EFFECT OF RECASTING Ti-6Al-4V ALLOY ON THE INTERNAL AND MARGINAL ACCURACY OF COMPLETE CAST CROWN

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ABSTRACT

The purpose of the study was to investigate the effect of recasting Ti-6Al-4V on the marginal accuracy and internal fit of complete cast crowns.

Ti-6Al-4V was used to cast 18 single crowns, six of each group. Three groups of Ti-6Al-4V ingots were tested. The first group was as received from manufacturer, second group was a mixture (1:1 ratio) of as received and the alloy that was once used and the last group was an alloy used once (recast). A traveling microscope was used to measure the marginal and internal gaps between the metal die and the casting. The fitting discrepancies were analyzed with a 1-way ANOVA and Tukey's multiple range (a=.05).

The lowest mean marginal gap was recorded for the as-received (36.87 μm) and the highest was for the 100% reused (39.24 μm). However, these differences were not statistically significant (P=0.192). For the internal fitting, no significant difference was shown between as-received and 50% reused groups (P>0.91). Yet, the alloys in both the groups showed gaps that were significantly smaller than the 100% reused alloy (P<0.002).

Used Ti-6Al-4V metals could be melted and utilized again for casting single crowns. As-received and 50% reused metals demonstrated better internal fit than the 100% reused metals.

Key words. Marginal accuracy, fit discrepancy, titanium alloys, re-casting.

INTRODUCTION

Commercially pure titanium (CPTi) and its alloys (TiA) have become materials of great interest in dentistry because of their excellent biocompatibility, desirable physical and mechanical properties, and relatively low cost.1-3 They have been increasingly used for the construction of metal-ceramic restorations. However, CPTi showed some disadvantages such as low strength, difficulty in polishing and poor wear resistance.4-6 Therefore, several TiAs have been formulated for biomechanical applications. Titanium can be alloyed with various elements such as Al, V, Zr, Nb, Ta and Pt primarily to improve the mechanical properties such as strength, high temperature performance, creep resistance, weldability, and formability.4,7

Among the various TiAs, the titanium-aluminum-vanadium (Ti-6Al-4V) alloy was FDA-approved and one of the commonly used TiAs in implant dentistry because of the improved physical and mechanical properties in comparison to CPTi.3,7 Ti-6Al-4V alloy showed greater bending strength and greater hardness than CPTi,8 and has a melting point of 1650°C which is lower than that of CPTi (1720°C).7 The low elastic modulus (50 to 60% of those of the Co-Cr alloys) and high yield points

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of Ti-6Al-4V result in high springback suitable for the retentive forces required for the clasp of removable partial dentures or for orthodontic uses.'

Alloying elements are added to stabilize alpha or beta phases by either raising or lowering the transformation temperatures. The most popular alloy of alpha-beta titanium is Ti-6Al-4V. Aluminum is a typical alpha stabilizer which increases the alpha-beta transformation temperature and maintains the improved mechanical properties over CPTi while, Vanadium is a continuous solid-solution-type beta stabilizer. Alpha-beta titanium alloys are more formable than alpha alloys.

Marginal accuracy is considered a crucial factor in the success and longevity of a cast restoration; inadequate adaptation of cast restoration may be detrimental to both the tooth and supporting periodontium. Ideally, cemented cast restoration margins meet prepared teeth finish line in perfect nondetectable junctions. However, in reality, clinical perfection is hard to achieve and difficult to verify. Many authors agreed that a marginal gap less than 100 pm appears to be within the range of what is clinically acceptable for longevity of restorations or prostheses. Dedmon in an in-vitro study using a stainless-steel device reported that the minimal marginal openings acceptable by a group of prosthodontists averaged 114 and 93 pm. McLean and von Fraunhofer reported that discrepancies less than 80 pm were difficult to detect under clinical conditions.

Studies in the marginal fit of cast CPTi crowns showed values within the acceptable limit of 100 pm. Contreras et al studied the fit of cast CPTi and Ti-6Al14V alloy crowns. The results showed that the marginal fit of Ti-6Al-4V alloy crowns (50.8 pm) was significantly better than that of cast CPTi (83.9 pm). They related the better fit of Ti-6Al-4V alloy crowns to the improved castability which could be attributed to differences in melting temperature, thermal expansion coefficient, and density.

In many dental laboratories, previously used gold alloy may combine with new alloy, as-received from the manufacturer. McLean has suggested that at least 50% new metal be included in copings for metal-ceramic restorations. However, there is sparse experimental justification for this rule. The basis for this empirical guideline is that certain important secondary elements, present in a few percent in the fresh alloy may be lost during casting procedure through volatilization or oxidation."

