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A comparison of the marginal adaptation of cathode-arc vapor-deposited titanium and cast base metal copings

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Statement of problem. A new fabrication process where a titanium coping, with a gold colored titanium nitride outer layer, can be reliably fused to porcelain; however, the marginal adaptation characteristics are undetermined.

Purpose. The purpose of the study was to compare the clinically acceptable marginal adaptation (CAMA - defined as a marginal gap mean of ≤ 60 μm) rates of cathode-arc vapor-deposited titanium and cast base metal copings to determine whether the titanium copings would produce a higher CAMA rate than the cast base metal copings.

Material and methods. Thirty-seven cathode-arc vapor-deposited titanium copings and 40 cast base metal copings were evaluated using an optical microscope. Fifty vertical marginal gap measurements were made of each coping, and the mean of these measurements was used to form the gap score. A 1-tailed *t* test was used to compare the CAMA rates, and the Satterthwaite t-score was used to analyze the consistency of the coping adaptation (α=.05).

Results. CAMA was achieved by 24 of the 37 (64.86%) titanium copings compared to 19 of the 40 (47.50%) base metal copings. A 1-tailed *t* test produced a Z-score of 1.533 (1-tailed *P*=.063), which allowed acceptance of the study hypothesis with only a modest risk of a Type I error.

Conclusions. Cathode-arc vapor-deposited titanium copings exhibited a higher rate of CAMA compared to base metal copings. (J Prosthet Dent 2011;105:403-409)

Clinical Implications

The higher rate of clinically acceptable marginal adaptation (CAMA) of cathode-arc vapor-deposited titanium copings makes them an attractive alternative to conventional cast base metal copings.

Titanium alloys are an attractive alternative to conventional cast gold and base metal alloys, due to their high strength-to-weight ratio, excellent corrosion and fatigue resistance, and high biocompatibility.[1] The lower thermal conductivity, radiographic translucency, and low unit metal costs are other characteristics that have increased interest in using titanium alloys for crowns.[2,3] The biocompatibility and corrosion resistance of titanium depends on the thickness, tenacity, and stability of the surface oxide film.[1]

The marginal adaptation of restorations is critical for longevity and periodontal health as marginal discrepancies contribute to cement dissolution and plaque accumulation, resulting in recurrent decay and periodontal disease.[4,5] Factors that may affect marginal adaptation include tooth preparation, margin design,

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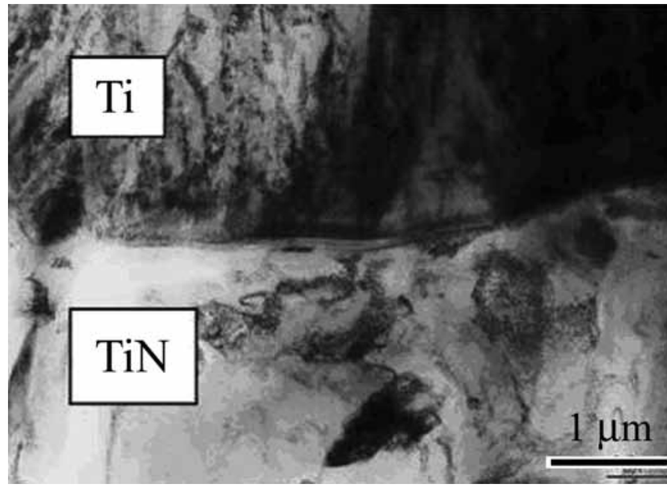
alloy types, casting procedures, porcelain firing cycles, and cementation techniques.[6-8] Shoulder and shoulder-bevel designs were found to have less marginal distortion than chamfer designs.[7] Marginal adaptation assessments can be completed by direct visualization of the crown on the die, clinical evaluation of the tooth/restoration interface, impression replica technique, or use of a cross-sectional view.[9] Use of high-powered image magnification allows more precise measurements, and requires the specimen to be positioned perpendicular to the microscope lens.[10] Definitions of marginal adaptation can vary greatly and make comparisons of studies difficult. Holmes et al[11] defined an external marginal and an internal marginal gap that was influenced by the horizontal over extension and under extension of the restoration margin. There are also variations in the methods used to measure the marginal adaptation of crowns due to complex gap morphology and the number of sites measured.[11] One study defined the vertical discrepancy as measured from the most external point of the crown margin to the most external point of the tooth preparation finish line.[12]

