Original Article

Analyse the effect of different investment techniques and pattern materials on surface roughness of raw Ni-Cr castings – An *In Vitro* study

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Abstract

Aims: This study aimed to analyze the effect of different investment techniques and pattern materials on the surface roughness of raw castings from nickel-chromium alloy.

Settings and Design: This is an experimental in vitro study carried out in Bharati Vidyapeeth Dental College and Hospital, Sangli, Maharastra.

Materials and Methods: Sixty square-shaped wax patterns, measuring 10 mm × 10 mm × 2 mm, were divided into four groups. A phosphate-bonded investment material (Bellasun, Bego, Germany) was used to invest 15 samples of inlay wax and kept under normal atmospheric pressure and the remaining 15 wax patterns were invested under a pressure of 3 bars for 30 min, and then allowed to bench set for another 30 min. The same investing techniques were carried out for the remaining thirty samples made from pattern resin.

Statistical Analysis Used: The surface roughness (µm) of the castings was measured by a profilometer. Student's "unpaired *t*-test" was used for the statistical analysis.

Results: Specimens that were invested at atmospheric pressure had significantly more surface roughness (µm) values than those invested under increased pressure ($P < 0.01$).

Conclusions: Wax patterns exhibited the least surface roughness when invested under pressure and can be recommended as the material and technique of choice. In addition, resin patterns invested under increased pressure produced smoother casting surface than those invested at atmospheric pressure, and the difference is highly significant.

Keywords: Nickel-chromium alloy, raw nickel-chromium castings, surface roughness

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INTRODUCTION

Cast restorations are an inherent part of prosthodontic treatment. Taggart[1] in 1907 introduced lost wax process for cast restorations, which is used frequently in dentistry. The objective of the casting is to fabricate an exact replica of wax pattern in an alloy which fits accurately on the

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die and in turn in the oral cavity. The casting should be smooth and devoid of any defects, especially at the margins. Smoothness of the casting and accurate fit can reduce the time required for finishing and polishing.

Rough surface and margin gap augment plaque accumulation which may ultimately lead to periodontal destruction resulting in loss of abutment and failure of restoration. Because of various materials and procedures used in the fabrication of cast restorations, some defects are often observed. These casting defects are classified into the following four categories: (1) distortion, (2) surface roughness and irregularities, (3) porosities, and (4) incomplete or missing castings. Surface roughness are nothing but spaced imperfections, of which the height, width, and direction establish the predominant surface pattern.[2,3] Minimal surface roughness on the outer surface of the casting can be removed during finishing and polishing procedures, but these defects on the intaglio surface have a great bearing on the overall longevity of the restorations.[4] Therefore, our aim should be to have decreased surface roughness and irregularities on the "as-cast" restorations, especially on the intaglio surface.[5]

Bedi *et al*.[6] studied the effect of different investment techniques on the surface roughness and irregularities of gold palladium alloy castings and concluded that surface irregularities were decreased on castings produced in a positive pressure chamber. As a result, finishing of the crown will be faster with improved fit of the restoration.

Due to unaffordable high prices of gold, the use of precious metal alloys has decreased considerably and replaced by base metal alloys to a large extent owing to improved physical and mechanical properties, including low specific gravity which reduces the weight of the castings and very high bond strength to the base metal alloys.[7,8]

Various studies are available on the factors affecting the accuracy of cast restorations made from wax patterns, but there is a dearth of literature on the effect of resin being used for the fabrication of pattern. In addition, literature is lacking on the effect of investing under more-than-normal atmospheric (positive) pressure on the surface roughness of raw nickel-chromium (Ni-Cr) alloy castings. Hence, the purpose of this study was to evaluate the effect of different investment techniques and two pattern materials on the surface roughness of the castings obtained from Ni-Cr alloys.

The null hypothesis was that the different pattern materials and investment techniques would have no effect on the surface roughness of castings when Ni-Cr alloy and phosphate-bonded investment materials were used.

