Original Article

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Effect of commercial dental investments at low temperature on the marginal adaptation of cast cp Ti inlays

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Abstract

Aim: The purpose of this study was to evaluate the adaptation of inlay restorations cast in commercially pure titanium (cp Ti) after inclusion of the wax patterns in either a phosphate-bonded investment (Rematitan Plus®) or a silicon oxide-based investment (Termocast®). **Methods:** The wax patterns were prepared over an inlay-type mold. After waxing, 5 measurements of the marginal adaptation were made on the mesial and distal faces. Five wax patterns were included in each type of investment under vacuum. The cast specimens were repositioned in the mold and other 5 measurements of the adaptation were made based on the same initial testing conditions. Data were analyzed statistically by two-way ANOVA and Duncan's post-hoc ($P<0.01$) using the SPSS statistical software package version 12.0 (SPSS, Chicago, IL, USA). **Results:** The mean marginal discrepancies of the MOD inlays were higher in the Termocast® Group. Termocast® presented significantly greater marginal discrepancy than Rematitan Plus®. Due to the great permeability of the investment refractory material, internal porosity was extremely rare in Rematitan Plus® and more common in Termocast®. **Conclusion:** It may be concluded that Termocast® investment should not be indicated for cp Ti casting due to poor adaptation and porosity on the casting surface.

Keywords: marginal adaptation, titanium, investment, inlay, porosity.

Introduction

Some properties of commercially pure titanium (cp Ti), such as good biocompatibility[1-2] resistance to corrosion[3-5], low density[4] and high mechanical strength[4-7], have led to an increasing use of this material for casting inlays and partial crowns. In addition, titanium alloys present as an alternative for patients allergic to Ni-containing dental alloys[8-9].

In theory, the low weight of titanium and its high strength-to-weight ratio allow the design of more functional and comfortable prosthetic restorations[10]. However, the mechanical properties of cast titanium may be affected by the casting process itself[11-12]. Titanium has an extremely high melting point and react with elements in the air (e.g.: oxygen and nitrogen) and with some investment components (e.g.: magnesium, alumina and calcium) at high temperatures[6,12-14]. Typically, molten titanium (melting temperature = 1660ºC) is forced into a room temperature or preheated (<800ºC) mold[6]. The reactions between molten metal and investment materials result in the formation of the alpha-case (α-case) layer[14-15], which will change the mechanical properties of the surface of titanium castings[16].

The investments usually used for other alloys are based on silica, but this component is present in a low content in investments indicated for titanium casting, because its chemical

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affinity with silicon (Si) affects negatively its mechanical properties[13]. SiO_2 is more unstable and easily reacts with titanium to form more Ti_xO_y, increasing the oxide content in the composite and resulting in higher microhardness of the surface-reaction layers. This is also the reason why the reaction layers formed in specimens cast with SiO_2-based investments are thicker compared to those with Al_2O_3- and MgO-based investments[17].

The specific molds for titanium castings reduce the production of á-case thickness[18], but they are expensive materials and their thermal expansion is not enough to compensate for the titanium casting shrinkage[5,18]. A possibility to overcome these deficiencies would be using investments with smaller silica content and injecting the material in the molds at a low temperature (430ºC)[19]. However, the castability of an alloy is often associated with its ability to fill the mold[20], and mold filling is dependent on numerous factors other than the metal or alloy, such as mold temperature, superheating of the casting, pressure, type of machine, and chemical stability of the investment against the molten titanium[21].

The aim of the present study was to evaluate the accuracy of cp Ti casting when phosphate-bonded and silicon oxide-based investments at a low temperature were used. The null hypothesis tested was that there is no difference between the investments regarding the marginal adaptation of the cast crowns.

Material and methods

The MOD design used in the plastic-die method described in a previous study was employed for the assessment of cast inlay accuracy (Figure 1). Initially, an inlay wax pattern was annealed at room temperature and a reference line was engraved on the wax pattern aligned with a line on the plastic die. The distance separating the margin of the plastic die was measured at two mesial and distal fixed points. Five patterns were made for each investment and a total of 20 inlay specimens were produced, being 10 for Rematitan Plus® phosphate-bonded investment (Dentaurum J.P. Winkelstroeter KG, Pforzheim, German) (Group 1) and 10 for Termocast® silicon oxide-based investment (Polidental Ind. e Com. Ltda., São Paulo, SP, Brazil) (Group 2).

The investments were mixed according to the manufacturers' instructions under vacuum, and were poured over the patterns previously adapted to silicone casting rings by means of a wax sprue. The molds in Group 1 were heated to 150ºC for dewaxing and maintained at this temperature for 90 min, then heated to 250ºC and maintained at this temperature for 90 min. Finally, they were heated to 1000ºC for 1 h to ensure thermal expansion. In Group 2, the molds were heated to 950ºC for dewaxing and maintained at this temperature for 180 min, after which the molds were slowly cooled inside the furnace to a final temperature of 430ºC. Heating was conducted in an electric furnace ((EDG 7000; EDG Equipamentos e Controles Ltda., São Carlos, SP, Brazil) in both groups.