A marginal opening of 120 μm or less has been determined as clinically acceptable,[13,14] while most clinicians would prefer a vertical marginal gap of 60 μm or less.[15] Approximately 50 measurements along the margin of a crown were reported to yield clinically relevant information, and can provide a consistent estimate of the marginal gap of a restoration.[12,16]

Previous challenges with casting titanium alloys with conventional casting systems included the metal's low density, high melting temperature (1672°C), and high chemical reactivity. Low density, for example, results in difficulty filling the mold and can result in incomplete margins.[17] At elevated temperatures, titanium reacts with oxygen, hydrogen, and nitrogen, which decreases the metal's ductility and strength.[18] Chambers with inert gas pressure and vacuum casting systems were developed to minimize reactions with other elements, but marginal adaptation was still considered inferior to cast noble alloys.[19] Electrical discharge machining (EDM), or spark erosion, has been used since the 1980s for fabrication of titanium copings, implant restorations, infrastructure bars, and removable superstructures for implant prostheses.[20,21] EDM has also been used with computer-aided design/computer aided manufacturing (CAD-CAM) to fabricate titanium ceramic crowns.[20]



1 Transmission electron microscopy (TEM-x50,8000 magnification) cross-section of titanium coping. Ti=titanium and TiN=titanium nitride

The development of a new cathodic arc deposition system in a high vacuum chamber by Nano-Write Corp (Livermore, Calif) has allowed the fabrication of an accurate restoration without use of the lost wax method.[22] The cathode-arc vapor-deposited titanium coping is made of grade 2 titanium with a titanium nitride outer layer and can be used for single unit anterior and posterior metal ceramic restorations. The nanostructure (Ti, TiN) process received Food and Drug Administration (FDA) approval in June 2003. The titanium coping is formed by a cathode-arc deposition system, where a uniform collection of atomic titanium vapor (0.5 nm) is deposited onto a rotating refractory die in a high vacuum chamber. Cathodic-arc deposition consists of a titanium cathode material and metal plasma in a vacuum, sustained by a guided plasma arc on the cathode surface. The refractory die is rotated in the vacuum, while the titanium metal is deposited. The coping thickness can be controlled to between 100 to 350 μm by regulating the ion deposition with a titanium grain size of 50 to 500 nm. After the desired titanium coping thickness is achieved, nitrogen gas is added to the titanium vapor to form the exterior titanium nitride layer (5 to 10 μm thick) (Fig. 1), which is yellow gold in color preventing the formation of the thick, dark titanium oxide layer.

The new cathode-arc vapor fabrication system takes 10 minutes which is more efficient than traditional cast metal coping methods. With traditional methods, the waxing, investment, and casting of metal alloys are potential sources of error with marginal gaps that can range from 23 μm to 110 μm.[7] Boening et al[3] found a 53 μm mean marginal gap in titanium copings fabricated using CAD-CAM. Leong et al[14] observed marginal gaps of 54 μm with milled titanium (CAD-CAM) and 60 μm with cast titanium crowns. In another study using cast commercially pure titanium and Ti-6Al-4V alloy crowns, the marginal adaptation was 83 μm and 50 μm respectively.[23] The crowns were placed onto bovine teeth and measured at x50 magnification. Use of EDM marginal refinement after casting significantly improved the marginal adaptation of both alloys.[23] In another study comparing the vertical marginal gaps of CAD/CAM titanium and conventional cast restorations, it was determined that the cast restorations had smaller marginal gaps of 24 µm compared to 79 µm in the CAD/CAM restorations. [24]

The titanium nitride layer was determined to have better adhesion to the porcelain than the cast and CAD-CAM titanium grade 2 copings in the original manufacturer's data.[22] The adhesion of the titanium nitride layer to porcelain was approximately 35 MPa, whereas, compared with conventional cast and CAD-CAM methods of titanium coping fabrication, it was approximately 25 to 30 MPA.[25] The nanometer size of the deposited titanium particles provided the name of the manufactured product, NanoTi crowns.