MATERIALS AND METHODS

This is an experimental *in vitro* study. The sample size was calculated using "G power" software Version 3.1.9.2 (Heinrich Heine University, Dusseldorf, Germany), based on the article and was estimated accordingly. The study was conducted in 2012 and approved by institutional review board.

Fabrication of metal die

A stainless steel die of 28 mm × 28 mm was used to fabricate the standardized patterns. This stainless steel die was 8 mm thick and had a square slot at the center of the die measuring 10 mm × 10 mm [Figure 1]. A flat, snugly fitting steel plate could pass through this die, leaving a slot of 10 mm × 10 mm × 2 mm dimension above the plate, and a base is provided over which the molten inlay wax (Bego, Germany) and pattern resin (GC Corporation, Tokyo, Japan) could be poured in. The steel plate could be removed from the die after the pattern materials hardened.

Fabrication of patterns

Wax patterns were prepared by pouring molten inlay wax into a square mold which produced test samples of 10 mm × 10 mm × 2 mm in dimension. After filling the mold with molten wax, a lubricated glass slab was placed in contact with the die. The lubricated glass slab removed excess wax and provided a smooth, glossy, and standardized wax pattern surface. The surface of the wax pattern in contact with the lubricated glass slab was used to evaluate surface roughness in order to reduce processing errors. The wax was allowed to cool until it lost its luster completely, and then the glass slab was removed. The mold assembly was immersed in room-temperature water. In few minutes, the specimens could be removed easily without marring the surface which had been in contact with the glass slab. Care was exercised not to touch the smooth surface during the subsequent procedure. The surface of the wax pattern in contact with the glass slab was used for evaluating the surface roughness and

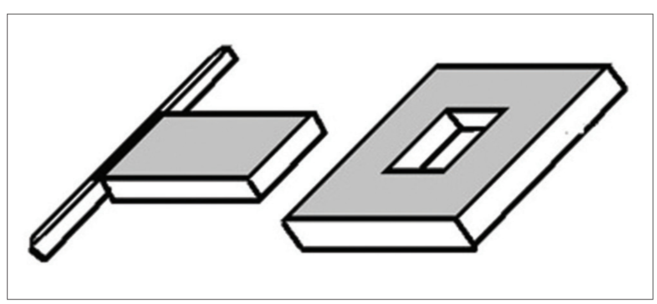


Figure 1: Schematic diagram of the metal die

irregularities of the castings. Thirty such specimens were prepared for casting. The same standardization was followed for the fabrication of thirty pattern resin test samples with the brush-on technique. A total of sixty patterns (thirty wax and thirty pattern resin) were sprued on four runner bars. It was ensured that the smooth surface of all the patterns was facing toward the center of the ring only so that after casting, the surface to be tested could be easily identified. The patterns of different groups were attached to the crucible former and marked as Groups A, B, C, and D.

Investing

The set of 15 samples in each group were divided as follows:

- Group A: Fifteen samples of inlay wax invested and kept under normal atmospheric pressure
- Group B: Fifteen samples of inlay wax invested and kept under 3 bars positive pressure
- Group C: Fifteen samples of pattern resin invested and kept under normal atmospheric pressure
- Group D: Fifteen samples of pattern resin invested and kept under 3 bars positive pressure.

Investing was done in a phosphate-bonded investment material (Bellasun, Bego, Germany). Investment material powder was mixed with 100% special liquid (Begosol, Bego, Germany) as per manufacturer's recommendations. Investing was completed for the total of sixty samples in four rings with two different investing techniques.

Group A and Group C patterns were allowed to set under normal atmospheric pressure for 1 h. The Group B and Group D patterns were placed in a pressure chamber (Acryfam-acrylic facing machine, Vilman, Pune, Maharashtra, India) immediately after investing and allowed to set under 3 bars of pressure for 30 min, followed by bench set for another 30 min. After setting, indications of Group A, Group B, Group C, and Group D were marked on the top of the ring for easy identification.

