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Effect of Recasting Nickel-Chromium Alloy on Surface Roughness: An *in vitro* Study

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Abstract

Background: Dental casting alloys play a crucial role in the restoration of partial dentition. Among these, Nickel-Chromium (Ni-Cr) alloys are widely used due to their ease of availability, low cost and favourable physical properties. Incorporating at least 50% new alloy into recast Ni-Cr alloy does not significantly alter the mechanical properties of porcelain-fused-to-metal restorations. From both environmental and economic perspectives, recycling dental alloys is a highly beneficial practice.

Aim: To study the influence of recasting Nickel-chromium base metal alloy on surface roughness.

Materials and Methods: A total of 120 wax patterns (10 × 6 × 1 mm) were prepared using modelling wax and invested with phosphate-bonded investment material. After setting, they were subjected to burnout to eliminate wax. A Nickel-Chromium (Ni-Cr) alloy was melted using a torch flame as per manufacturer instructions and cast using a centrifugal casting machine. Castings were bench-cooled, divested, and cleaned. Sprues were removed with high-speed cutting discs, and residual investment was eliminated by sandblasting with 250-µm aluminum oxide for five minutes at a 50 mm distance, followed by ultrasonic cleaning in distilled water. Specimens were divided into six groups (n = 20 each): Group 1 used 100% new alloy, while Groups 2–6 were sequentially cast with 50% new alloy and 50% reused alloy from the preceding group. The surface roughness (Ra) of each specimen was measured using a surface roughness tester, and values were recorded in micrometres (µm). The obtained data was subjected to one-way ANOVA.

Results: Recasting of the alloy showed an increased surface roughness from groups 1 to 6. One-way ANOVA displayed a significant difference among the groups.

Conclusion: Reusing the Ni-Cr alloy resulted in a progressive increase in surface roughness. With each cycle of reuse, a statistically significant rise in the average surface roughness (Ra) was observed.

Keywords: Base metal alloys, Casting, Ni-Cr alloy, Surface roughness.

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1. Introduction

A significant aspect of restoring partial dentition involves the use of dental casting metals, which are essential for fabricating durable and accurate restorations. According to the American Dental Association (ADA) classification system, casting alloys are categorized into three groups based on their weight percentage composition. [1]. High-grade alloys include high-noble dental casting alloys such as gold-platinum (Au-Pt), gold-palladium (Au-Pd), and gold-copper-silver (Au-Cu-Ag), which are known for their excellent biocompatibility and corrosion resistance. Noble alloys, which contain gold along with other elements like palladium or silver, display a more varied composition compared to high-noble alloys and are commonly used in various restorative applications. Predominantly base metal alloys are further classified into four groups: Ni-Cr-Be, Ni-Cr, Ni-high-Cr, and Co-Cr, based on their elemental composition and performance characteristics [2]. These base metal alloys have gained popularity due to their favourable mechanical properties, lower cost, and widespread availability [3].

Base metal alloys were first introduced to dentistry by Eardle and Prange in the 1930s. These alloys, including cobalt, chromium, nickel, and their combinations, offer physical and mechanical properties comparable to those of gold alloys, while also being more cost-effective and having a lower specific gravity [4]. Due to their excellent strength, hardness, and lower density, base metal alloys, particularly Ni–Cr alloys, have become widely used in restorative dentistry. While high-noble alloys were traditionally favoured for their corrosion resistance and biocompatibility, the affordability, availability, and superior mechanical performance of Ni–Cr alloys have contributed significantly to their popularity [5].

The most widely used nickel-based dental alloys typically contain 11 to 25 Wt% Chromium, which contributes to their corrosion resistance and mechanical strength. However, studies have shown that recasting Co–Cr and Ni–Cr alloys can lead to the release of additional elements, including iron (Fe) and copper (Cu), into cell-culture media. This release may have implications for the biocompatibility of these alloys, particularly with repeated reuse [3].

For porcelain fused to metal repairs, adding at least 50% new alloy to recast the old alloy has no discernible effect on the mechanical or physicochemical properties [6]. Predictable expenses can be reduced by 30–40% by reusing the basic metal alloy. Recycling alloys is very beneficial for the environment and the economy because it uses fewer natural resources and lessens contamination from mineral extraction and casting emissions [7]. However, significant research is necessary to completely understand how this procedure affects the quality of dental prostheses. Therefore, this study aimed to evaluate the surface roughness of the new and recast Ni-Cr alloy.