Epoxy dies were used in the present study to measure the marginal adaptation of electrodeposited titanium and cast base metal copings. This comparison was facilitated by the accuracy of the epoxy resin die material.[26,27] Variations in the methods used by different investigators, varying sample sizes, and an inconsistent number of measurements per specimen, could contribute to differences in results.[28]

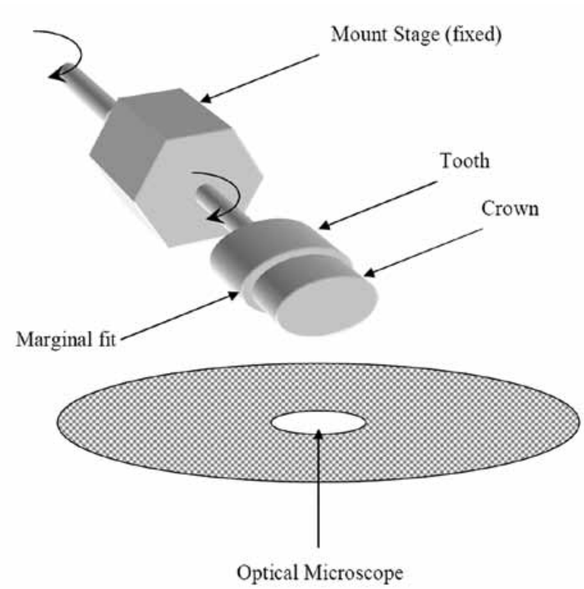
Optical microscope image analysis was used to compare the marginal adaptation of the titanium and base metal copings on epoxy dies in the current study. Base metal and titanium have high modulus of elasticity, and low density, unlike high noble alloys.[29] The high cost of gold-platinum alloys and limited economic resources resulted in the use of a base metal for this study. The rational for using titanium and base metal castings was that they have similar physical properties and similar cost. The purpose of the study was to compare the clinically acceptable marginal adaptation (CAMA), defined as a marginal gap mean of ≥ 60 µm, rates of cathode-arc vapor-deposited titanium and cast base metal copings to determine whether the titanium copings would produce a higher CAMA rate than the cast base metal copings. The research hypothesis was that the titanium copings would have a higher CAMA rate than the cast base metal copings.

MATERIAL AND METHODS

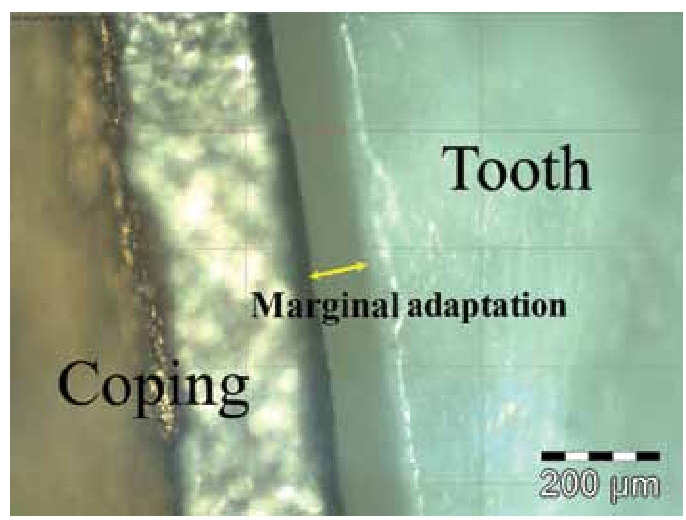
An extracted unrestored human premolar was prepared for a complete coverage crown with an occlusal reduction of 2 mm, an axial reduction of 1.5 mm, with a 1.5 mm shoulder, and a 6-degree taper. A review of previous studies indicated a sample size of 35 to 40 specimens per group would be adequate for this study.[11,13,27,30] No power analysis was performed before the study to determine adequate sample size. Forty custom impression trays were fabricated using autopolymerized acrylic resin (COE Tray Plastic; GC America Inc, Alsip, Ill) to allow definitive polyvinyl siloxane impressions (Extrude; Kerr Corp, Orange, Calif) for the fabrication of epoxy dies (Tri-Dynamics Tri-Epoxy; Keystone Industries, Cherry Hill, NJ). One dental technician followed the manufacturer's recommendations for fabricating the cathode-arc vapor-deposited titanium copings (Nano-TiCrown; Nano-Write Corp, Livermore, Calif) and the cast base metal copings (Argeloy N.P. (Be-Free); The Argen Corp, San Diego, Calif). The marginal adaptation was evaluated by measuring the vertical gap between the edge of the coping and the prepared tooth finish line with an optical microscope and image processing software (Nikon Epiphot equipped with an Olympus Charge-Coupled Device (CCD) camera; Nikon Inc, Tokyo, Japan) (Olympus M3 3.2 Version, 2003; Olympus America Inc, Center Valley, Pa). The accuracy of the optical microscope was confirmed to be 0.1 µm at a magnification of ×240. A marginal adaptation measurement was made as the minimum distance between one point on the coping edge and a line determined by the least squares of points to the tooth margin. Fifty selected points were used to make these measurements for each coping with spacing of approximately 400 µm. The vertical marginal gap score for each specimen was defined as the mean value of the 50 measurements. The criterion of 60 µm was used as the maximum clinically acceptable vertical marginal gap.[13]