After the heating period, the investment block was transferred to a vacuum-pressure casting machine with 2 chambers and a voltaic arc (Discovery Plasma; EDG Equipamentos e Controles Ltda), programmed and adjusted for a 22-g ingot of CP Ti for each casting (Tritan, grade 1; Dentaurum J.P. Winkelstroeter KG). The upper melting chamber houses a copper crucible and a tungsten electrode, and the lower casting chamber where the invested mold is placed. Titanium was placed on the cooper crucible and the centrally aligned tungsten electrode was positioned 5 mm above the titanium surface. An argon gas pressure and a current were chosen and the mold was shifted from

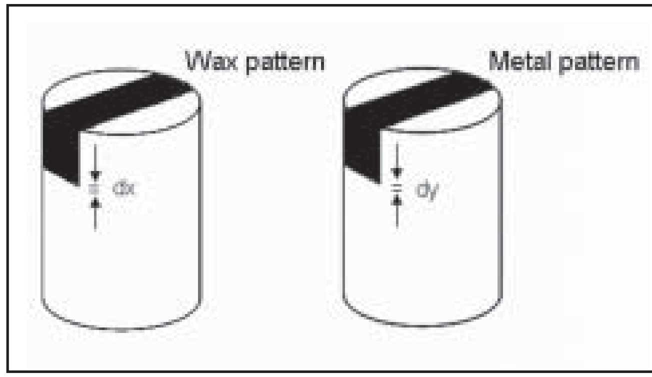

Fig. 1. Dimensional accuracy of a cast crown expressed by the discrepancy measured on its was pattern (dx) and coating (dy) on the same die.

the furnace to the casting.

After cooling to room temperature, the cp Ti castings were divested and airborne-particle abraded with 110-μm aluminum oxide (Renfert GmbH, Germany) at 80 psi to remove the excess investment. A diamond-coated disc was used to separate the inlays from the sprues and they were radiographed to detect possible casting defects that could contraindicate their use[22]. A conventional x-ray equipment (Spectro X; Dabi Atlante SA, Ribeirao Preto, SP, Brazil) set to 70 kV (peak) and 8 mA for a 2-second exposure time was used. The films were developed in a dark chamber according to the manufacturer's instructions and views on the radiograph illuminator. Each inlay was seated in the original plastic die and the distances separating the margin of the inlay were measured at the same two fixed points as the wax pattern using an image analysis system (Leica Microsystems Imaging Solutions Ltd., Cambridge, England) (Figure 1). The internal porosity of the titanium castings was evaluated from the examination of radiographic films of the castings. Porosity was ranked as 0 (without porosity) and 1 (with porosity).

Data were analyzed statistically by two-way ANOVA and Duncan's post-hoc ($P<0.01$) using the SPSS statistical software package version 12.0 (SPSS, Chicago, IL, USA).

Results

The mean marginal discrepancies of the MOD inlays are shown in Figure 2. Group 2 (Termocast®) presented significantly greater marginal discrepancy than Group 1 (Rematitan Plus®) ($P<0.01$). Due to the great permeability of the investment refractory material, internal porosity was extremely rare in Group 1 (Rematitan Plus®) and more common in Group 2 (Termocast®) (Figure 3).

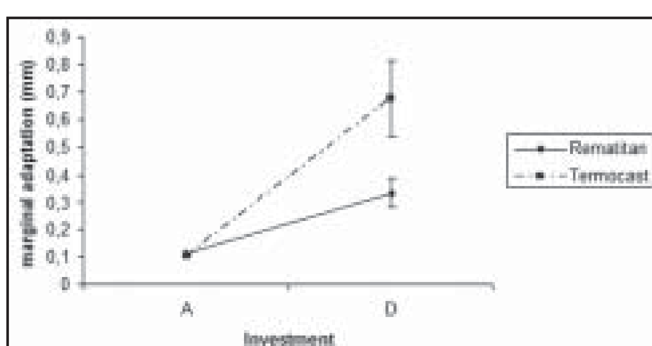

Fig. 2. Marginal discrepancies of the cast MOD titanium inlays invested with Rematitan Plus® and Termocast®. Each line represents the means and standard deviation before (A) and after (B) casting.

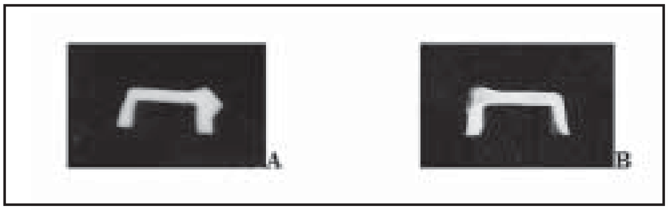

Fig. 3. Radiographic images of a titanium inlay cast with Rematitan Plus® (A) and Termocast® (B).

