Braz Oral Res
2005;19(2):139-43

Prosthodontics

The influence of mold temperature on the fit of cast crowns with commercially pure titanium

Influência de temperaturas do molde na adaptação de coroas fundidas em titânio comercialmente puro

Wagner Sotero Fragoso*
Guilherme Elias Pessanha Henriques**
Edwin Fernando Ruiz Contreras*
Marcelo Ferraz Mesquita**

ABSTRACT: Commercially pure titanium (CP Ti) has been widely applied to fabricate cast devices because of its favorable properties. However, the mold temperature recommended for the manufacture of casts has been considered relatively low, causing inadequate castability and poor marginal fit of cast crowns. This study evaluated and compared the influence of mold temperature (430°C - as control, 550°C, 670°C) on the marginal discrepancies of cast CP Ti crowns. Eight bovine teeth were prepared on a mechanical grinding device and impressions were used to duplicate each tooth and produce eight master dies. Twenty-four crowns were fabricated using CP Ti in three different groups of mold temperature (n = 8): 430°C (as control), 550°C and 670°C. The gap between the crown and the bovine tooth was measured at 50 X magnification with a traveling microscope. The marginal fit values of the cast CP Ti crowns were submitted to the Kruskal-Wallis test (p = 0.03). The 550°C group (95.0 μm) showed significantly better marginal fit than the crowns of the 430°C group (203.4 μm) and 670°C group (213.8 μm). Better marginal fit for cast CP Ti crowns was observed with the mold temperature of 550°C, differing from the 430°C recommended by the manufacturer.
DESCRIPTORS: Marginal adaptation (Dentistry); Crowns; Titanium; Dental casting investment.

RESUMO: O titânio comercialmente puro (Ti c.p.) tem sido largamente empregado na elaboração de estruturas protéticas fundidas devido às suas propriedades favoráveis. Entretanto, a temperatura do molde recomendada pelo fabricante tem sido considerada baixa, causando inadequada fundibilidade e precária adaptação marginal de coroas fundidas. Este estudo avaliou e comparou a influência de temperaturas do molde (430°C – como controle, 550°C, 670°C) na discrepância marginal de coroas fundidas em Ti c.p. Oito dentes bovinos foram preparados em um torno mecânico e moldados para produzirem oito modelos-mestre. Vinte e quatro coroas foram confeccionadas em Ti c.p. para três grupos de temperatura do molde (n = 8): 430°C (como controle), 550°C e 670°C. A fenda marginal entre a coroa e o dente bovino foi observada em microscópio mensurador (50 X). Os valores de adaptação marginal das coroas fundidas em Ti c.p. foram submetidos ao teste de Kruskal-Wallis (p = 0,03). O grupo fundido a 550°C (95,0 μm) exibiu adaptação marginal significativamente melhor que as coroas dos grupos 430°C (203,4 μm) e 670°C (213,8 μm). Foi observada melhor adaptação marginal das coroas fundidas em Ti c.p. com a temperatura do molde a 550°C, diferindo da temperatura recomendada pelo fabricante, de 430°C.
DESCRITORES: Adaptação marginal (Odontologia); Coroas; Titânio; Revestimento para fundição odontológica.

INTRODUCTION

Commercially pure titanium (CP Ti) has come to be regarded as a promising material for dental prosthetic devices because of its excellent biocompatibility, radiographic radiopacity, high ductility, low thermal conductivity and relatively non-corrosive nature[5]. The possibility of fusing ceramics with titanium crowns has contributed to the rapid growing interest in CP Ti in dentistry. CP Ti has been extensively used to make crowns and fixed prostheses because of its biological and mechanical properties[8,18].

However, in spite of its reliable mechanical properties, when titanium is used to fabricate cast devices, its high melting point and highly chemical reactivity at high temperatures make the manipulation of this material difficult[7]. Titanium has strong affinity to ambient elements and at high temperatures it can be easily oxidized, dissolving

* PhD Candidates; **Associate Professors – Department of Prosthodontics, School of Dentistry of Piracicaba, State University of Campinas.

elements as oxygen, nitrogen and hydrogen[14,18]. Therefore, the reactive nature of titanium and uncontrolled atmospheres used in fabrication of denture frameworks might deleteriously alter the composition and microstructure of the products as provided by the manufacturers[4]. Cast machines have been developed to use inert atmospheric gas to avoid contamination during melting and casting. Titanium has been melted in arc-melting furnace or high frequency heating in argon or helium gas[14].