Casting procedure and retrieval of test samples

The castings were done with Ni-Cr base metal alloy (Wiron 99, Bego, Bremer Goldcschlagerei Wilh.Herbst GmbH & Co.KG, Bremen, Germany). The castings were not sandblasted. Care was taken not to touch the surface being tested with bur or any sharp instrument. All the samples after cleaning were tested as raw castings.

Measurement of surface roughness

Surface roughness (R_a) was measured with the help of a profilometer [SJ – 210 Surftest, Mitutoyo, Neuss, Germany, Europe, Figure 2] which had a working range of 250 μ. The specimens of one group were placed on the platform of the profilometer one by one. The diamond stylus tip of the profilometer contacted the surface of the specimen at different places at a constant speed of 0.05 mm/s with a force of 0.7 mN.

As soon as the tip contacted the surface of the specimen, the surface roughness measurement was recorded which was characterized by height parameter R_a in microns. Five such readings were recorded by the profilometer for each specimen over the transverse length of 10 mm, and the same procedure was followed for the remaining specimens. The arithmetic mean of these absolute values of the profile departures was calculated automatically by the equipment and was displayed on the screen as average surface roughness. All the samples of the four groups were tested, and the values obtained were tabulated [Figure 3].

Table 1: Surface roughness in all groups under study

Samples	Group A (μm)	Group B (μm)	Group C (μm)	Group D (μm)
1	5.888	1.598	4.343	3.767
2	6.889	1.490	5.444	4.787
3	6.587	1.722	3.423	2.564
4	4.188	2.028	3.545	3.676
5	3.289	2.392	4.545	4.689
6	3.988	3.798	4.698	6.889
7	4.988	3.414	5.676	4.565
8	5.289	2.018	6.787	5.887
9	4.478	2.696	7.988	4.575
10	6.278	2.501	5.789	4 0.676
11	5.208	3.022	5.897	4.266
12	5.277	2.342	5.989	4.578
13	5.116	2.342	5.989	5.689
14	4.177	2.482	6.997	4.877
15	3.345	2.696	6.387	6.544
Mean	5.186	2.436	5.573	4.801

Figure 2: Profilometer – To check surface roughness

RESULTS

After testing the samples, the data obtained were tabulated and subjected to statistical analysis using Student's "unpaired *t*-test" [Tables 1 and 2]. Group B showed minimum surface roughness with the least standard deviation value of 2.44 ± 0.64 μm, which proves that the wax patterns invested under more than atmospheric pressure produced the smoothest surface [Graphs 1-3]. This may be because of the pressure which forces the investment material more closely to the pattern and also reduces the size of air bubbles. In addition, the smoothness and compactness of the wax patterns may be another reason for less surface roughness.