Discussion

Although the interest in the use of cp Ti and titanium alloys for fabricating restorations increased remarkably in the early 1980s, casting difficulties and structure imperfections are obstacles to be overcome[23]. One of these difficulties is the high reactivity of titanium with some investment elements at high temperatures, in addition to easy oxidization, especially reducing its mechanical properties. In this study, the high reactivity of titanium with the phosphate-bonded base material was manipulated by lowering the investment temperature when molten titanium got in contact with the mold walls.

Luo *et al.*[5] suggested reducing the temperature to minimize the contamination area. Nevertheless, the marginal discrepancy of cast inlay restorations is still higher than the clinically acceptable levels (50 μm)[24], indicating that the reduction of the phosphate-bonded investment temperature does not result in a better adaptation.

In the present study, there was a significant difference in titanium inlays cast in different types of investments. Smaller marginal discrepancy was obtained with Rematitan Plus® investment, which could be explained by lower reactivity between this material and the metal. It is suggested that the better castability obtained with titanium is associated with the chemical stability of the investment against molten titanium, which is one of the main factors of mold filling[19,21]. A greater chemical stability would result in a smaller reaction layer on the titanium surface, resulting in lower fluidity. Also, according to Taira et al.[25], alloying could reduce the detrimental mold reaction because the reactivity of titanium with oxygen could be lowered by the addition of other metallic elements that have a higher affinity for oxygen.

Previous studies[13-14] have reported that titanium restorations cast in phosphate-bonded based investments, such as those in Rematitan Plus (Group 1), resulted in a contaminated surface, with a thickness of 200 μm. Indirectly produced cast restorations have a process that induce marginal discrepancy. Because of the solubility of the cement in the saliva, a marginal cementation line will develop before long into a marginal gap[24].

This contamination of the cast restoration occurred due to the presence of elements such as phosphorus, silicon, and oxygen in the investment material[6,12,16,25]. Especially when the liquid titanium fills the mold at high temperatures, it reduces some of the oxides of the investment material and the free elements (mainly Si, O, P, and Fe) are dissolved into the molten metal; their presence strongly affects the solidification process and, therefore, the final microstructure of the castings[13].

This phenomenon does not occur in the Rematitan Plus® investment due to the presence of magnesium oxide (MgO), calcium oxide (CaO), and aluminum oxide (Al_2O_3) in its composition, which reduces the interaction of titanium with the investment material[26], minimizing the á-case extension[16]. Guilin *et al.*[17] observed that the type of investment affects the reaction layer and the microhardness on the surface of cast titanium, obtaining better results with an MgO-base investment, since it reduces the á-case layer thickness. Nevertheless, the formation of this layer does not result from the reaction between molten titanium and investment, but from cooling molten titanium rapidly. Sung and Kim[15] called it the 'hardening layer'. Thus, the á -case layer of titanium castings consists of the reaction layers, which resulted from the oxide layer, the alloy layer, and the hardening layer.

The reactivity of the alloy with the investment components[27-28], as well as with the gases released[5,28], leads to the formation of porous areas in the inlay restorations cast with phosphate-base investment, which contributes to some mechanical properties suffering variations in ductility, tensile strength, elongation, fatigue and corrosion resistance[11,29], in addition to contributing to a greater marginal desadaptation due to hard reactive areas on the titanium casting surfaces of the molten titanium inter-diffusion with the investment[30]

Internal porosities are commonly observed defects in titanium castings[31] and the technology available for casting titanium also has problems, such as argon pressure affecting the quality of titanium castings. The formation of undesirable porosity affects negatively the mechanical properties of titanium, such as decrease of the tensile strength and elongation[11]. Radiographic analysis of titanium castings with Termocast® (Group 2) revealed an inconsistency of internal porosity. By using x-ray inspection of titanium castings, Wang and Boyle[22] found porosity to be a common occurrence. Results of the present study indicated that Rematitan Plus® investments result in less porosity for the cast titanium MOD inlays. This good castability is probably due to the superior gas permeability caused by the investment[32]. This strongly suggested that radiographic examination should be used to analyze titanium casting for internal porosity before clinical use.

Cast restorations produced indirectly show a process-induced marginal discrepancy, being one of the disadvantages of titanium[33]. Successful restoration must have good marginal seal and design because these factors are essential to protect the luting agent from dissolution and prevent microorganism retention[34]. The primary consequences of the adherence of pathogenic microorganisms to irregular surfaces are the increase of the incidence of oral diseases[34] and the acceleration of biocorrosion by providing retentive niches.

The null hypothesis of this study was rejected, since there was significant difference in the marginal discrepancy between the groups. The investment material should be carefully selected, so that satisfactory castability and accuracy can be obtained.

This study demonstrated that the type of investment affects the marginal adaptation and internal porosity of titanium castings. Cp Ti castings presented higher marginal discrepancy and increased internal porosity when invested with Termocast®.

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