Original Article

Marginal accuracy of nickel chromium copings fabricated by conventional and accelerated casting procedures, produced with ringless and metal ring investment procedures: A comparative *in vitro* study

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Abstract

Background: Conventional investing and casting techniques are time-consuming and usually requires 2–4 h for completion. Accelerated nonstandard, casting techniques have been reported to achieve similar quality results in significantly less time, namely, in 30–40 min. During casting, it is essential to achieve compensation for the shrinkage of solidifying alloy by investment expansion. The metal casting ring restricts the thermal expansion of investment because the thermal expansion of the ring is lesser than that of the investment. The use of casting ring was challenged with the introduction of the ringless technique.

Materials and Methods: A total of 40 test samples of nickel chromium (Ni-Cr) cast copings were obtained from the patterns fabricated using inlay casting wax. The 20 wax patterns were invested using metal ring and 20 wax patterns were invested using the ringless investment system. Of both the groups, 10 samples underwent conventional casting, and the other 10 underwent accelerated casting. The patterns were casted using the induction casting technique. All the test samples of cast copings were evaluated for vertical marginal gaps at four points on the die employing a stereo optical microscope.

Results: The vertical marginal discrepancy data obtained were tabulated. Mean and standard deviations were obtained. Vertical discrepancies were analyzed using analysis of variance and Tukey honestly significantly different. The data obtained were found to be very highly significant ($P < 0.001$). Mean vertical gap was the maximum for Group II (53.64 μm) followed by Group IV (47.62 μm), Group I (44.83 μm) and Group III (35.35 μm).

Conclusion: The Ni-Cr cast copings fabricated with the conventional casting using ringless investment system showed significantly better marginal fit than that of cast copings fabricated from conventional and accelerated casting with metal ring investment and accelerated casting using ringless investment since those copings had shown the least vertical marginal discrepancies among the four methods evaluated in this study.

Key Words: Accelerated casting, conventional casting, marginal accuracy, ringless casting

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Received: 14th January, 2015, **Accepted:** 27th March, 2015

Access this article online	
Quick Response Code:	Website: www.j-ips.org
	DOI: 10.4103/0972-4052.155043

INTRODUCTION

The success of any dental cast restoration depends upon the marginal adaptation (fit) of casting to the underlying tooth structure. The accuracy of the marginal fit of then restoration is essential for its longevity and a healthy periodontium. Precise marginal adaptation is necessary to achieve better mechanical, biological and esthetic prognosis. The marginal fit of castings basically relies on perceptive tooth preparation, accurate impressions, precision castings with careful finishing and cementation procedures.[1,2] The marginal discrepancies of cast restorations are inevitable in spite of careful attention being given to clinical and laboratory procedures. The literature revealed that clinically acceptable marginal discrepancy for cast restorations ranges from 10 to 160 µm.[1] Still, most of the authors have considered marginal discrepancies exceeding 100 µm as an unacceptable marginal opening. Despite sound clinical and laboratory techniques, there is always a microscopic gap at the tooth restoration interface that should be sealed with cement.[3] However; cement will dissolve rapidly under the margins if the gap is too large.

There have been numerous reports on attempts to perfect casting procedure in dentistry by improving materials and technique. The majority of these efforts deal with the so-called "conventional" investing and casting techniques. This technique usually requires at least 1 h for the investment to set, followed by a one or two stage wax elimination procedure before casting is done. This procedure is time-consuming and requires approximately 2–4 h for completion.[4] Accelerated casting technique has been reported in an effort to achieve similar quality results in significantly less time, namely in 30–40 min for the fabrication of high noble alloy crowns. These studies show that the marginal accuracy of castings with accelerated casting technique was comparable to that of the conventional casting technique.[4,5] The metal casting ring restricts the thermal expansion of the investment because the thermal expansion of the ring is less than that of the investment. This was challenged with the introduction of a ringless technique initially for removable partial denture frameworks[6] and recently, for conventional fixed restorations.[7] High strength of the investment material makes it possible to cast without the ring. Nickel chromium (Ni-Cr) base metal alloy has been chosen for this study to fabricate the test samples of cast copings since it is the most widely used alloy for the fabrication of dental cast restorations in the field of fixed prosthodontics. The factors which favor Ni-Cr alloy to be used are their high yield strength, susceptibility, the strain hardening, high modulus of elasticity, greater hardness, and greater resistance to sag deformation, low specific gravity and porcelain to metal bonding ability.[8]

MATERIALS AND METHODS

In this study, a total of 40 test samples of Ni-Cr cast copings were obtained from the patterns fabricated using inlay casting wax. The test samples were grouped as follows:

Twenty samples of cast metal copings will be prepared using a metal ring during investment and casting:

- Group I: 10 samples will be prepared using conventional casting procedure
- Group II: 10 samples will be prepared using accelerated casting procedure.