Ayad investigated the effect of combining new and recast type III gold alloy on the marginal accuracy of complete cast crowns. He found that the marginal opening of all casting was less than 25 pm, with the lowest discrepancy recorded for the as-received alloy group. Mosleh et al assessed the castability and recastability of four ceramo-metal alloys including gold alloy as control, nickel-chromium, cobalt-chromium, and titanium. They found that titanium alloy produced the least castability values among the tested groups. They attributed the lower recorded value by the titanium alloy to the lower fluidity of the molten alloy as well as a probable higher heat capacity and conductivity resulting in a higher cooling rate with a decrease in castability values. However, they utilized a conventional casting machine to cast all the specimens.

The effect of combining new and recast TiA's on the accuracy of the final cast restoration has not been investigated. The purpose of the study was to investigate the effect of recasting Ti-6Al-4V on the marginal accuracy and internal fit of complete cast crowns.

**MATERIALS AND METHODS**

Three groups of TiA ingots were prepared. The first group was as received from manufacturer Ti-6Al-4V (Vsmo, Parkovaya St., Verkhnaya Salda, Sverdlovsk reg., Russia), second group was 1:1 ratio of as received and once used TiA and the last group was once used (recast) TiA.

Group 3 (recast) ingots were obtained by casting a new 31 gm TiA ingots into a copper ring that acted as a mold. Two ingots of as received and 2 ingots of once used were chosen to be sectioned into equal halves. Each of group 3 ingots was formed from one-half ingot of as received and another half from once used.

Eighteen single crowns were fabricated, six of each group. The apparatus used for testing the distortion was a 3-section aluminum mold, previously described, that could accommodate as many as four stainless steel dies (Fig 1). The first die represented a first molar.
Fig 1. Schematic drawing of the aluminum mold which was used in this study. It was 5.8 mm long with 5-degree axial wall taper and had a 1 mm shoulder. The gingival diameter was 7.5 mm. A v-shaped groove was placed in the occlusal surface to serve as an anti rotational index. The die was removable, attached to the mold base and locked with Allen-head screws. The mid section fits around the finish line of the die and has a 5-degree outward taper from the gingival margin to the shoulder. The top section of the mold forms the upper portions of the crown and had a 5-degree inward taper. Opening on the top section, opposite to the die, were prepared to facilitate pouring of the molten wax.

Three coats of die spacer (True-Fit, Geo Taub, Jersey City, USA), kept within 1 mm of margins, were applied to the die. Prior to waxing up, the die were lubricated with a die separating agent (Die Lube, Dentaurum, Ispringen, Germany) and the three sections of the mold were secured to each other. Inlay wax (BioWax, Type III Dental Inlay Casting Wax, Dentsply, York, PA, USA) was warmed for 5 minutes along with the dies assembly in a furnace held at 50°C. The wax was poured into the mold through the openings in the top section. The mold was kept at ambient room temperature (23°C) for 1 minute prior to retrieving the wax pattern. Remargination was carried out by adding warmed inlay wax crowns margin. Excess wax was carefully removed by using PKT (Thomas) No. 4. Accuracy of margins was checked by using a Stereo 80 wide field microscope (Swift Instruments International, Tokyo, Japan).

The wax patterns were invested under vacuum (Combination Unit, Whip Mix Corporation, Louisville, KY, USA) using a silica-free and phosphate-free, alumina and magnesia-based investment (Rematitan Ultra, Dentaurum). Titanium casting machine (Castmatic, Dentaurum) was used to cast the specimens following manufacturer's instructions. The casting machine was thoroughly cleaned following manufacturer's instructions to avoid contamination during casting procedure.

Nodules in the internal surface of the castings were removed with a mini and midi titanium hard metal bur (Dentaurum) under a Stereo 80 wide field microscope (Swift Instruments International). Fit checker (Ghmspray, Hanel, Langenau, Germany) was sprayed in internal side of each casting that was seated with finger pressure. The binding areas were removed by midi bur (Dentaurum). This procedure was repeated five times for each casting. Pressure spot indicator (Coltene PSColtênee, Ateñan, SAlstättenand) was mixed according to manufacturer’s instructions and applied to the internal surface of the casting. Each casting was seated over its corresponding die with finger pressure and held until setting of the indicator. Binding areas were marked with pencil and eliminated by grinding with midi bur. This procedure was repeated 2 times. Specimens’ preparation and fitting procedures were achieved by a single investigator.

