Technical note

An Experimental Model for the Assessment of Titanium Denture Casting Techniques

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In order to establish the most suitable technique for the construction of cast titanium denture frames, an experimental model was developed for the quantification of casting success. A relatively large wax pattern (36×29×0.9 mm) was prepared from a grid sheet used for the construction of cast cobalt chromium partial denture frames. The pattern consisted of 100 circles and the number of completely cast circles was counted to obtain a percentage success rate. The castings were complete with pure titanium but incomplete (average 54%) with a titanium alloy. For an inspection of internal defects the radiographic conditions were optimised by adopting a relative density of about 2.0. The procedures described will help in establishing the most suitable casting technique for the construction of titanium denture frames for any casting system employed in a laboratory.

Key words: Cast denture frames, Experimental model, Titanium

INTRODUCTION

Research for special casting machines and investment materials has lead to the development of various techniques for casting titanium (Ti). A simple and objective method is required for the assessment of these techniques. Many methods available for this purpose have recently been reviewed1). Among these that described by Hinman et al.2) for assessing cobalt chromium (Co-Cr) alloy casting uses polyester sieve cloth which provides 100 open squares and 220 segments. The number of completely cast segments gives a percentage designated the 'castability value'. The method is simple and has been adopted for the assessment of Ti castings3-5). However, the counting procedure of incomplete segments may require a photo-enlargement2) and is still somewhat complicated5). The sieves employed by these investigators are up to about 20×20 mm and have a criss-cross design which are small and far from the simulation in view of denture frame casting. It is assumed that various wax patterns available for the construction of Co-Cr denture frames are widely used also for the construction of cast Ti dentures. The purpose of the present study was to develop a simple experimental model which would assist in establishing the most suitable casting technique for the construction Ti denture frames.
MATERIALS AND METHODS

A wax grid sheet* supplied for the construction of base metal denture frames was chosen and this was cut to obtain 100 circles. This simplified the production of wax patterns and the quantification of casting results, and provided an enlarged pattern size, $36 \times 29 \times 9 \text{ mm}$. The diameter of the retention circles was 2.5 mm and the narrowest passage between two circles was 1.0 mm. The peripheries (1.1 mm wide) of the original sheet were retained on two sides of the pattern to examine any effect of the asymmetry on the flow of molten metal. A sprue**, 6 mm in diameter, was attached to the pattern and then to a crucible former in such a way that the length of exposed sprue was 4 mm. Fig. 1 shows the pattern placed in a metal ring, 48 mm in diameter and 70 mm high, lined with a 2 mm thick liner#. The distances between the pattern and the ring wall and ring top were 7.5 and 15 mm, respectively.

An Al$_2$O$_3$/MgO based investment## was mixed with the liquid supplied at a liquid/powder ratio of 0.16 by mass. The liquid was dispensed to a mixing vessel and the investment powder was sifted into it in 15 s. During the next 15 s the powder was fully incorporated into the liquid, the vessel was assembled within 10 s, and mixing was carried out under vacuum at a speed of 425 rpm for 30 s using a mechanical mixer@. The moulds thus prepared were kept in a sealed plastic bag overnight. Ambient laboratory conditions during the preparation and investing of wax patterns were $22 \pm 1^\circ \text{C}$ and $50 \pm 10\%$ relative humidity.

The moulds were heated in an electric furnace at a rate of $7^\circ \text{C/minute}$ to the recommended temperature (900$^\circ \text{C}$), maintained at this temperature for 1 h and then cooled down to 620$^\circ \text{C}$. The casting was carried out in a pressure casting machine@@ at an argon pressure of 200 kPa.

![Fig. 1 A grid sheet wax pattern (36 x 29 x 0.9 mm) placed in a casting ring.](image)

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* Wax retainer, Renfert, Hilzingen, Germany  
** Wax wire, Renfert, Hilzingen, Germany  
# Ceramic liner, Morita, Osaka, Japan  
## Titavest CB, Morita, Osaka, Japan  
@ Combination unit, Whip-Mix, Louisville, USA  
@@ Cyclarc, Morita, Osaka, Japan
Two types of metal, commercially pure Ti (Japanese Industrial Standard Class 2) and Ti alloy (90 Ti-6Al-4V), were cast under a melting program of 20 s. A 10 g ingot was used for each casting and three castings were made for each metal. The casting was complete within 3 min after a ring was transferred from the furnace to the casting machine in each operation. All castings were bench-cooled. Specific cleaning was not carried out since all castings exhibited little reaction with the mould. The sprue was carefully removed to record the mass of the casting and the number of complete circles was counted to obtain a percentage success rate.

The quantitative assessment was followed by an inspection for internal defects. For this optimisation of radiographic conditions was first carried out using one of the pure Ti castings. Four different exposure times, 0.64, 0.5, 0.4 and 0.32 s, were chosen for a dental X-ray unit at 70 kV and 70 mA. A focus film distance of 265 mm was employed for a dental occlusal film which contained two films in the packet. The same recordings were repeated on a different day to monitor variations in the film processing of an automatic processor. Each film developed was placed on a viewing screen and radiographic density was measured at the centre and four corners of the image using a densitometer. An optimised exposure time (0.5 s) was then used for the inspection of the remainder of the castings.