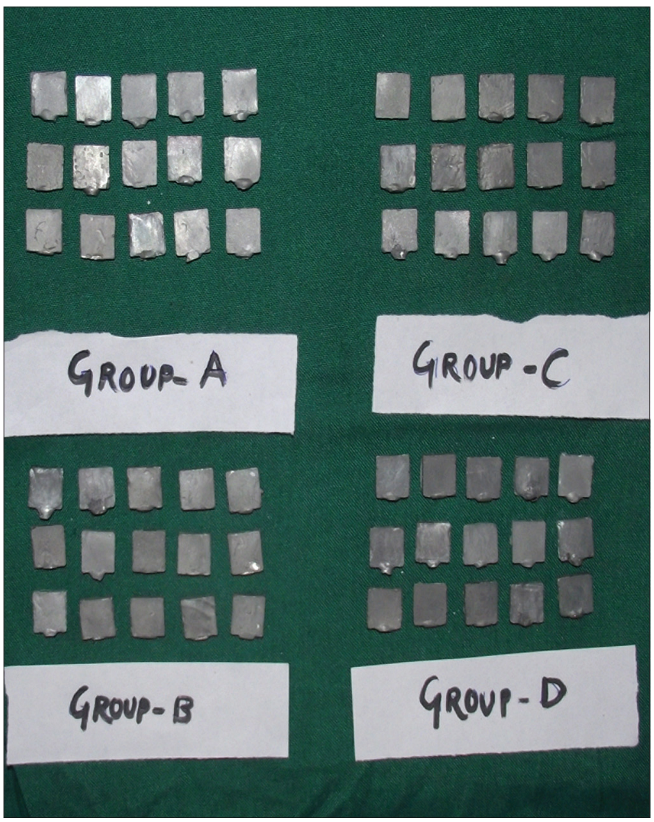
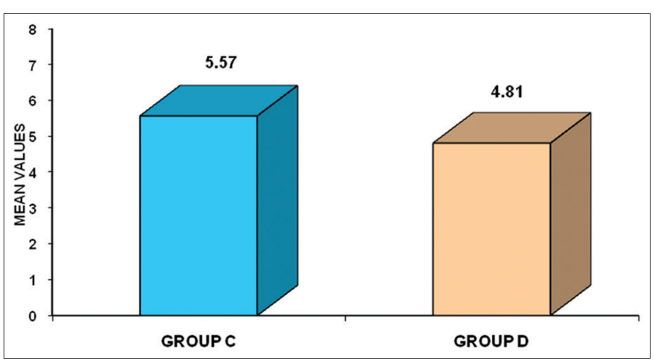


Figure 3: All the samples from different groups



Graph 2: Comparison of mean surface roughness in Group C and Group D

Table 3 and Graph 4 show the comparison of mean and standard deviation (SD) of surface roughness (μm) between Group A and Group B. The mean ± SD of Group A was 5.18 ± 1.07 and that of Group B was

Table 2: Mean and standard deviation values of surface roughness in all groups under study (*n*=15)

	Surface roughness (μm)	
	Mean±SD	Range
Group A	5.18±1.07	3.988-6.899
Group B	2.44±0.64	1.4903-3.798
Group C	5.57±1.27	3.424-7.988
Group D	4.81±1.14	2.564-6.889

SD: Standard deviation

Table 3: Comparison of mean values of surface roughness (μm) in Group A and Group B (*n*=15)

Mean±SD		Unpaired *t*-test value	*P*	Result
Group A	Group B			
5.18±1.07	2.44±0.64	17.12	<0.01	Highly significant

SD: Standard deviation

Table 4: Comparison of mean values of surface roughness (μm) in Group B and Group D (*n*=15)

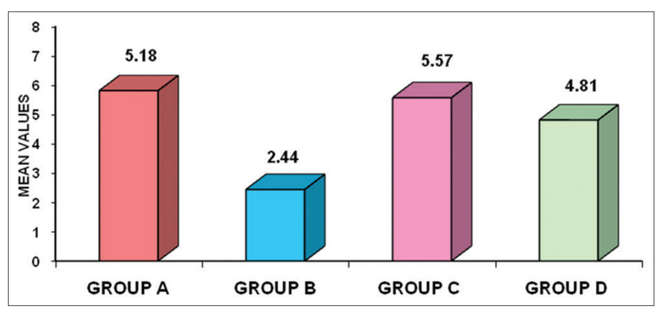
Mean±SD		Unpaired *t*-test value	*P*	Result
Group B	Group D			
2.44±0.64	4.81±1.14	14.36	<0.01	Highly significant

SD: Standard deviation

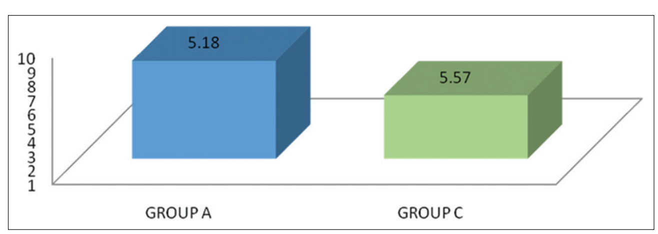
Table 5: Comparison of mean values of surface roughness (μm) in Group A and Group C (*n*=15)