The base metal Ni-Cr (Argeloy N.P. (Be-Free)) copings were fabricated and finished using the conventional lost wax casting technique and conventional dental laboratory finishing equipment. The die was dipped into a wax pot (Hotty; Renfert GmbH, Hilzingen, Germany) containing type-B dipping wax (Bellewax; Kerr Corp, Orange, Calif), then cooled and carved. Each coping was confirmed to be 0.3 mm in thickness as measured with a conventional dental caliper (Hu-Friedy, Chicago, Ill) graded to 0.1 mm. No die spacer was used and each coping was waxed directly onto the epoxy die. The wax copings were invested in a phosphate bonded investment (Starvest-Microfine; Emdin Intl Corp, Irwindale, Calif) and eliminated following the manufacturer's instructions (Ney-Vulcan furnace; Ney Dental Equipment, York, Pa). The base metal was melted in a quartz crucible using a hydrogen/oxygen torch and cast with a centrifugal casting machine (Centrifico Casting Machine; Apex Industrial Electronics, Ambala, India). The internal fit of each coping was verified at ×10 magnification using a stereomicroscope (OPMI Pico; Carl Zeiss, Jena, NY) with a disclosing medium (Fit Checker; GC Corp, Tokyo, Japan). It was then adjusted with a green oxide stone (Kontour Stones; Brasseler USA, Savannah, Ga) at 5000 RPM using an electric handpiece (Electrotorque; KavoAmerica, Lake Zurich, Ill). The outer coping surface was adjusted for thickness with the green oxide stone, and the margin edge was finished with a silicone abrasive wheel (Kontour Stones; Brasseler USA). The base metal copings were then steam cleaned before placement on the prepared tooth specimen for measurement. Each coping was stabilized on the tooth preparation with water surface tension. The titanium copings (Nano-TiCrown; Nano-Write Corp) consisted of 98.2% grade 2 titanium with an exterior layer of titanium nitride fabricated with the cathodic-arc vapor-deposition process.[21] The titanium copings were formed by a collection of atomic titanium vapor onto a refractory die in a high vacuum chamber (Nano-Write Corp). The chamber vacuum during the deposition process was between $1x10^{-4}$ to $3x10^{-7}$ Torr, (1 atm.=760 Torr). The cathodic-arc deposition process consisted of a directed plume of titanium vapor emitted from the titanium cathode, as a result of a magnetically guided arc on the titanium cathode. The resulting plume consisted primarily of titanium ions and a small percentage of macro droplets with a ratio of 10:1. The titanium vapor was directed onto the refractory die, developing the coping thickness, atom by atom, to approximately 0.2 to 0.4 mm, as determined by cross sectional scanning microscopy studies performed by the manufacturer. High purity nitrogen gas was added to the titanium vapor after the desired coping thickness was achieved. The nitrogen gas addition reacted with the titanium ions to form the exterior titanium nitride layer. The titanium nitride layer is typically 10 μm thick and is 50% titanium and 50% nitride, according to the manufacturer. Typical titanium coping thickness was 0.3 mm as measured by dental calipers (Hu-Friedy). The density of the Nano-Ti copings was 4.74 gm/cm^3 and the elastic modulus was 61GPa, according to the manufacturer's data.[21]

Composition analysis of the deposited titanium material by the manufacturer showed no reaction to the refractory substrate and zero alpha phase development. On removal of the internal refractory material with aluminum oxide, the internal fit and margin adaptation were verified with a disclosing medium (Fit Checker; GC Corp), and any internal casting discrepancies were adjusted with an electric handpiece and green stone as during the finishing of the cast base metal copings. The margin edge was finished with a silicone abrasive wheel. The time required for the cathode-arc deposition process was 10 minutes.

