# Effect of casting technique on surface roughness and consequent mass loss after polishing of NiCr and CoCr base metal alloys: A comparative study with titanium

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**Statement of problem.** Surface roughness of cast metal frameworks may lead to difficulties in finishing or polishing procedures and weaken the framework.

**Purpose.** The aim of this study was to assess the surface roughness of 2 base metal alloys, submitted to different casting techniques, to determine the influence of surface roughness on loss of mass after polishing compared to commercially pure titanium castings.

**Material and methods.** Forty disk-shaped wax patterns (8 × 2 mm) were randomly assigned to 5 groups (n=8): (1) CoCr alloy (Wironit), acetylene-oxygen flame casting (WFC), (2) NiCr alloy (Verabond II), acetylene-oxygen flame casting (VFC), (3) CoCr alloy, vacuum casting (WVC), (4) NiCr alloy, vacuum casting (VVC), and (5) commercially pure Ti alloy (Ti) melted by electric arc in argon gas atmosphere. WFC and VFC served as controls. Both NiCr and CoCr alloys were invested in phosphate-bonded investment (Termocast). Ti was invested in ammonium dihydrogen phosphate (Rematitam Plus). The wax patterns and casting techniques were standardized. All specimens were cleaned with airborne-particle abrasion (aluminum oxide). Surface roughness (Ra) was assessed using a surface-test analyzer at 3 different sites. To evaluate the loss of mass, the specimens were weighed on a precision balance, then polished with 150-600 grain sandpaper until clinically acceptable (minimum roughness of 0.09 μm). The specimens were then reweighed. A 1-way analysis of variance (ANOVA) and Tukey HSD test ($\alpha$=.05) were performed.

**Results.** Statistical analysis showed that VVC and WVC had significantly (*P*=.0050; *P*=.0057) smoother surfaces (2.43 ± 0.53 and 2.23 ± 0.49, respectively) than VFC and WFC (2.99 ± 0.44 and 2.83 ± 0.61, respectively), but were not significantly different from Ti (2.49 ± 0.62). The loss of mass (in %) was not significantly different for any group (3.18 ± 0.72, 3.14 ± 0.93, 3.36 ± 1.05%, and 4.14 ± 1.28% for VVC, WVC, VFC, and WFC, respectively). The mass loss of Ti was 4.32 ± 1.16.

**Conclusion.** Within the limitations of this study, the base metal alloys submitted to vacuum casting showed decreased surface roughness, similar to that of titanium, compared to base metal alloys submitted to acetylene-oxygen flame casting. There were no significant differences in loss of mass after polishing for all tested specimens. (J Prosthet Dent 2004;92:274-7.)

## CLINICAL IMPLICATIONS

*In this in vitro study, vacuum casting provided smoother surfaces of NiCr and CoCr alloys than acetylene-oxygen flame casting. Smoother surfaces ease finishing and polishing procedures, especially in areas of difficult access, such as the intaglio surfaces of removable partial denture frameworks. The surface smoothness obtained with vacuum casting was similar to that of titanium.*

Base metal alloys, such as cobalt-chromium (CoCr) and nickel-chromium (NiCr), have been widely used in the fabrication of fixed and removable partial denture frameworks since being introduced to dentistry in 1929.[1,2] These alloys have increasingly replaced gold alloys owing to improved mechanical properties and decreased cost.[3-5] The primary physical-chemical properties of base metal alloys include a lower density than gold alloys, a particularly useful feature in fabricating

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**Table I.** Commercial metal alloys and investments used

| Metal Alloy | Composition (wt%) | Manufacturer | Investment Manufacturer |
|---|---|---|---|
| Verabond II | Ni 75.0; Cr 11.5; Mo 3.5; Si 3.5; Al 2.25; Nb 4.25. | Aalba Dent, Cordelia, Calif | Termocast Polydental, São Paulo, Brazil |
| Wironit | Co 65; Cr 28; Mo 5 | Bego Laboratories, Bremen, Germany | Termocast Polydental |
| Ti | Ti 99.6 | Dentaurum, Ispringen, Germany | Rematitan Plus; Dentaurum |

bulky or extensive maxillary prostheses, and a modulus of elasticity that is nearly twice that of gold alloys, providing fixed and removable partial dentures (FPD and RPD) with the advantage of maintaining rigidity with less bulk.[5] These properties allow for improved esthetics and physiological contouring and the development of a suitable occlusion with less tooth structure reduction.[5] However, technical shortcomings, such as the increased difficulty of grinding and polishing procedures with conventional chairside and laboratory instruments, restricted the use of base metal alloys in dental practice.[5,6] More recently, improvement in alloy composition and development of new manufacturing techniques have optimized the use of these alloys.[6] Despite these advances, shortcomings of the alloys have not been completely overcome and, coupled with improper management procedures such as overheating the alloy or using the oxidizing zone of the flame during casting,[7] repeated failures can occur.[6]

