Enhancement of a Titanium Denture Frame Model: Mold Temperature and Spruing Factors

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Received July 31, 1995/Accepted October 27, 1995

This study evaluated the sensitivity of an experimental model to mold temperature using a two-chamber casting machine and its recommended investment (Exp. 1), and the effect of sprue diameter and length using a one-chamber casting machine and its recommended investment (Exp. 2). Experimental patterns were cast from commercially pure titanium and percentage casting success obtained. Mold temperatures of 620, 350 and less than 100°C, and sprues, 4 or 6 mm diameter and 5, 20 or 26 mm long, were used. The effect on casting success of a "non-system" investment was also evaluated in both experiments. The experimental model did not discriminate the two lower mold temperatures (Exp. 1). Casting success was significantly lower with a 4 mm sprue diameter but was not affected by sprue length (Exp. 2). The results suggest the importance of the combination of casting machine, investment type and mold dimension.

Key words: Titanium denture casting, Mold temperature, Sprue dimension

INTRODUCTION

Titanium could be a desirable metal for removable prosthodontics, provided easy and predictable casting were achievable. A simple and objective means of assessing casting techniques is required. Low et al. proposed the use of a wax grid pattern employed in the construction of cast cobalt chromium partial denture frameworks as an experimental model. The model was found to be sensitive to titanium composition. The present study aims at expanding the clinical relevance of Low's model and consists of two parts. The first evaluates the sensitivity of the model to mold temperature using a two-chamber casting system (Experiment 1), and the second examines the effect of sprue diameter and length using a one-chamber casting system (Experiment 2), where "casting system" refers to a casting machine and its manufacturer's recommended investment. A sprue diameter of 4 mm is commonly used in cobalt chromium denture casting and a hypothesis that successful titanium casting requires a sprue diameter greater than this was tested. In addition, the effect on casting success of a "non-system" investment was evaluated in each experiment.

MATERIALS AND METHODS

The experimental pattern (36 x 29 x 0.9 mm) consisted of 100 circles and was used in each experiment. The invested patterns of Experiments 1 and 2 are schematically represented in

* Wax retainer, Renfert, Hilzingen, Germany
All investments were mixed at powder/liquid ratios recommended by the manufacturers with the liquid dispensed into a mixing vessel and the powder sifted into it in 15 s. During the next 15 s the powder was fully incorporated, the vessel was assembled within 10 s, and mixing was carried out under vacuum at a speed of 425 rpm for the specified time using a mechanical mixer**. Ambient laboratory conditions during the preparation and investing of wax patterns were 22±1°C and 50±10% relative humidity. All molds were heated under a control# so that the recommended maximum temperature was achieved within the recommended time for each material. Mold temperature at casting was that recommended by the manufacturer, unless stated otherwise. Commercially pure titanium ingots##, 10 (Experiment 1) or 31 g (Experiment 2), were used for each casting. At least five castings were made for each experimental condition. The number of completely cast circles was counted to obtain a percentage casting success rate. Results were subjected to a Wilcoxon or Kruskal–Wallis rank test.

** Combination unit, Whip-Mix, Louisville, USA
# Eurotherm temperature controller # 818, UK
## KS-50, Japanese Industrial Standard Grade 2
ENHANCEMENT OF A TITANIUM DENTURE FRAME MODEL

Experiment 1
Apart from mold temperature, all experimental conditions employed were identical to those described in the previous study\(^1\), including the use of a two-chamber casting machine\(^*\) and its manufacturer’s recommended investment (A)\(^@\), a crown and bridge investment. Three mold temperatures were tested: the manufacturer’s recommendation 620°C (hereafter, hot mold), 350°C (medium) and less than 100°C (cold), the latter two arbitrarily chosen.

Experiment 2
This experiment used a one-chamber casting machine\(^$\) and its manufacturer’s recommended denture casting investment (B)\(^$$\) and crucible design. Sprues, 4 or 6 mm in diameter, and 5, 20 or 26 mm in length were used. In contrast to Experiment 1 a ringless mold method was used. The mold was formed using a polyvinyl chloride tube of 50 mm internal diameter which was removed after the mold set. A uniform 10 mm thickness of investment from the top of the pattern was maintained and restricted the maximum sprue length to 26 mm.

The investment material (B) was mixed for 30 s with deionised water at a liquid/powder ratio of 0.14 by mass. Ninety minutes after investing, the mold was trimmed flush with the ring top using abrasive paper, the crucible former and ring removed, and the mold placed in a sealed plastic bag for up to 3 h prior to heating.

A maximum of eleven molds were heated in an electric furnace\(^+$\) and then cooled in the furnace as recommended. Casting was carried out at an argon pressure of 570 kPa. The horizontal and vertical distances between the tilted crucible tip and the mold were 5 mm and less than 10 mm, respectively, as recommended. A titanium ingot was positioned 5 mm below the tungsten electrode and arc current was set at 250 A. Each casting was completed within 3 min of mold transfer from the furnace. Melting time was kept at 33±2 s. The molds were bench cooled before devesting in water and then lightly cleaned with glass beads to remove residual investment.