RESULTS

Fig. 2 shows the results from the castings of pure Ti and Ti alloy. All retention circles were completely cast for the three castings with pure Ti and the average (standard deviation) mass was 2.01 (±0.03) g. The casting of Ti alloy was less successful, giving an average success rate of 54% and an average mass of 1.33 (±0.40) g. The difference in the success rates was significant (p<0.05). An increased metal flow was observed along the vertical periphery in each alloy casting.

Table 1 summarises the results of density readings made on a pure Ti casting radiographed at four different exposure times. Fig. 3 shows representative radiographs of the pure Ti and Ti alloy castings taken at an optimised exposure time (0.5 s). None of the complete pure titanium castings were free from internal defects, while these were less prominent in the alloy castings despite their inferiority determined externally.

DISCUSSION

When Takahashi et al. quantified the success of Ti castings using the method described by Hinman et al., the maximum rate (‘castability value’) was about 15%. This is significantly lower than that achieved in the present study. Several factors can be attributed to the low rates. First of all, they had to choose a low mould temperature (350°C) for the conventional

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$\text{Heliodent 70, Siemens, Germany}$

$\text{Ultra-speed DF-49, Kodak, USA}$

$\text{Developer XR24, Durr Dental, Germany}$

$\text{Cool bright illuminator, Radx, Fleurier, Switzerland}$

$\text{Dual reference densitometer, Victoreen, New York, USA}$
SiO$_2$ based phosphate-bonded investments to minimise the reaction between molten metal and mould, and the relatively high mould temperature possible in the present study made the casting much easier, despite the fact that the pattern size was significantly enlarged. Secondly, segments of the Hinmen sieve through which the molten metal flows can be too narrow for rapidly cooling Ti, although the exact dimensions have not been given by the investigators$^{3-5}$. The woven criss-cross design of the sieve also makes the metal flow difficult.

The wax grid sheet chosen for the present study is a pattern used for the construction of base metal denture frames. The thickness (0.9 mm) and overall dimensions proved to be satisfactory only for the casting of pure Ti. The lower success rates with the alloy were
unexpected, since pure Ti and this alloy melt at similar temperatures of 1660 and 1650 to 1540°C, respectively. Each of the incomplete alloy castings exhibited a better metal flow at the periphery which was 0.1 mm wider than the passages between circles. This may indicate that an increase in the thickness is required if a cast denture frame were to be constructed with this alloy, while a thinner grid sheet (25 × 25 × 0.75 mm) has been used in a study of molten Ti flow. In clinical cases, however, major connectors can play a similar role as that displayed by the wider periphery of the present pattern. An alternative solution for the alloy can be an extension of melting time because the molten alloy could be too viscous to flow at the end of the 20 s melting time that was arbitrarily chosen in the present study. The hypothesis that the flow of the two metals is not the same appears to be supported by the difference in the distribution of internal defects revealed by the radiographs. The present method offers an opportunity of testing such a hypothesis and the statistically different success rate observed between the two metals appears to assure sensitivity of the method.

A clinical study on eight removable partial dentures, in which each patient received two dentures (Co-Cr and Ti) of the same design, has shown that the average mass difference between the two dentures is 2.8 g before the addition of resin saddles and teeth. Masses of these Ti denture frames have so far been between 2.7 and 5.0 g for 11 cases. The average mass obtained from the present pure Ti castings (2.0 g) is 74% of the lightest denture frame and further enlargement of the wax pattern or incorporation of a design for major connector might be justified to make the experimental model clinically more valid.

For the difficult process of casting Ti the inspection of internal defects is as essential as the external quantification. In fact externally complete pure Ti castings contain internal defects (Fig. 3). Interpretation of the radiographic information is primarily dependent on the quality of image on the film. Film processing can introduce high variability in density but the introduction of automatic processors has reduced this variability dramatically. A method used for the inspection of welded butt joints in metal recommends that the radiographic density shall not be less than 2.0 and not be above 3.5 inclusive of fog density of 0.3 maximum, although densities below 2.0 may be used. The value of images can also be lost if the viewing conditions are inadequate. For the density of 2.0 a light intensity of 10,000 cd/ m² is necessary but most illuminators used in medical diagnostic radiology are not sufficiently intense to produce adequate intensities for film areas with a density more than 2.0. It
seems reasonable therefore for the general viewing conditions available in medical and dental hospitals to optimise a density around 2.0. This was achieved at an exposure time of about 0.5 s with pure Ti (Table 1). The optimised exposure time is the one commonly used for dental radiography and much shorter than that necessary for Co-Cr and Ni-Cr castings. For example, Kawahara et al.\textsuperscript{11} found that an exposure time of about 90 s was required for these alloys having a similar thickness (1.05 mm) at 70 kV. It is significant that the low density of Ti makes non-destructive quality control of cast denture frames possible with ordinary dental X-ray units\textsuperscript{7}). A radiographic inspection of titanium castings with a clinically realistic design have been reported\textsuperscript{13}). Due to their complex shapes and variations in thickness a single radiograph is not enough for the examination of internal defects. A pattern having an even thickness is practical for the optimisation of radiographic conditions and the inspection of processed radiographs. This must be taken into consideration for further development of experimental models, if that is reasonable and rational. As Luk and Darvell\textsuperscript{1}) commented, the present grid method fails to discriminate between a casting that has only just been successful and one that achieved the target with ease. In the casting of dentures much thought is given to spruing in each case and this may make the actual casting generally easier than for the present model. This requires further investigation. While the comparison of the masses between the present pure Ti castings and available clinical cases indicates that further enlargement or modifications of the wax pattern is justified, the radiographic evidence suggests that the immediate target is to find the conditions which produce internally sound castings with the present model.