2. Materials and methods

2.1 Materials

In this study, Nickel- chromium alloy (G-Soft, Dentaurum, Germany) with the composition of 66.0% nickel, 26.5% chromium, 5% molybdenum, 1.5% silica, <1% aluminum, Manganese and Boron; modelling wax (AARC Dental, India) with 1 mm thickness, and phosphate-bonded investment (Bellawest, Bego, Bremen, Germany) materials were used.

2.2 Sample preparation

A total of 120 wax patterns of standardized dimensions (10 × 6 × 1 mm) were prepared using modelling wax. These patterns were invested using a phosphate-bonded investment material. After the investment material had been set, the burnout procedure was carried out at a temperature of 850°C to eliminate the wax, thereby creating mold cavities. A Nickel-Chromium (Ni-Cr) alloy was melted using a torch flame, following the manufacturer's recommended melting temperature of 1400°C. The molten alloy was then cast into the molds using a centrifugal casting machine (Fornex 35 E.M., Bego, Germany).

Following casting, the rings were allowed to bench cool to room temperature. The investments were divested, and the cast specimens were retrieved. Sprues were removed using high-speed cut-off discs (Carborandum disc), and any remaining investment material was eliminated by sandblasting with 250-µm aluminum oxide particles (Alox, Bego, Bremen, Germany). Each specimen was sandblasted for five minutes at a distance of 50 mm, followed by cleaning in an ultrasonic cleaner (Codyson, China) using distilled water.

The excess alloy obtained after casting and trimming was reused by mixing it with 50% new alloy. This process was repeated through a total of five recasting cycles using these combinations. A total of 120 cast specimens were fabricated and randomly divided into six groups with 20 in each (n = 20) for surface roughness evaluation. The group allocation was done as described below.
Group 1: Cast using 100% new Ni-Cr alloy.
Group 2: Cast using a mixture of 50% new alloy and 50% remnants from Group 1.
Group 3: Cast using a mixture of 50% new alloy and 50% remnants from Group 2.
Group 4: Cast using a mixture of 50% new alloy and 50% remnants from Group 3.
Group 5: Cast using a mixture of 50% new alloy and 50% remnants from Group 4.
Group 6: Cast using a mixture of 50% new alloy and 50% remnants from Group 5.

2.3 Evaluation of surface roughness

The surface roughness of each specimen was assessed using a contact-type surface roughness tester (profilometer) (Mitutoyo, Japan). Prior to measurement, the specimens were securely positioned on the device platform to ensure stability and minimize vibration during testing. The stylus of the profilometer, equipped with a diamond-tipped probe, was moved across the surface of each specimen under consistent pressure and speed.

The measurements were performed in a controlled environment to reduce the influence of external factors such as dust or temperature fluctuations. For each specimen, three readings were taken at different regions along the flat surface to account for any surface irregularities. The average of these three readings was calculated and recorded as the surface roughness value (Ra), expressed in micrometres (µm). The Ra value represents the arithmetic mean of the surface height deviations from the mean line over a defined evaluation length, providing a quantitative measure of surface texture.

2.4 Statistical analysis

The obtained data were subjected to statistical analysis using the statistical package for social sciences (SPSS) version 26.0, IBM Corporation, NY, USA. One-way ANOVA and post-hoc HSD tests were carried out for intra- and inter-group comparisons, respectively. The p value less than 0.05 was considered statistically significant.

3. Results

The mean surface roughness along with the standard deviation of all the groups are presented in Table 1. The recasting of the alloy demonstrated an increased surface roughness. The surface roughness was gradually increased from group 1 to 6. The group 6 showed the maximum surface roughness (5.2 ± 0.29 µm) and the least was exhibited by the group 1 (2.53 ± 0.15 µm). One-way ANOVA displayed a significant difference ($p<0.001$) among the groups (Table 1). Pair-wise comparison of surface roughness between the groups is presented in Table 2. A significant difference ($p<0.001$) was observed between all the groups.

4. Discussion

Base metal alloys commonly used in dentistry include two primary systems, Nickel-Chromium (Ni-Cr) and Cobalt-Chromium (Co-Cr). This study focused on evaluating the surface roughness of Ni-Cr alloys in both their new and recast forms. The null hypothesis stated that there would be no significant difference in surface roughness between the new and recast Ni-Cr alloys, However, the results of the study rejected the null hypothesis, indicating that surface roughness increased significantly with each cycle of recasting.