A traveling microscope (TM 10 Measuring Microscope, Titan, Buffalo, NY, USA) with micro calibrations 2.54 pm distances was used to record all the measurements. The accuracy of the microscope was tested by using a steel plate with a known thickness of 730 pm as measured with a digital micrometer (Fowler, Fred Fowler Co. Inc., Newton MA, USA). The vertical marginal discrepancies between the margin of the casting and the shoulder of the metal die were measured. Four equally spaced measuring sites were selected on the margins of the metal die to represent mid-buccal, mid-lingual, mid-distal, and mid-mesial. Measurements were repeated 3 times for each site. The grand means of the measurements of each die were obtained.

For the internal fit discrepancy, each casting was individually embedded in auto polymerizing acrylic resin and sectioned faciolingually through the long axis of the retainer using a precision saw (Isomet 200, Buehler, Ltd.). The internal gap was measured at 3
sites; halfway through the buccal and lingual wall occlusogingivally and halfway through the occlusal table mesiodistally. Measurements were repeated 3 times for each site and were completed by a single investigator.

Statistical software (SPSS for Windows, Release 11.0.0, 2001, SPSS Inc) was used to generate descriptive statistics and perform inferential tests. The 1-way analysis of variance (ANOVA) and the Post hoc Tukey's HSD test were used to find the statistical significance of the mean differences between groups. The confidence level was set at 95%. The paired t-test and the Pearson correlation were used to examine the intraexaminer reliability.

RESULTS

A high level of intra-examiner reliability was demonstrated by using the paired t-test and the Pearson correlation. The paired t-test showed that the difference was not significant with $P = 0.831$. The Pearson correlation was 95.3%.

The grand means and standard deviations for the marginal discrepancies are summarized in Table 1. The highest mean marginal gap was recorded for the 100% reused (39.24 pm) and the lowest was for the as-received (36.87 pm). However, these differences were not statistically significant as shown by the 1-way ANOVA ($P=0.192$).

The means and the standard deviations of the internal fit are depicted in Table 2. ANOVA test showed a significant difference in the internal fit discrepancy in relation to metal ($P<0.001$). The Tukey's test showed no significant difference in the three sites between as-received and 50% reused groups ($P>0.91$). However, both groups were significantly less than the 100% reused technique ($P<0.002$) in all the sites. The Tukey's test showed that the internal fit at mid-occlusal site was significantly greater than the axial fitting, which is true for all groups ($P<0.01$).

DISCUSSION

The effect of recasting of Ti-6Al-4V on fit of cast restorations have been investigated under controlled experimental conditions through measuring the marginal and internal fit discrepancies of single crown castings. The results of the Ayad18 study showed that increasing the percentage of reused Ti-6Al-4V for casting increased the marginal gap discrepancy. However, statistical analyses revealed that these differences were not significant. These findings agreed with the results of Ayad19 for combining new and recast type III gold alloy. In addition, the lowest discrepancy recorded for the internal fit was with contraction17,24. This may be explained by the potential loss of trace metal (e.g., Fe) present in the as received alloy during the remelting and re-casting procedure through volatilization or oxidation resulting in excessive solidification contraction17,24. In addition, aluminum is a known alpha stabilizer which increases the temperature of the alpha-beta transformation.9 Therefore, its loss may lead to an increase in melting temperature of the resultant metal and this may affect the ability of molten metal to fill the mold in quality similar to that of fresh metal. On the other hand, oxidation of titanium during casting procedure may have affected its behavior during remelting. Taira et al. reported that molten and heated CPTi reduced the oxides in the mold, and freed the oxygen diffused from the surface into the interior of titanium castings, which increased the microhardness proportional to the amount of absorbed oxygen. In addition, oxygen is an alpha stabilizer by

| TABLE 1: MEAN MARGINAL DISCREPANCY AND STANDARD DEVIATIONS (pM) |
|----------------------|--------|--------|--------|
| Technique            | Mid-   | Mid-   | Mid-   |
|                      | buccal | occlus | lingual |
| AR                   | 36.87  | 91.30  | 38.24  |
| (±3.15)              |        |        |        |
| 50%R                 | 38.24  | 91.44  | 38.10  |
| (±4.07)              |        |        |        |
| 100% R               | 39.24  | 96.38  | 40.50  |
| (±4.49)              |        |        |        |

Abbreviations: AR, as-received Ti-6Al-4V; 50%R, 1:1 ratio of as-received and once-used Ti-6Al-4V; 100%R, 100% once-used (recast) Ti-6Al-4V.