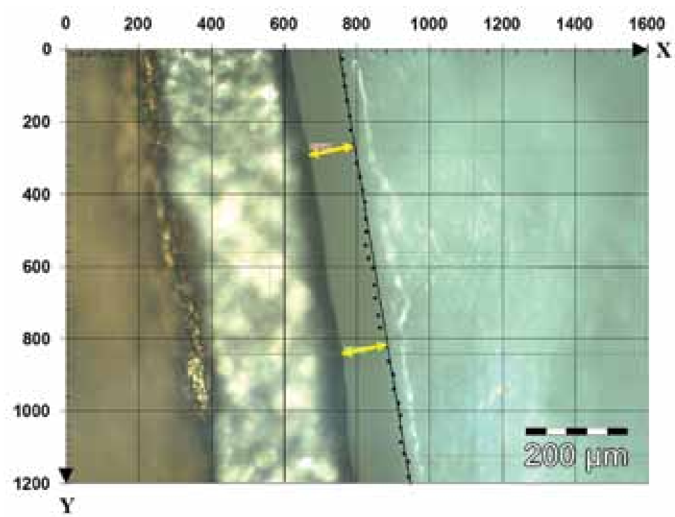


2 Diagram of tooth mounted on stage for examination with optical microscope.



3 Marginal adaptation of titanium coping under optical microscope (×100 magnification).

An optical microscope (Nikon EPIPHOT equipped with a CCD camera, Nikon Inc) was used to analyze the vertical marginal adaptation of each coping on the premolar tooth specimen (Fig. 2). Figure 3 is an optical microscope image of the vertical marginal fit of a coping on the tooth at a magnification level of ×100. Figure 4 illustrates the least squares line at the coping margin, and the X and Y coordinates were recorded by image processing hardware (Olympus MicroSuite-M3 3.2v, 2003, Olympus America Inc). Each point was plotted on a location diagram and the least squares line that best fit the points was determined. The vertical marginal gap was determined by the distance from the measuring point to the least squares line of the margin at 400 μm intervals. Fifty vertical marginal gap measurements were collected from each of the 77 copings, and the mean of these measurements was computed to form a gap score for each coping. The gap score was compared with the 60 μm criterion to



4 Marginal adaptation was measured from least squares line of margin to tooth (x100 magnification).

classify each coping as to whether it did or did not achieve CAMA. A comparison of the CAMA rates for each type of coping was used to test the 1-tailed hypothesis that the titanium copings had a higher rate of CAMA. Finally, the assertion that the titanium copings provide more consistency in their marginal gap performance was tested in 2 ways: first, the means of the titanium gap scores should exhibit a smaller variance than the means of the marginal gap scores for the base metal copings. Next, a 1-tailed *t* test of the difference between the mean of the standard deviations for each group was used to demonstrate the consistency of coping adaptation further. All statistics were computed using statistical software (SAS v9.2, SAS Institute, Cary, NC).

RESULTS

Clinically acceptable marginal adaption (CAMA) was achieved by 24 of the 37 (64.86%) titanium copings (Nano-TiCrown; Nano-Write Corp) and 19 of the 40 (47.5%) base metal copings (Argeloy N.P. (Be-Free); Argen Corp). Thus, the titanium copings produced a 17.36% higher CAMA rate than the base metal copings. A 1-tailed t test of the tentative hypothesis (H0: Titanium CAMA rate (LESS THAN/EQUAL TO SIGN) Base-Metal CAMA rate) produced a Z-score of 1.533 (1-tailed P=.063), which allowed acceptance of the research hypothesis with only a moderate risk of a Type I error.

In a secondary analysis to compare the adaption consistency of the titanium copings with that of their base-metal counterparts, the difference between the variance of the marginal gap scores for the titanium copings (594.8) and the variance of the marginal gap scores for the base metal copings (1510.9) was tested and found to be statistically significant (Folded-F test score=2.63, *P*=004). A second method for demonstrating this effect was to conduct a 1-tailed *t* test of the difference between the mean ±SD of the standard deviations of the marginal gap measurements for the titanium copings (29.98 ±10.1) and the mean ±SD of the standard deviations of the marginal gap measurements for the base metal copings (36.13, ±13.82). This test also indicated that the titanium adaption was significantly more consistent (Satterthwaite t-score=-2.24, 1-tailed *P*=.014).