The castability of titanium can be influenced by the investment material and mold temperature[17]. Investment materials used for casting titanium are refractory materials in which the reactivity with titanium is reduced by using components with low standard free energy of oxide, such as alumina, magnesia and zirconium oxide. However, the formation of the reaction layer or oxide layer is not inhibited by improvement of the investment[10].

The mold temperature recommended by the manufacturer is low to protect the metal from reacting with the investment[15]. However, high thermal expansion for the compensation of the metal shrinkage does not occur at this low temperature[12]. Higher mold temperatures may affect fit of cast titanium crowns by increasing the fluidity of the melted metal during injection in the mold, improving the castability and yielding crowns with clinically acceptable levels of fit[7].

Since the mold temperature recommended by manufacturers has been reported in the literature as relatively low to avoid chemical reactions, leading to lower castability and poor marginal fit of cast CP Ti crowns, the aim of this study was to evaluate and compare the influence of mold temperature of the investment (430°C - as control, 550°C, 670°C) in marginal fit of crowns made with CP Ti.

MATERIALS AND METHODS

Eight bovine teeth with their roots embedded in acrylic resin (Clássico Ltda., Campo Limpo Paulista, Brazil) blocks were prepared based on the protocol reported by Blackman *et al.*[3] (1992): 1.5 mm shoulder finish line and an 8° angle of axial convergence (Figure 1). Preparations were standardized on a mechanical grinding device (TR 600, Riosulense, Rio do Sul, SC, Brazil) with constant irrigation with distilled water at room temperature. Approximately 1 mm below the cervical preparation line, four diametrically opposed reference points (Figure 1) for marginal fit measuring procedures were made using a round bur (KG Sorensen Ind. e Com. Ltda., São Paulo, Brazil) in a rotary instrument (Dabi Atlante, Ribeirão Preto, Brazil)[6].

Twenty-four crowns were fabricated using CP Ti (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) in three different groups (n = 8), each one with a different mold temperature: 430°C (group 1 – control), 550°C (group 2) and 670°C (group 3). Impression trays (Clássico Ltda., Campo Limpo Paulista, Brazil) were used to standardize the thickness of impression material. Vinyl polysiloxane (Aquasil, Dentsply Detrey GmbH, Konstanz, Germany) impressions with a double-mix technique were used to duplicate each tooth and produce eight master dies. They were fabricated with type V dental stone (Exadur V, Polidental, São Paulo, SP, Brazil).

The 0.7 mm-thickness patterns were waxed (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) on the master dies through a wax dipping unit (Hotty, Renfert GmbH, Hilzingen, Germany) and a sprue was waxed in the labial cusp areas with 3.0 mm-diameter wax[13]. The investment material for titanium casts was used (Rematitan Plus, Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) with a ratio of 250 g of powder to 40 ml of liquid. The investment material was dispensed into a mixing vessel and the powder was fully incorporated. The mixing was carried out under vacuum at a speed of 425 rpm for 30 seconds using a mechanical mixer (Degussa, Frankfurt, Germany). The patterns were invested in casting rings (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) through mechanical vibration[12].

After setting, the investment blocks were put in an electric furnace (Vulcan 3.550, Ney Dental Inc.,

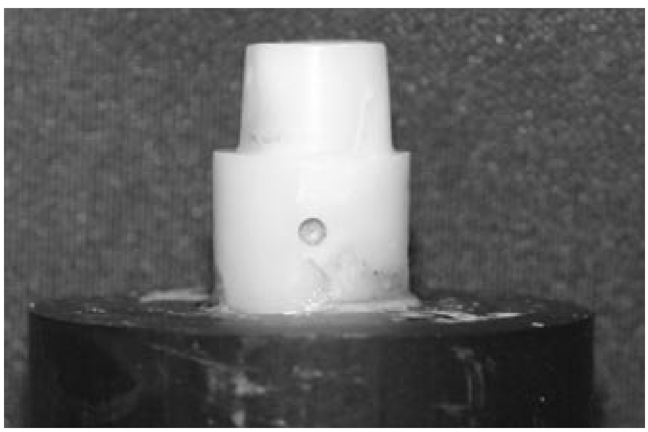

FIGURE 1 - Bovine tooth prepared for full crown restoration embedded in resin blocks and reference points below cervical line for marginal fit measuring procedures.