Twenty samples of cast metal copings will be prepared using a ringless investing system:

- Group III: 10 samples will be prepared using conventional casting procedure.
- Group IV: 10 samples will be prepared using accelerated casting procedure.

The patterns obtained were casted with an induction casting machine and Ni-Cr copings were obtained.

Preparation of patterns for fabrication of nickel chromium cast copings

The customized stainless steel die assembly [Figure 1] was used to obtain standardized patterns for all the test specimens employed in this study. Double layer of Die spacer (Han Dae Chemical Co) was applied on the die to create space for the luting cement. The inlay casting wax (Bego, Germany) was melted and filled in the stainless steel former and was pressed on the stainless steel die. The stainless steel die and former assembly were held together for 1 min with finger pressure. The die was then separated from the former, and the wax pattern was obtained. A uniform thickness of 0.5 mm was obtained throughout the coping. The coping pattern was checked for uniform thickness of wax using a wax caliper. In this manner, a total of 40 wax pattern copings were made.

Investing procedures for the patterns

Investment for patterns using metal ring for investment

All the test pattern copings were invested individually using graphite free phosphate-bonded investment material (Bellasun, Bego, Germany). A single layer of ceramic liner was adapted to

Figure 1: The customized stainless steel die assembly

the casting ring. As per the manufacturers' recommendation, phosphate-bonded investment was mixed with colloidal silica. The entire pattern was then sprayed with surfactant spray (Aurofilm, Bego, Germany), and the pattern was painted with a thin layer of investment using a small paint brush. The ring was positioned on the crucible former, and the remainder of the investment was vibrated slowly into the ring. The investing procedure was same for all the test specimens of Groups I and II.

Investment of patterns for ringless investment system

For Groups III and IV instead of metal ring, a ring-less system – Siliring (Delta, India) was used. All the test pattern copings were invested individually using graphite free phosphate-bonded investment material (Bellosun, Bego, Germany). Once the investment was mixed, the entire pattern is sprayed with surfactant spray (Aurofilm, Bego, Germany), and the pattern was painted with a thin layer of investment using a small paint brush. The ring was positioned on the base former, and the remainder of the investment was vibrated slowly into the ring. The molds were removed from the ring after initial setting of investment material.

Bench set following investment

- Groups I and III: The investment was allowed to set for 2–3 h before proceeding with burnout
- Groups II and IV: The investment was allowed to set for 13–17 min before proceeding with burnout.

Pattern elimination by burnout technique

Pattern elimination for conventional casting

After bench set, the set investment was placed in the burnout furnace (Sirio Dental SNC, Italy, SR 730 L). Burnout of the wax pattern was done using a programed preheating technique. The investment was kept in the furnace at room temperature and was heated continuously until 950°C at the rate of 8°C/min. The investment mold was initially placed in the furnace such that the crucible end was in contact with the floor of the furnace for the escape of melting wax. The investment mold was reversed later near the end of the burnout cycle with the sprue hole facing upward to enable escape of the entrapped gases and allow oxygen contact to ensure complete burnout of the wax pattern and allow mold expansion. This procedure is repeated for all the 20 test specimens of Group I and Group III.

Pattern elimination for accelerated casting

After the bench set, the molds were placed in an oven which was preheated to 815°C for 20 min. This procedure is repeated for all the 20 test specimens of Group II and Group IV.

Casting procedure

Casting was accomplished with a Ni-Cr alloy (Bellabond plus, Bego, Germany) melted in an induction casting machine (FornaxGeu, Germany). The casting procedure was performed quickly to prevent heat loss resulting in the thermal contraction of the mold. The Ni-Cr alloy was heated sufficiently until the alloy ingot turned to the molten state, and the crucible was released and centrifugal force ensured the completion of the casting procedure. This procedure is repeated for all the test specimens of all four groups.