| TABLE 2: MEAN INTERNAL DISCREPANCY AND STANDARD DEVIATIONS (pM) |
|----------------------|--------|--------|--------|
| Technique            | Mid-buccal | Mid-ocular | Mid-lingual |
|                      |          |           |           |
| AR                   | 40.64    | 91.30     | 38.24     |
| (±3.20)              |          |           |           |
| 50%R                 | 40.65    | 91.44     | 38.10     |
| (±4.07)              |          |           |           |
| 100% R               | 43.60    | 96.38     | 40.50     |
| (±4.49)              |          |           |           |

The grand means and standard deviations for the internal fit discrepancies are summarized in Table 2. ANOVA test showed a significant difference in the internal fit discrepancy in relation to metal ($P<0.001$). The Tukey's test showed no significant difference in the three sites between as-received and 50% reused groups ($P>0.91$). However, both groups were significantly less than the 100% reused technique ($P<0.002$) in all the sites. The Tukey's test showed that the internal fit at mid-occlusal site was significantly greater than the axial fitting, which is true for all groups ($P<0.01$).
forming interstitial solid solutions of titanium. Because of this, re-melting may affect the amount of oxygen in the metal and lead to change in metal behavior. However, TiAs are less affected by oxygen hardening because, it was superimposed on the hardening as a result of alloying. In addition, reactivity of titanium with oxygen could be reduced by addition of other metallic elements which have higher affinity for oxygen such as Fe. The re-melting may reduce the amount of these elements and deprive the resulting metal from their advantages.

Even though there was a controversy about the acceptable marginal gap, several investigators agreed that a marginal gap of about 100 pm appears to be within the range of what is clinically acceptable for longevity of restorations. If the 100 pm were used as a limiting measure, all the discrepancy measurements lie within the acceptable range.

The results of the present study showed that the mean marginal gap for the as-received metal of single crown castings was 36.87 pm, which was smaller than the values reported by Contreras et al10 (50.8 pm). This improvement in marginal gaps in the present study might be due to using different investment material, the silica-free and phosphate-free, alumina and magnesia-based investment material. Furthermore, this improvement can be attributed to the differences in the methodology such as the direct technique of waxing and the fit-checking procedures.

This study also demonstrated better marginal fit of cast Ti-6Al-4V single crown than reported for cast Ti-6Al-4V or machine-milled CPTi crowns. Contreras et al10 studied the fit of cast CPTi and Ti-6Al-4V alloy crowns before and after marginal refinement by electrical discharge machining (EDM). They concluded that the marginal fit of cast Ti-6Al-4V alloy crowns was significantly better than that of cast CPTi crowns, both before and after the EDM process. Valderrama et al22 reported the internal fit of CPTi crowns made by Procera system to be 511µm at mid axial wall and 134 µm at mid occlusal which was greater than that reported in the present study for Ti-6Al-4V. The better fit of Ti-6Al-4V alloy crowns can be explained by the improved castability which could be attributed to differences in melting temperature, thermal expansion coefficient, and density.

The internal discrepancy results showed that the gap between the restorations and the die were greater at mid-occlusal site than axial sites. This confirmed the finding of Valderrama et al22 for machine-milled Ti crown and Marker et al24 for gold alloy crowns. The most plausible explanation for the difference in the internal discrepancy between occlusal and axial areas is the expansion behavior of the investment material in the casting ring. Both the setting expansion and the thermal expansion during elimination of wax are substantially restricted by the walls of the metal investment ring. Whereas the occlusal surface is unrestricted since it is towards the open ends of the investment ring. Thus the occlusal surface expands more than the axial resulting in a large discrepancy.

One of the limitations of this investigation was that the castings were not cemented prior to internal fit measurements, since minor movement might affect the readings. However, the metal die's 1 mm shoulder and the occlusal v-shaped groove should have decreased the possibility of movements.

The present study results suggest that the remelting of used TiA would result in greater marginal gap than the as received metal. However, these gaps were within the range of what is considered clinically acceptable. The distortion expected to be greater with FPDs. Therefore, investigating the effect of recasting TiA on the accuracy of FPDs of different length appears to be advisable for future studies.

**CONCLUSIONS**

Within the limitations of this investigation, the following conclusions were made:

1. Used Ti-6Al-4V metals could be re-melted once and utilized for casting of single crowns.
2. As-received and 50% reused metal demonstrated better internal fit than the 100% reused metals.
3. Mid occlusal internal fit demonstrated greater value than axial internal fit.

**REFERENCES**