DISCUSSION

Cathode-arc vapor-deposited titanium copings exhibited a significantly higher rate of CAMA than the comparison base metal copings supporting the research hypothesis. Comparison of the coping marginal adaption score variances and direct assessment of the coping marginal adaption scores provided additional evidence that the titanium copings performed better and with more consistency than their base metal counterparts did. The results of this study confirm that, on average, the titanium copings had an acceptable adaptation of less than 60 mm, while the cast base metal copings did not. The results demonstrated significant differences between groups. The larger standard deviation for the base metal group could be due to the technique-sensitive method of casting this base metal alloy. The cathode-arc vapor-deposited titanium copings were more consistent in marginal adaptation and had a smaller mean marginal gap (57 µm).

This new method of titanium coping fabrication provides a solution to previous challenges of achieving an anatomically correct restoration with minimal marginal discrepancies.[19,21,22] The other sources of error in fabrication such as waxing, investing, and casting are eliminated with the vapor-arc-deposited system. The reasonable material costs and shorter time for fabrication are also attractive features of this newer system compared with other technologies such as CAD/CAM or EDM.[22]

Previous studies evaluating various titanium crown fabrication systems have reported 53 to 70 µm mean marginal gaps.[3,14,19,21,22] These values are similar to the mean marginal gaps seen with the titanium copings in the present study (57 µm). In this quantitative method of assessment, the specimens were not sectioned and were only visualized with direct microscopic evaluation. This required the specimen to be observed within a specific plane of focus that was perpendicular to the microscope objective or parallel to the mounting stage.[10]

The low density characteristic of titanium is desirable when fabricating larger prostheses, while a high modulus of elasticity offers rigidity. However, the high melting point of titanium, high chemical reactivity at elevated temperatures and low density, results in casting difficulties and challenges with proper mold filling.[31] The density of NanoTI copings (4.74 gm/cm^3) and the elastic modulus (61 GPa) reported by the manufacturer apply only to the composite structure of the crown and the external titanium nitride layer, and are not comparable to bulk titanium properties.[21] It is also unclear how the manufacturer obtained these measurements, as the minimal thickness of the specimen would make such determinations a challenge.

A critical parameter for successful metal ceramic restorations is the quality of the porcelain bond and the esthetics of the veneering porcelain. Titanium-ceramic bonding is challenged by the excessive oxidation of titanium during porcelain firing.[32] Previous challenges involving the dark color of the titanium oxide layer resulted in compromised esthetics of the veneering porcelain. Firing porcelain in a reduced argon atmosphere was shown to significantly improve the porcelain to titanium bond strength.[32] However, conventional noble metal-porcelain bonding was superior when compared to titanium-porcelain bonding.[32] The true value of reported porcelain to metal bond strengths is difficult to obtain due to residual stresses at the porcelain-metal interface attributed to differences in the coefficient of thermal expansion (CTE).[33] Future studies are required to analyze the interfacial variables of porcelain adherence to the titanium nitride layer of the cathode-arc vapor-deposited titanium coping. Of particular interest is the flexural and shear strength between the titanium nitride layer and the veneering porcelain, and the effect of thermocycling on the fracture value.

Limitations of this study include that the restorations were not cemented onto the tooth specimen to simulate the clinical scenario. If the specimens were cemented onto the tooth, it would be difficult to visualize the reference points if the margins were covered with luting material.[30] The various cementation procedures might affect the marginal adaptation due to differences in cement viscosity and placement forces used during cementation.[30] The internal adaptation of the copings was not evaluated. To measure the internal adaptation, the specimens must be sectioned and the number of measurements per specimen is limited.[11] Individual measurements at various locations on the margin may reveal significant deviation from the mean, and this may result in the coping having a clinically unacceptable margin. Finally, the use of base metal instead of gold-colored high noble alloys could have affected the results of the comparison group marginal adaptation.

Future evaluation of internal fit, marginal adaptation after porcelain firing, esthetic evaluation, and clinical performance of cathode-arc vapor-deposited titanium copings is needed. Vapor deposition technology could be applied to fabricate CAD/CAM custom abutments and copings for implant superstructures with a gold color TiN coating.

CONCLUSIONS

Cathode-arc vapor-deposited titanium copings exhibited a significantly higher rate of CAMA than the base metal copings. Comparison of the coping marginal adaption score variances and direct assessment of the coping marginal adaption scores indicated that the titanium copings performed better and with more consistency than their base metal counterparts did.

The higher rate of clinically acceptable marginal adaptation of cathode-arc vapor-deposited titanium copings, coupled with their desirable properties of biocompatibility, strength, low thermal conductivity, and reasonable cost make them an attractive alternative to conventional cast base metal copings.

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