Table 1: Comparison between groups of recasting alloy for Average surface roughness

Groups	Mean	Standard Deviation	P-Value
Group 1	2.53	0.15	< 0.001
Group 2	3.32	0.13	
Group 3	3.71	0.11	
Group 4	4.31	0.12	
Group 5	4.72	0.16	
Group 6	5.2	0.29	

Table 2: pair-wise comparison of surface roughness between the groups

Groups		Mean difference	Standard Error	p-value
Group 1	Group 2	0.79	0.054	< 0.001
	Group 3	1.18	0.054	< 0.001
	Group 4	1.78	0.054	< 0.001
	Group 5	2.2	0.054	< 0.001
	Group 6	2.68	0.054	< 0.001
Group 2	Group 3	0.39	0.054	< 0.001
	Group 4	0.99	0.054	< 0.001
	Group 5	1.41	0.054	< 0.001
	Group 6	1.89	0.054	< 0.001
Group 3	Group 4	0.6	0.054	< 0.001
	Group 5	1.02	0.054	< 0.001
	Group 6	1.5	0.054	< 0.001
Group 4	Group 5	0.41	0.054	< 0.001
	Group 6	0.89	0.054	< 0.001
Group 5	Group 6	0.48	0.054	< 0.001

Presswood RG examined the chemical composition and colour of recast alloys and reported no significant change in elemental composition even after six melting cycles, suggesting that the alloy remained chemically stable and highly castable [8]. However, his study also noted variations in surface roughness and tensile strength both within and between groups. These inconsistencies were attributed to factors such as the angle and direction of a sprue attachment [8]. Similarly, the present study observed a progressive increase in surface roughness with repeated recasting of Ni-Cr alloy, despite maintaining a consistent 50% addition of new alloy in each cycle. Although the chemical stability of the alloy may remain intact, the results are consistent with Presswood's observation that mechanical surface properties can be influenced by casting process variables, emphasizing the need for careful control of these parameters in both clinical and laboratory environments.

According to Anusavice, surface imperfections and roughness are key contributors to poor-quality castings. Irregularities on the tissue surface can interfere with the proper seating of the restoration, while roughness on the external surface necessitates additional time and effort for finishing and polishing procedures [9].

In contrast to the findings of the present study, which demonstrated a significant increase in surface roughness with each successive recasting of the Ni-Cr alloy, Hesby et al. reported no notable changes in the physical properties of the alloy even after four recasting cycles. This discrepancy may be attributed to differences in methodology, such as the percentage of new alloy added, casting technique, or surface treatment protocols, all of which can influence the final surface characteristics of the castings [10].

Agrawal A *et al*. [2] reported that recasting significantly increases the surface roughness of dental alloys, supporting the findings of the present study. Similar to their observations, our results demonstrated a progressive rise in surface roughness with each recasting cycle of the Ni-Cr alloy, even when supplemented with 50% new alloy. This reinforces the concern that repeated reuse of alloy can adversely affect surface quality, potentially impacting the fit and finishing of cast restorations.

Jadhav VD *et al*. evaluated the surface roughness of disc-shaped metal specimens fabricated using two different casting techniques. Upon examination under a scanning electron microscope, they observed that specimens produced through the accelerated casting method exhibited greater surface roughness compared to those fabricated using the conventional casting technique. These findings highlight the influence of casting protocols on the final surface texture of dental alloys [11].

Based on the findings of the present study, it can be hypothesized that the observed increase in surface roughness is likely attributed to multiple factors, including changes in alloy composition, the development of microporosity, loss of critical trace elements such as manganese, chromium, and molybdenum, formation of oxide layers, and the incorporation of atmospheric gases like oxygen and nitrogen during repeated melting and casting cycles. Surface roughness is a persistent issue that is easily noticeable in all of the castings under consideration. Porosity-containing castings have a smaller effective cross-sectional area that is equivalent to the defect's magnitude [12]. These are basically weak spots that have an impact on physical characteristics and change test outcomes.

The present study, while providing valuable insights into the effect of recasting on the surface roughness of Ni-Cr dental alloys, has certain limitations. The study was limited to a single alloy system and a fixed 50% new-to-old alloy ratio, which may not reflect variations in clinical practice. Moreover, only up to five recasting cycles were analyzed. Additionally, only surface roughness was evaluated, without assessing other critical properties such as tensile strength, hardness, corrosion resistance, and metal-ceramic bond strength. Future studies should focus on a comprehensive evaluation of mechanical and metallurgical properties, include in vivo investigations, and explore the effects of different casting techniques and alloy systems. Assessing the impact of recasting on the bond strength with porcelain and varying new-to-old alloy ratios would also enhance the clinical relevance of such research.

5. Conclusion

Based on the results, this study concludes that the fresh alloy (Group 1) showed a notable difference in both maximum and average surface roughness compared to the recast alloy (Groups 2 to 6). The surface roughness progressively increased with each recasting cycle, indicating a cumulative effect on surface quality despite the addition of 50% new alloy in each subsequent group.

Conflicts of interest: Authors declared no conflicts of interest.
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