Due to the hardness of these alloys, special equipment is required for cleaning and smoothing the restoration after casting, which considerably limits these procedures in dental offices. Furthermore, machining has been routinely delegated to commercial laboratories, which may lack standardized direct-flame casting equipment, producing frameworks with porous and rough surfaces.[8] An earlier investigation[9] demonstrated that there is considerable loss of RPD framework metal during finishing and polishing techniques, resulting in poor fit of retentive clasp arms and improper contact at the tooth-clasps interface, thus affecting the retention and stability of the RPDs.[10]

According to Dharmar et al,[6] the primary disadvantage of using base metal alloys is the possibility of fracturing RPD clasps during adjustment due to external defects and internal microporosities.[11,12] It has been reported that acetylene-oxygen flame casting procedures may add carbon to the metal alloy,[13,14] thereby modifying its microscopic structure and mechanical properties.[7] In an in vivo study, Quirynen et al[15] concluded that the surface roughness of implant-supported prostheses significantly increased the adhesion of supragingival bacterial plaque, increasing the incidence of dental caries, gingivitis, and periodontal disease.[16,17,18,19,20] Aydin[21] assessed the effect of finishing and polishing on surface roughness of cobalt-chromium castings and reported that appropriate smoothing techniques are fundamental for contouring. This approach may improve oral health, decrease plaque retention, and increase alloy resistance to corrosion.

Although interest in the use of pure titanium (Ti) and titanium alloys for fabricating RPD increased notably in the early 1980s, casting difficulties and framework imperfections were obstacles to be overcome.[22] Mori et al[23] radiographically inspected pure Ti and CoCr alloys and found internal defects in titanium frameworks. Although failures may also exist within CoCr castings, these failures remained undetected, possibly due to the higher density of these alloys. The primary advantages of titanium, in spite of its complex casting technique, are lower weight compared to CoCr frameworks of identical construction, biocompatibility, excellent resistance to corrosion, flexibility, low heat conductivity, and adequate mechanical resistance.[24] The aim of this study was to assess the surface roughness of 2 base metal alloys, NiCr and CoCr, submitted to different casting techniques, and the influence on the loss of mass after polishing, as compared to commercially pure titanium castings.

## MATERIAL AND METHODS

Forty disk-shaped wax patterns ($8 \times 2$ mm) were prepared and randomly assigned to 5 groups of 8 specimens per group. The wax patterns cast with base metal alloys, CoCr (Wironit) and NiCr (Verabond II), were invested in phosphate-bonded investment (Termocast), whereas ammonium dihydrogen phosphate investment (Rematitam Plus) was used for those cast with pure Ti. The materials tested, compositions, specifications, and manufacturer information are listed in Table I. Casting for the various groups was as follows: (1) CoCr alloy, acetylene-oxygen flame casting (WFC), (2) NiCr alloy, acetylene-oxygen flame casting (VFC), (3) CoCr alloy, vacuum casting (WVC), (4) NiCr alloy, vacuum casting (VVC), and (5) commercially pure Ti alloy (Ti) melted by electric arc in an argon gas atmosphere. Vacuum casting of NiCr and CoCr specimens was performed using a casting machine (Neutrodyn Easyti Machine; Manfredi, Torino, Italy) under vacuum pressure (580 mm Hg) and at a temperature of 1370°C for CoCr and 1340°C for NiCr

**Table II.** Effect of casting technique on surface roughness (Ra) and mass loss for CoCr and NiCr alloys compared to pure Ti

| Casting techniques and alloys | Ra (μm) mean ± SD n=8 | Mass loss (%) mean ± SD n=8 |
|---|---|---|
| Acetylene-oxygen flame casting | | |
| CoCr alloy | 2.83[a] ± 0.61 | 4.14[a] ± 0.61 |
| NiCr alloy | 2.99[a] ± 0.44 | 3.36[a] ± 1.05 |
| Vacuum casting | | |
| CoCr alloy | 2.23[b] ± 0.49 | 3.14[a] ± 0.93 |
| NiCr alloy | 2.43[b] ± 0.53 | 3.18[a] ± 0.72 |
| Electric arc in argon gas atmosphere | | |
| Titanium | 2.49[b] ± 0.62 | 4.32[a] ± 1.16 |

[a,b]Different letters indicate significant statistical differences (ANOVA, Tukey test, $P<.05$).

**Table III.** ANOVA surface roughness

| | Sum of squares | *df* | Mean square | F value | *P* value |
|---|---|---|---|---|---|
| Between groups | 8.39 | 4.00 | 2.10 | 7.00 | .00005 |
| Within groups | 32.43 | 109.00 | 0.30 | | |

specimens. Casting of Ti specimens was accomplished using an appropriate casting machine (Rematitam; Dentaurum, Ispringen, Germany).