The procedures described in this study are feasible in any dental laboratory and facilitate the study of factors influencing the casting success. Some experimental conditions employed in the present study are not those recommended by the manufacturer and their effects can also be investigated. Any model to be used for the improvement of casting should be sensitive to important variables. Much lower mould temperatures than that used in the present study are widely employed for Ti casting. Sensitivity of the present model to the change in mould temperature will be reported in a following paper.

CONCLUSION

The average mass of 2.0 g obtained with the pure Ti castings was 74% of the lightest clinical Ti removable partial denture frame and this may justify further enlargement or modifications of the wax pattern to make the experimental model clinically more valid. However, the immediate target is to make the complete castings free from internal defects. The procedures described in this study will help in establishing the most suitable casting technique for construction of titanium denture frames for any casting system employed in a laboratory.

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使用時の 6.3 MPa に比べ、12.5 MPa の接着強さがあり、さらに 4-META を含まない MMA-TBBO レジンによっても 13.5 MPa という大きな接着強さが得られ、プライマーの有効性が明らかにされた。銅塩含有プライマーを利用することにより、エナメル質と象牙質を 10％リン酸で同時に処理することが可能となり、MMA-TBBO 系レジンの接着操作の簡便化、確実化に寄与するものと思われる。

磁性アタッチメントの MRI への影響
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MRI が応用される場合、撮像領域内に金属、とくに磁性合金が存在すると、アーチワイヤが大きく生じることが、いろいろな文献により、すでに指摘されている。したがって、磁性アタッチメントの MRI への影響を詳細に調べ、明らかにしておくことは、磁性アタッチメントを、設計、製造し、使用する上で、また、MRI を診断に用いる上でも大切であると思われる。そこで、磁性ステンレス鋼として 447J1、XM27、430 の 3 種類を用い磁気特性、寸法、形状のアーチワイヤへの影響を検討した。その結果、それぞれの試料のアーチワイヤの中で、447J1 が最も大きなアーチワイヤを生じる傾向を示し、形状によるアーチワイヤへの差は認められなかった。また、寸法とアーチワイヤの影響距離は比例していた。今回の場合は、材料の透磁率が MRI 画像のアーチワイヤに影響したものと思われる。

タンニン・フッ化物合剤を配合したグラスアイオノマーセメントを作用させた象牙質の F の取り込みと結晶性について
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セメント粉末にタンニン・フッ化物合剤（HY 剤）を 0 wt% (HYO)、1.5 wt% (HY1.5)、5.0 wt% (HY5) および 10.0 wt% (HY10) 配合したグラスアイオノマーセメント（GIC）を作用させたウシ象牙質への F の層別の取り込み量ならびに HYO および HY10 を作用させた象牙質の結晶性を調べた。配合割合が高いほど F の象牙質への浸透が深くなり、アパタイトと結合した F の取り込み量が多かった。全 F の取り込みに対して F がアパタイトと安定に結合するのは時間がかかることが示唆された。また、HY 剤を配合した GIC を作用させることで象牙質の結晶性がより向上することが示唆された。

チタン鋳造床作製技法を評価するための実験モデル
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チタン鋳造床作製における各種の鋳造方法を評価し、最適の鋳造法を確立するために、コバルト・クロム鋳造床の作製に使用されている既製のワックスパターンを用いる実験モデルを検討した。採用したパターンは厚さ
0.9 mm のもので、これをレジン保持孔が総計 100 となるよう 36×29 mm の長方形に切り出した。鉄造が完全であった保持孔の数により成功率を算出することとし、三個の鉄造を純チタンおよびチタン合金（90Ti-6Al-4V）についておこなったところ、平均成功率はそれぞれ100％および54％であった。鉄造体の内部欠陥を検討するにあたっての X 線像の透黒化度はおよそ 2.0 と判断され、純チタンの場合、照射時間 0.5 秒が適当であった。純チタン鉄造体の平均重量は 2.0 g で、11 の臨床例の中で最も軽い鉄造体の 74 ％に相当した。本実験で使用したパターンあるいはこれに類似するパターンの作製は容易であり、成功率 100 ％で内部欠陥のない鉄造体を得る条件をみいだすことが当面の課題と考えられる。