The "non–system" investment incorporated into both experiments was a denture casting investment, (C)\(^++\). It was mixed as recommended with chilled liquid\(^&\) at a liquid/powder ratio of 0.16 by mass, for 60 s. In Experiment 2 when molds prepared from C reached casting temperature they were transferred from the electric furnace to a second smaller furnace \(^&&\) programmed to hold the recommended mold temperature. Casting was commenced 15 min later, taking molds from the second furnace, one at a time. All molds were transferred sequentially, two at a time, to the second furnace where they were held for a minimum of 12 min prior to casting.

\(^*\) Cyclarc, Morita, Osaka, Japan
\(^@\) Titavest CB, Morita, Osaka, Japan
\(^$\) Autocast HC–III, GC Corp., Tokyo, Japan
\(^$$\) T-Invest, GC Corp., Tokyo, Japan
\(^+$\) Carbolite Furnace, Sheffield, UK
\(^++\) Rematitan Plus, Dentaurum Inc, Pforzheim, Germany
\(^&\) Liquid 107–601, Dentaurum Inc, Pforzheim, Germany
\(^&&\) Ceramic Engineering, Sydney, Australia
RESULTS

Experiment 1
The results are summarised in Table 1. The cold mold temperature was approximately 70°C for both A and C. Complete success was obtained with A at the hot mold temperature and this was significantly different from the cold and medium groups (p<0.05). There was no difference between the cold and medium groups with either investment. Success rates from A and C were significantly different (p<0.05) from each other with the "non-system" investment giving lower, but less variable, success rates.

Experiment 2
The results are summarised in Table 2. Mean mold temperatures were 64°C (B) and 430°C (C).

With B, all circles were completely cast only under the most favourable conditions (6 mm sprue diameter and 5 mm sprue length) but there was no significant difference between the three lengths. The success rate was significantly lower when the diameter was reduced to 4 mm (p<0.05), again with no significant difference between the three lengths.

With C, all circles were completely cast regardless of sprue diameter and length but a number of circles (<5%) had full or partial metal infills.

DISCUSSION
The difficulty of casting titanium is often attributed to its high melting temperature (1668°C) but the real difficulty is the large discrepancy between the melting temperature and a low mold temperature. Hinman's pattern demonstrated the impact of this discrepancy on casting success of cobalt chromium alloys. Thus it was important to test the sensitivity of the experimental model to mold temperature and to include an investment recommended for
titanium denture casting. The investment selected (C) had a recommended mold temperature of 420°C and so the hot mold range was not tested. The result demonstrated no significant difference between the cold and medium mold groups for either A or C. The model is not sufficiently discriminative at these temperatures with these machine/investment combinations. The performance of the two-chamber casting machine with regard to denture frame casting requires further investigation with its recommended investment for removable prostheses.

Investments for titanium casting are designed to complement specific casting machines (casting systems). The two-chamber machine uses vacuum/pressure whilst the one-chamber machine uses high pressure argon infusion and consequently their mold permeability requirements differ. Castings from molds with dimensions identical to Experiment 1 (minimum mold thickness 7.5 mm), when cast in the one-chamber machine, were improved by masking the mold4. Hence for Experiment 2 a greater (10 mm) minimum mold thickness was used to standardise argon infusion into the mold during casting. This restricted the maximum sprue length to 26 mm. A pilot study of eight castings, using four masked and four unmasked molds, showed no difference between the two groups, indicating that the greater mold dimensions eliminated the problem of argon infusion in the one-chamber machine.

Experiment 2 demonstrated no statistical difference between sprue lengths. The size and complexity of the casting and the sprue lengths tested, relative to the sophistication of the machine, may account for this. Sprue lengths of up to 35 mm are common clinically but could not be tested under the experimental parameters.

The hypothesis that successful titanium casting requires a sprue diameter greater than that commonly used with cobalt chromium dentures was confirmed in the one-chamber casting system, but it did not hold true for the non-system investment at these sprue lengths. The superior results from C with the 4 mm sprue diameter could be due to the higher recommended mold temperature (420°C). To test this an additional experiment was conducted under the same conditions but at a lowered mold temperature, 70°C. Castings with longer sprue lengths were done first and the high casting success under these adverse conditions precluded the need to test the more favourable 5 mm lengths. The results are summarised in Table 3.

Lowering the mold temperature of C did not significantly affect casting success (p<0.05), corroborating the results of Experiment 1. Interestingly C, designed for a two-chamber system, performed better in the one-chamber machine despite adverse sprue conditions. This suggests the importance of the machine/investment combination.