Yucaipa, USA) at a heating rate of 7°C/minute, following the cycle: 250°C/60 minutes, 1,000°C/90 minutes, and then, cooling in the furnace at a rate of 7°C/minute for the target temperature of each group (430°C, 550°C and 670°C), which was maintained for two hours. The CP Ti crowns were cast in a titanium-casting machine (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) with the use of 31 g ingots and 0.95 bar argon pressure[1,6,19].

After casting, the investment blocks were immediately quenched in cold water and castings were covered with the aid of a sandblaster (Odontolarcon Ind. Bras. Ltda., Maringá, Brazil) using 100 µm-aluminum oxide (N. Martins, São Paulo, Brazil) for 5 seconds at 5.5 bars[3,6,19]. Sprues were removed with a separating disk (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany) and external surfaces of the crowns were finished with tungsten burs (Dentaurum JP Winkelstroeter KG, Pforzheim, Germany). Any nodules that might prevent complete seating of copings were removed with a round bur at low speed.

Each crown of groups 1, 2 and 3 was positioned on their respective bovine teeth and axially loaded at 8.82 N/m^2 to avoid uncontrolled displacement or seating error by application of finger pressure. The gap between the crown and the bovine tooth was measured at 50 X magnification with a traveling microscope (STM, Olympus Optical Co, Tokyo, Japan), accurate to 0.5 µm. An acrylic resin device (Figure 2) was used to align the crown and the tooth margins in the same optic reading plane. The measurements of marginal gap were recorded three times for each predetermined set of reference point. The mean of 12 measurements was considered for each tooth.

The statistical significances were evaluated by the nonparametric Kruskal-Wallis test at the 3% significance level. The identification of the groups that showed significant differences was carried out by the multiple comparison test at the 5% significance level.

RESULTS

The marginal fit values (and standard deviations - SD) of the cast CP Ti crowns fabricated at 430°C, 550°C and 670°C investment mold temperatures are shown in Table 1. The Kruskal-Wallis test revealed statistically significant differences among groups (p = 0.03). The multiple comparison test showed that there were no significant differences between group 1 (203.4 µm) and group 3

TABLE 1 - Means (in micrometers) and standard deviations (SD) of marginal gap for cast CP Ti crowns fabricated at 430°C, 550°C and 670°C mold temperatures.

Group	Means (µm)
1 (430°C)	203.4 A (111.8)
2 (550°C)	95.0 B (26.0)
3 (670°C)	213.8 A (109.1)

Means followed by the same letter do not present statistical difference by the Kruskal-Wallis test at the 3% significance level. Standard deviations in parentheses.