Mean±SD		Unpaired *t*-test value	*P*	Result
Group A	Group C			
5.18±0.64	5.57±1.14	1.46	>0.05	Not significant

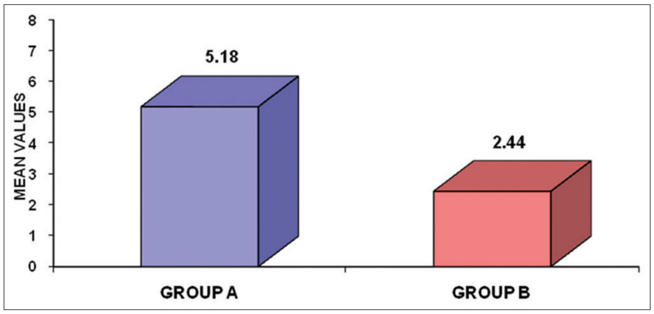
SD: Standard deviation



Graph 1: Surface roughness in all groups



Graph 3: Comparison of mean surface roughness in Group A and Group C



Graph 4: Comparison of mean values of surface roughness in Group A and Group B

Table 6: Comparison of mean values of surface roughness (μm) in Group C and Group D (*n*=15)

Mean±SD		Unpaired *t*-test value	*P*	Result
Group C	Group D			
5.57±1.27	4.81±1.14	1.72	>0.05	Not significant

SD: Standard deviation

2.44 ± 0.64. By applying Student's "unpaired *t*–test," there was a highly statistically significant difference between mean values of surface roughness in Group "A" and Group "B" (i.e., $P < 0.01$).

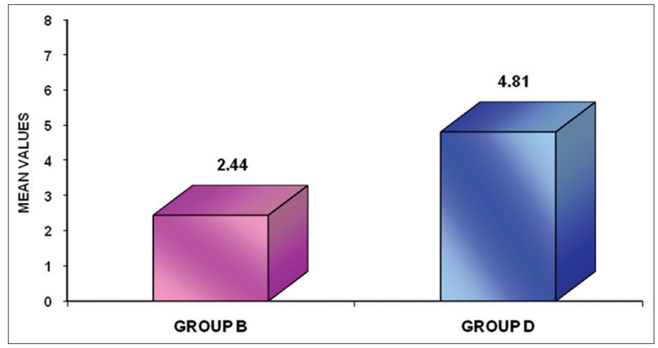
Table 4 and Graph 5 show the comparison of mean values of surface roughness (μm) in Group B and Group D. The mean ± SD of Group B was 2.44 ± 0.64 and that of Group D was 4.81 ± 1.14 [Tables 5 and 6]. After applying Student's "unpaired *t*–test," there was a highly statistically significant difference between the mean values of surface roughness in Group "B" and Group "D" (i.e., $P < 0.01$).

DISCUSSION

Based on the results, the null hypothesis was rejected. A significant difference was observed in the surface roughness of dental castings obtained from different pattern materials set under positive pressure.

Surface roughness of dental castings can potentially affect their marginal fit and the time required for finishing and polishing. It is preferable that the surface of "raw" crowns be smooth to obtain better marginal fit and reduce the finishing and polishing time. Surface morphology and increased bacterial adhesion may enhance the corrosion process.[9,10] Surface quality also governs fatigue life. The fatigue phenomenon, generally evaluated by corrosion–fatigue strength tests, is accelerated by surface qualities.[11,12] There is a tendency toward greater loss of mass for specimens that were rougher initially.

Due to the hardness of base metal alloys, special equipment/materials are required for finishing and



Graph 5: Comparison of mean surface roughness in Group B and Group D

polishing the restoration after casting, which considerably limits these procedures in dental offices.[13,14] Significant metal surface roughness requires extra time for finishing and polishing procedures, which gets added to the cost of cast prosthesis.[15,16] Furthermore, less roughness of raw crowns prevents possible weakening of the structure.[17,18]

Studies conducted by Lacy *et al.*[19] and Johnson[20] had shown that vacuum mixing was more beneficial than hand mixing in reducing air bubbles. Hence, in the present study, the investment was mixed using a vacuum mixer. According to Johnson and Winstanley,[21] application of positive pressure to setting investment decreases air bubble entrapment. Therefore, investment technique that combines vacuum mixing and positive pressure investing was used as one method for investing.