Table 3  Mean success rate (%)±SD obtained for different combinations of sprue diameter and length with investments C at the lowered mold temperature

<table>
<thead>
<tr>
<th>Investment (mold temperature)</th>
<th>Sprue diameter</th>
<th>Sprue length 26mm</th>
<th>Sprue length 20mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (cold)</td>
<td>4mm</td>
<td>97.0±4.2 (5)</td>
<td>100 (5)</td>
</tr>
<tr>
<td></td>
<td>6mm</td>
<td>99.2±1.3 (5)</td>
<td>99.4±1.3 (6)</td>
</tr>
</tbody>
</table>

*Figures in brackets are number of castings
The amount of residual gas in the mold cavity at casting will vary between casting machines and must be eliminated during casting to prevent it entering the molten metal. Image analysis of the castings made in these experiments would be useful to investigate the distribution of these gases. Gas elimination requires a mold permeability appropriate for the machine. Subjectively B and C differed with respect to ease of devestment, density and mold permeability, with B appearing more permeable than C. Investment A is known to be very permeable\textsuperscript{5}). As part of a two-chamber system reliant on low gas pressure (200 kPa) and a pressure differential between chambers, a permeable mold would facilitate gas elimination, optimising casting success. A denser investment in the same circumstances might hinder purging, adversely affecting casting success. Conversely in a one-chamber system, with high pressure argon infusion (570 kPa) a denser or thicker mold may be advantageous in minimising argon infusion into the mold. These results confirm the need for further investigation.

The best results, from the point of view of number of complete circles cast, were obtained with C. However, the investment mix was very viscous and had a short working time, in spite of chilling the liquid. The resultant castings had metal infill in areas where investment failed to flow through the circles, potentially promoting high casting success.

In dental laboratories reliability and complete casting reproduction are of primary concern. The experimental model demonstrated greater reliability with C and the benefit of larger sprues for B under the present experimental conditions. However it is still not possible to differentiate between a casting completed easily or one just achieving completeness. Thus it is not possible to calibrate the sensitivity of the model or to relate the model to clinical success, although some guidance has been gained from the results.

**CONCLUSION**

1. The pattern proposed by Low et al. was tested for sensitivity to mold temperature using a two-chamber casting system. When casting below the recommended hot mold temperature, a significant decrease in casting success was evident but the experimental model did not show sensitivity to the difference between the two lower mold temperatures.
2. A non-system investment (C) confirmed the experimental model’s lack of sensitivity at the lower mold temperatures.
3. The hypothesis that successful titanium casting requires a sprue diameter (6 mm) greater than that commonly used with cobalt chromium dentures (4 mm) was substantiated in the one-chamber casting system. There was no statistical difference between the three sprue lengths tested. Incorporation of a long sprue (up to 26 mm) for clinical simulation will not be necessary with this casting system.
4. The hypothesis did not hold true for the non-system investment (C) at these sprue lengths and complete casting success was obtained for all sprue diameters and lengths. Under the experimental conditions, the model could not discriminate whether a thicker sprue gave better results.
5. The interaction of factors such as the casting machine, investment type or mold dimension significantly affects casting success and warrants further study.
REFERENCES


熱湯浸漬処理が硬質石こう模型の表面粗さおよび
表面微細構造に及ぼす影響
鬼塚 雅, 上村典子, 梶原浩志, 中島厚生, 末永健市
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熱湯浸漬が硬質石こう模型表面に及ぼす影響を調べる
ために、熱湯浸漬前後の石こう試料表面について、表面
粗さ・二種硬さの測定、および走査型電子顕微鏡の観察
を行い比較検討を行った。その結果、アクリル板に接
して硬化した石こう試料表面は、アクリル板の表面に比
べ表面粗さの増加が認められた。またSEM像では石こ
う結晶の凝集面に多数の空隙が生じていた。これに対
して熱湯浸漬後の試料は、明らかに面荒れが生じ、SEM
像の観察では結晶自体が細くなり、お互いの絡み合いも
弱まっていた。アクリル板は、熱湯浸漬により著しい硬
度の低下を示した。また、熱湯処理後の超硬質石こうと
未処理の硬質石こうとの硬度の比較では、硬質石こうと
同程度か、あるいはそれ以下の値に低下した。以上の結
果から、短時間の熱湯浸漬が石こう模型に大きく影響を
及ぼすことがわかった。

チタン鍛造床作製モデルと臨床要因：鍛型温度とスプルー条件
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前回報告したチタン鍛造床作製技法を評価するための
実験モデルに、二種の臨床要因を加えてさらに検討を加
えた。鍛造機とそれに推奨されている埋没材の組み合わ
せを鍛造システムと呼ぶことにし、実験1では二室構造
鍛造機を用いる鍛造システムによる鍛型温度の影響、実
験2では一室構造鍛造機を用いる鍛造システムによるス
プルー条件の影響を検討した。既製の鍛造システムに第
三の埋没材を導入することの影響も検討した。完全に鍛
造されたモデルパターン保持孔の数により鍛造の成功率
を算出した。メーカー指定の高温鍛型（620℃）では完
全な成功率を得たが、任意に選出した中温（350℃）と低
温（100℃以下）では成功率は低下した。中温と低温では
有意な差がなく、これは第三の埋没材でも同様であった。
コバルトクロム床で一般的な4 mm直径のスプルーよ
リも大きなもののが有利であるという仮定が一室構造鍛
造機システムで証明されたが、臨床使用するような長
いスプルー（26 mm）と短いスプルー（5 mm）との間
には有意な差がみられなかった。第三の埋没材では4
mmの直径でも高い成功率が得られ、鍛造機の作動原理
と埋没材の組み合わせを考慮することの必要性が示唆さ
れた。