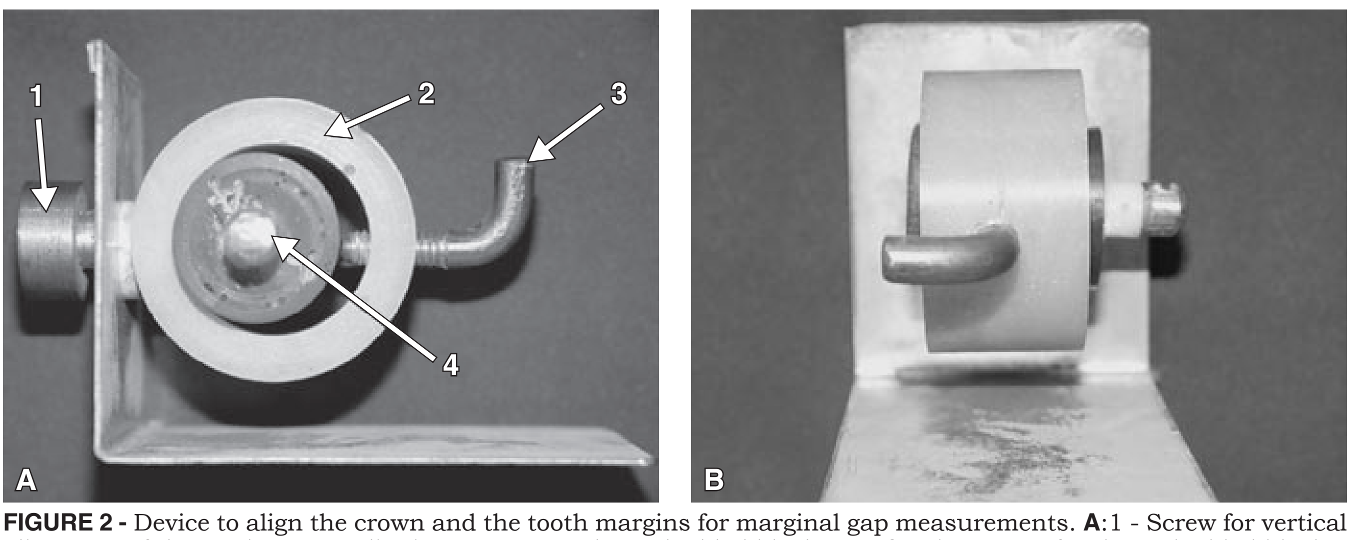

FIGURE 2 - Device to align the crown and the tooth margins for marginal gap measurements. **A**:1 - Screw for vertical alignment of the tooth; 2 - Acrylic ring to support the embedded blocks; 3 - fixation screw for the embedded blocks; 4 - titanium crown; **B**: Lateral view.

(213.8 µm). However, group 2 (95.0 µm) exhibited significantly better marginal fit than the crowns of group 1 and group 3.

DISCUSSION

The technique for accurate CP Ti castings is not yet fully optimized to prevent reactions between the molten metal and investment material[2]. Molten titanium reacts with investment materials, particularly with SiO_2-based or phosphate-bonded investments. This reactivity results in the formation of hard, brittle reaction layers on the cast surfaces, called α-case oxide layer[14,18]. This layer has been removed during the cleaning of cast CP Ti crowns[12], and although the formation of an oxide layer cannot be completely inhibited, low mold temperatures have been used to accelerate the solidification of molten titanium, reducing the reactivity with the investment. As a result, manufacturers have recommended low mold temperatures to minimize the formation of the reaction layer. Nevertheless, this procedure has reduced metal castability and consequently produced dimensional changes in the castings[15].

The castability of CP Ti is modified by factors such as: mold temperature, mold permeability, viscosity and fluidity of metal. Pure titanium can produce more casting defects than other dental alloys, mainly when the investment mold does not allow adequate fluidity of the metal[17]. These factors are under control and CP Ti has been used for fixed partial denture frameworks[18]. However, many studies have still shown that the casting temperature of investment mold presented unsatisfactory results[7,12]. This study analyzed different mold temperatures to find an appropriate investment temperature to cast CP Ti crowns with clinically acceptable marginal gaps, and consequently, the low mold temperature of 430°C (recommended by the manufacturer) was found to show high values of marginal gap (203.4 µm).

Increased gaps when using low mold temperatures were explained by Kikuchi *et al.*[10] (2001), who reported accelerated solidification of molten titanium and reduced castability. In addition, Takahashi *et al.*[15] (1990) reported undersized cast CP Ti crowns for mold temperatures of 350°C. Conversely, Blackman *et al.*[3] (1992) showed satisfactory mean marginal gap (50 µm) using the mold temperature suggested by the manufacturers, although adopting an investment material that allowed control of thermal expansion.

With high mold temperatures, Takahashi *et al.*[16] (1993a) obtained high thermal expansion that allowed compensation for the casting shrinkage of titanium, but greater reaction with investment was produced. Mori *et al.*[12] (1994) and Watanabe *et al.*[18] (1999) reported that the reaction layer is thicker when using high mold temperatures. Air-abrasion with aluminum powder is effective in removing this oxide layer, but the marginal gap of crowns can be enlarged. Supporting this hypothesis, the present study also found greater values of marginal gap (213.8 µm) with a mold temperature of 670°C.

In the present study, the 550°C-mold temperature (different from the manufacturer's instructions) produced 95 µm of mean marginal gap for CP Ti crowns, which was statistically better than that produced with 430°C (recommended temperature) and 670°C. At this intermediate temperature, the fluidity of the molten metal was maintained and marginal gaps were kept to a minimum, even after sandblasting.

In addition, following the manufacturer's instructions and using 430°C as the final casting temperature, the heating cycle for the titanium investment material lasts about 10 hours. After reaching the maximum temperature (1,000°C), with the period of cooling for the target temperature changed to 550°C, the heat cycle can be reduced in about 1 hour, reducing costs in commercial laboratories.