The cast specimens were carefully cleaned using airborne-particle abrasion with aluminum oxide (50 μm) for 15 seconds to remove investment residues. Afterwards, surface roughness average of the specimens (Ra) was analyzed by a surface-test analyzer (Prazis Rug-03; Arotec, São Paulo, Brazil) at 3 different sites: (1) the center along the diametrical line, (2) 2 mm to the right of the center point and parallel to the diametrical line, and (3) 2 mm to the left of the center point and parallel to the diametrical line. Specimens were numbered and selected at random, using a random number table for polishing and mass loss evaluation. The averages of Ra (μm) and loss of mass (%) were calculated. For the evaluation of loss of mass, the specimens were weighed on a precision balance (AB204; Mettler-Toledo, Greifensee, Switzerland) prior to polishing with 150-600-grit sandpaper (DPV-10; Struers, Ballerup, Denmark).

In a pilot experiment, 3 specimens, 1 of each of the 3 materials tested, were polished until a clinically acceptable smoothness was obtained. Then the roughness of these specimens was determined. An average Ra of 0.09 ± 0.01 μm was obtained. This value was then adopted as a "limit value" to establish the final acceptable polishing condition for subsequent tests. Each specimen was carefully polished alternating with roughness measurements until the limit value was attained. At this point, the specimens were weighed again. Then, the loss of mass percentage related to the initial mass was determined from the difference between the initial and final masses. One-way ANOVA and the Tukey HSD test were used for statistical analyses ($\alpha$=.05).

**Table IV.** ANOVA loss of mass

| | Sum of squares | *df* | Mean square | F value | *P* value |
|---|---|---|---|---|---|
| Between groups | 10.00 | 4.00 | 2.50 | 2.28 | .08 |
| Within groups | 38.36 | 35.00 | 1.10 | | |

## RESULTS

The mean values of surface roughness and ANOVA results for the experimental groups are presented in Tables II and III, respectively. Statistical analysis showed that NiCr and CoCr specimens obtained by acetylene-oxygen flame casting exhibited significantly rougher surfaces than those obtained by vacuum casting (VFC/VVC $P$=.0050; WFC/WVC $P$=.0057). There was no significant difference between the roughness values found for specimens obtained using the vacuum casting technique and pure Ti specimens. The loss of mass was not significantly different for all groups, as observed in the results presented in Tables II and IV.

## DISCUSSION

As previously stated, surface smoothness of cast RPD frameworks is of great importance in preventing retention of microorganisms. The 2 primary consequences of the attachment of pathogenic microorganisms to rough framework surfaces are the increase in the incidence of oral diseases[20,25] and the acceleration of biocorrosion by providing retentive niches.[23] In the present study, vacuum casting significantly decreased surface roughness compared to acetylene-oxygen flame casting for all NiCr and CoCr alloy specimens. The authors could find no literature comparing various casting techniques used for base metal alloys on surface roughness or the comparison of surface roughness of these alloys with titanium. Acetylene-oxygen flame casting may cause overheating of the alloy; moreover, the use of the oxidizing zone of the flame at lower temperatures and an environment rich in oxygen increases oxidation and can result in increased surface roughness.[7] An oxygen-free atmosphere and the absence of flame during induction casting of NiCr and CoCr alloys prevented damage by oxidation to the surface of alloys during casting procedures. The control of the casting temperature may prevent overheating of the materials and, consequently, preclude the creation of porosities by volatilization of components with lower fusion temperatures. Casting of Ti using the electric arc in an argon atmosphere produced similar results. These factors may explain the decreased surface roughness of specimens observed in the present study. It is important to note that there was no difference in surface roughness of NiCr and CoCr within the same casting process, therefore, it can be concluded that the composition of the alloys did not influence surface roughness as much as the casting procedures.

Finishing and polishing procedures can compensate for greater surface roughness resulting from casting processes. Greater surface roughness requires additional finishing and polishing procedures,[7] increasing the time necessary to complete these procedures. Although the time spent for finishing and polishing was not measured in this study, considerably greater time is generally needed to finish and polish rougher specimens. In this regard, using the vacuum casting technique, rather than flame casting, appears to be more advantageous. Furthermore, the removal of additional material to provide a clinically acceptable finish can affect the fit[6] and the resistance of the metal structure,[26] which is important for RPDs, especially in thin areas that require finishing of both the external and intaglio surfaces. Less initial roughness prevents possible weakening of the structure and also contributes to improved internal surface smoothness of RPD components in contact with the mucosa or teeth where access is frequently difficult.

A limitation of this study is that the specimens were polished on only 1 surface and there was no significant loss of mass, thus preventing direct comparison to the clinical situation where the surface of an RPD is polished on both external and intaglio surfaces. However, as expected, there was a tendency towards greater loss of mass for specimens that were rougher initially. From this observation, the conclusion may be drawn that with larger components and more surface area to be polished, the tendency for mass loss should be greater. Also, this study did not evaluate possible structural weakening due to polishing; however, this is an area for future research.

## CONCLUSIONS

On the basis of these findings and within the limitations of this in vitro study, it may be concluded that:

1. Vacuum casting provided significantly smoother alloy specimens compared to flame casting.
2. Vacuum casting of base metal alloys provided specimens with a surface smoothness that was not significantly different from those of commercially pure titanium.
3. There were no significant differences in loss of mass after polishing for all tested specimens.

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