Studies done by Ogura *et al.*[22] on surface roughness of cast base metal alloys suggested that the surface of "raw" restorations obtained with wax patterns ranged from 9 to 11 μm. The surface roughness values in the present study varied between 2.44 and 5.18 μm for the castings obtained from wax pattern samples, which is much more superior and more acceptable as far as plaque accumulation is concerned.

The accuracy of the wax pattern is very important for obtaining a well-fitting casting. Among the materials used in dentistry, dental waxes have greater coefficient of thermal expansion.[23] When a wax pattern is made with molten wax, there is shrinkage of the pattern on hardening. In addition, internal stresses develop in the pattern which get released only when the pattern is removed from the die. This may distort the pattern, which will ultimately lead to inaccurate casting release when the pattern is removed from the die.

Research studies showed that the surface roughness of as-cast crowns is always greater than that of wax patterns from which castings are obtained.[24,25] Even though the patterns obtained from wax have some advantages, the aforementioned disadvantages do not make it a suitable material for all conditions.[26] Hence, pattern resin can be used as an alternative material in certain cases such as implant restorations, extensive core buildup, and telescopic bridges. The pattern resin has definite advantages, for example, it has great stability even in thin layers, good surface reproduction, no deformation at room temperature, less dimensional changes, and perfect fit of the pattern. No study have been done on the surface roughness of castings obtained from Ni-Cr alloy which used pattern resin as a pattern material.

The use of pressure which is greater than the atmospheric pressure may also be an effective method to produce smooth castings.[27-30] The rationale is that the pressure acts by reducing the size of the air bubbles present in the investment. The rationale is that the pressure acts by reducing the size of the air bubbles present in the investment. Chandler *et al*.[31] recommended positive pressure during investing and documented that this technique had been successfully used by them for more than 20,000 castings. Johnson[20] studied the effect of five investing techniques on air bubble entrapment and nodules formed during casting. He reported that the use of pressure in investing significantly reduced the number of nodules. Johnson and Winstanley[21] studied the effect of pattern angle and investment technique on air bubble entrapment. The volume of air bubbles was not found to be significantly affected by the different investing techniques under normal atmospheric pressure. This is in accordance with the findings of Johnson and Winstanley[20,21] who also concluded that the use of pressure chamber showed a marked improvement in the surface roughness and surface irregularities of the castings. The results of the present study are in agreement with those published by Johnson.[20]

The accuracy of the marginal fit of restoration is essential for its longevity and a healthy periodontium.[32] Surface roughness and accurate fitting are important criteria for clinical longevity of fixed dental prosthesis. Rough surface can indirectly result in marginal gap width and ultimately to microleakage.[33] Vertical marginal discrepancy of cast copings fabricated with pattern resin had less marginal discrepancy compared with that of inlay casting wax.[34]

CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:

1. Pressure has significant effect on surface roughness from as-cast restorations from resin patterns. Wax patterns invested under normal atmospheric pressure produced poorest results, whereas wax patterns invested under positive pressure gave the best results
2. Wax can be recommended for routine use as a pattern material to be invested under positive pressure. However, pattern resin should be used in situations which demand multiple restorations, extensive core buildup, and implant restorations

Clinical implications

Wax can be recommended for routine use as a pattern material to be invested under positive pressure. However, pattern resin should be used for situations which demand multiple restorations, extensive core buildup, and implant restorations. As a result, adjustment and finishing of the crown can be easier for both the technician and the clinician while the fit of the restorations can be improved as well.

Future research directions

Different alloys such as titanium can be evaluated.[35]

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Conflicts of interest

There are no conflicts of interest.

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