In the related literature, one frequently finds controversial opinions on the clinical relevance of the size of marginal gap. McLean, von Fraunhofer[11] (1971) reported that restorations with a gap extending over a range of 10 to 160 µm at the cervical margin might be tolerable. In the present study, only the 550°C-mold temperature crowns could be considered adequate for clinical application. These results are similar to others that advocated an acceptable clinically marginal fit in the order of 100 µm[6,9,11].

CONCLUSIONS

Within the limitations of this study, it can be concluded that:

1. Commercially pure titanium crowns demonstrated marginal fit clinically acceptable when castings were performed with a mold temperature of 550°C.
2. The fit of CP titanium crowns with the mold temperature of 430°C – as recommended by the manufacturer – and 670°C was considered clinically unacceptable.

REFERENCES

1. Bergman B, Bessing C, Ericson G, Lundquist P, Nilson H, Andersson M. A 2-year follow-up study of titanium crowns. Acta Odontol Scand 1990;48:113-7.
2. Bessing C, Bergman M. The castability of unalloyed titanium in three different casting machines. Swed Dent J 1992; 16:109-13.
3. Blackman R, Baez R, Barghi N. Marginal accuracy and geometry of cast titanium copings. J Prosthet Dent 1992; 67:435-40.
4. Carr AB, Brantley WA. Titanium alloy cylinder in implant framework fabrication: a study of the cylinder-alloy interface. J Prosthet Dent 1993;69:391-7.
5. Cecconi BT, Koeppen RG, Phoenix RD, Cecconi ML. Casting titanium partial denture frameworks: a radiographic evaluation. J Prosthet Dent 2002;87:277-80.
6. Contreras EFR, Henriques GEP, Giolo SR, Nobilo MAA. Fit of cast commercially pure titanium and Ti-6Al-4V alloy crowns before and after marginal refinement by electrical discharge machining. J Prosthet Dent 2002;88:467-72.
7. Inoue T, Inoue A, Asai M, Komasa Y. Fit and dimensional changes of cast CP titanium crowns fabricated using sintered molds. Dent Mater J 2001;20:195-205.
8. Jang KS, Youn SJ, Kim YS. Comparison of castability and surface roughness of commercially pure titanium and cobalt-chromium denture frameworks. J Prosthet Dent 2001;86:93-8.
9. Karlsson S. The fit of Procera titanium crowns. An *in vitro* and clinical study. Acta Odontol Scand 1993;51:129-34.
10. Kikuchi H, Onouchi M, Hsu HC, Kurotani T, Nishiyama M. Titanium casting: the surface reaction layer of castings obtained using ultra-low-temperature molds. J Oral Sci 2001;43:27-33.
11. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an *in vivo* technique. Br Dent J 1971;131:107-11.
12. Mori T, Jean-Louis M, Yabugami M, Togaya T. The effect of investment type on the fit of cast titanium crowns. Australian Dent J 1994;39:348-52.
13. Oruç S, Tulunoglu Y. Fit of titanium and a base metal alloy metal-ceramic crown. J Prosthet Dent 2000;83:314-8.
14. Tajima K, Matsuda S, Kitajima S, Yokoyama Y, Kakigawa H, Kozono Y. Efficacy of gas purging for titanium casting. Dent Mater J 1994;13:206-13.
15. Takahashi J, Kimura H, Lautenschlager EP, Chern Lin JH, Moser JB, Greener EH. Casting pure titanium into commercial phosphate-bonded SiO_2 investment molds. J Dent Res 1990;69:1800-5.
16. Takahashi J, Zhang JZ, Okazaki M. Castability and surface hardness of titanium cast plates obtained from experimental phosphate-bond silica investment molds. Dent Mater J 1993a;12:238-44.
17. Takahashi J, Zhang JZ, Okazaki M. Effect of casting methods on castability of pure titanium. Dent Mater J 1993b;12:245-52.
18. Watanabe I, Watanabe E, Yoshida K, Okabe T. Effect of surface contamination on adhesive bonding of cast pure titanium and Ti-6Al-4V alloy. J Prosthet Dent 1999;81:270-6.
19. Zavanelli RA, Pessanha Henriques GE, Ferreira I, de Almeida Rollo JM. Corrosion-fatigue life of commercially pure titanium and Ti-6Al-4V alloys in different storage environments. J Prosthet Dent 2000;84:274-9.

Received for publication on Jul 13, 2004
Sent for alterations on Mar 03, 2005
Accepted for publication on May 12, 2005