MPa) were statistically ($p<0.05$) lower than those to the gold alloy (52.6 MPa).

DISCUSSION

Results from the three-point bending test indicate that the difference in alumina particle size did not affect the bond strength of porcelain for titanium (Table 1). However, the speci-

Table 1 Fracture force (F_f) and deflection (D_f) at fracture for titanium that was air-particle abraded or cast using retention beads

	Air-particle abrasion (μ m)			Retention beads (μ m)		
	50	125	250	150	200	600
F_f (N)	17.4 (0.6) ^a	15.6 (1.8) ^a	16.0 (1.0) ^a	20.9 (1.4)	23.2 (0.7)	28.2 (2.9)
D_f (mm)	0.17 (0.01) ^a	0.15 (0.02) ^a	0.15 (0.01) ^a	0.21 (0.03) ^b	0.21 (0.04) ^b	0.25 (0.04)

One standard deviation in parentheses. Identical letters indicate no statistical differences ($p>0.05$) in the same row

Table 2 Results of modulus of elasticity (E_M), mean shear stress (σ_{xy}) under unit load $F=1$ N, fracture force (F_f) under $d_M=0.5$, and calculated mean bond strength (τ_b) of porcelain to each metal

	E_M (GPa)	σ_{xy}	F_f (N)	τ_b (MPa)
Ti	108	2.82	17.4	49.6
Gold alloy	82	3.04	17.3	52.6

mens air-abraded with $50\text{ }\mu\text{m}$ alumina showed higher F_f and D_f values compared to those air-abraded with $150\text{ }\mu\text{m}$ and $250\text{ }\mu\text{m}$ alumina although there were no statistical differences ($p>0.05$) in F_f and D_f values among the groups of different particle sizes. It is possible that the hard surface reaction layer (approx. $<50\text{ }\mu\text{m}$) resulting from the reaction with the investment materials is not entirely removed after air-abrasion with $50\text{ }\mu\text{m}$ alumina powder. The alumina particle sizes of $150\text{ }\mu\text{m}$ and $250\text{ }\mu\text{m}$ might be appropriate to remove the top of the reaction layers. To bend a cast plate with the reaction layer remaining, it is necessary to apply higher force (F_f value) to fracture the porcelain compared to the force needed to bend a specimen without the reaction layer. The existence of the reaction layer might also affect the results of calculated mean bond strengths (τ_b), in which the CP Ti showed a lower τ_b value compared to the gold alloy (Table 2).

Use of the retention beads significantly improved the F_f values to both metals. An increase in the size of the beads significantly increased the F_f and D_f values of the titanium specimen. Comparing the F_f values between the $50\text{ }\mu\text{m}$ air-abrasion and the $200\text{ }\mu\text{m}$ retention beads specimens, the gold alloy specimens showed particular improvement. The increase in the mean F_f values of the gold alloy was approximately 67%, whereas the increase for CP Ti was approximately 33%. It can thus be said that the application of retention beads is more

suitable for the gold alloy rather than the CP Ti. It is also interesting that, to achieve similar F_f values for both metals ($50\text{ }\mu\text{m}$ air-abrasion), the gold alloy ($0.23\pm0.01\text{ mm}$) deflected more compared to the CP Ti ($0.17\pm0.01\text{ mm}$). This high D_f value for the gold alloy may be attributed to the difference in the moduli of elasticity between both metals. The elastic modulus (82 GPa) of the gold alloy is lower than that of CP Ti (108 GPa) (Table 2), which indicates that the gold alloy requires a higher strain value compared to CP Ti to obtain the same level of stress in a conventional strain-stress curve¹⁸⁾. The F_f and D_f values of the specimens cast using the $600\text{ }\mu\text{m}$ retention beads were the highest of all of the specimens, indicating effective mechanical interlocking of porcelain to metal. However, increasing the size of the retention beads increases the thickness of the porcelain layers, requiring a greater reduction of the tooth. For this reason, application of $600\text{ }\mu\text{m}$ -sized retention beads is not suitable for making a metal ceramic restoration. Therefore, to achieve reliable clinical results, $200\text{ }\mu\text{m}$ or $150\text{ }\mu\text{m}$ -sized retention beads are appropriate for making titanium ceramic prostheses.

CONCLUSION

The application of retention beads significantly improved the three-point bending strength of porcelain to cast titanium as well as to gold alloy. The use of the $200\text{ }\mu\text{m}$ or $150\text{ }\mu\text{m}$ -sized retention beads is appropriate for making clinically reliable titanium ceramic prostheses.

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