Divestment and finishing of cast copings

Following casting, the hot casting ring was bench cooled to room temperature. Divestment was done to retrieve the cast coping from the investment. Care was employed to prevent damage to the margins. Adherent investment was removed from the casting by sandblasting with 110 μm alumina at 80 psi pressure. The internal surface was inspected under magnification and relieved of all nodules with a round carbide bur and steam cleaned. This procedure was repeated for all the 40 Ni-Cr cast copings used as test samples.

Measurement of vertical marginal gap

Each cast coping was seated on the stainless steel die with finger pressure. The vertical marginal discrepancy was determined as the maximum distance between the tooth preparation margin and the most apical part of the casting margin in a plane parallel to the long axis of the tooth. The vertical marginal gap at the margin of the casting and the die was measured microscopically, at magnification, under a stereo optical microscope. Marginal gaps were measured to the nearest micron on each cast coping at the four predetermined reference points on the stainless steel die. The same procedure was followed to record the vertical marginal gap for each of the 10 samples of the four test groups. The measurements thus obtained were tabulated and statistically analyzed.

RESULTS

Vertical marginal gap in microns with mean for each test sample of Group I measured at four reference points and the mean value for Group I test samples [Table 1].

Vertical marginal gap in microns with mean for each test sample of Group II measured at four reference points, and the mean value for Group II test samples [Table 2].

Vertical marginal gap in microns with mean for each test sample of Group III measured at eight reference points, and the mean value for Group III test samples [Table 3].

Vertical marginal gap in microns with mean for each test sample of Group IV measured at eight reference points, and the mean value for Group IV test samples [Table 4].

Statistical analysis

Mean and standard deviations were determined for vertical marginal gap from the samples for each study group. The vertical marginal gap data were analyzed using Kruskal–Wallis test followed by Mann–Whitney U-test and the horizontal marginal gap data were analyzed using analysis of variance followed by Tukey honestly significantly different tests. In the present study, $P < 0.05$ was considered as the level of significance [Tables 5 and 6].

DISCUSSION

Fixed prosthodontics has become a major part of current restorative dentistry because people are living longer, seeking more dental care, and are more educated about their dental health.[9] Fixed partial denture is any dental prosthesis that is luted, screwed or mechanically attached or otherwise securely retained to natural teeth, tooth roots, and/or dental implant abutments that furnish the primary support for the dental prosthesis (GPT 8). Casting metals by the lost wax process have been recognized in the industry and the arts for many years. No record exists when and where this type of the casting procedure was first developed. In dentistry, lost wax process of casting metals became common practice after it was introduced by Taggart in 1907.[4] Castings made by Taggart were generally too small and did not fit the cavities properly.[10,11] The fit of a casting can be well-defined in terms of "misfit" measured at various points between casting surface and tooth. Measurements between the casting and tooth can be made from points along the internal surface, at the margin or on the external surface of the casting.[12] Clinically, important measures are the marginal gap that is the distance from the internal surface of the casting to the axial wall of the preparation margin.[13] The accuracy of fit of casting is essential for longevity and clinical success of the cast restoration in the oral cavity.[14] Clinically, defective margins act as a niche for dental plaque. It can also cause secondary caries below the margins of the crown. Precise marginal seal is important in dental restorations to fulfill biologic, physical and cosmetic requirements, lest the restorations fail.

The majority of the fixed partial dentures are fabricated using "conventional" investing and casting techniques, which usually require at least 1 h setting time for the investment, followed by a two-stage (temperature is increased from room temperature to 250°C and held for 60 min and then the temperature is increased to 950°C gradually and held for 30 min) for wax elimination procedure before casting is done. The whole process requires approximately 2–4 h for completion and is time-consuming.[2,3,9,17,18] A modified technique called accelerated casting technique has been reported with comparable results.[4,5,9,17,18] The accuracy of fit of a cast restoration is essential for its clinical success and longevity because it allows for less plaque accumulation at the marginal area, provides better mechanical properties, less exposure of cement to the oral environment and better esthetic result. Marzouk and Kerby in 1988 made an attempt to accelerate the lost wax technique with the use of a phosphate-bonded investment, and they recognized the importance of investment temperature. They used finger touch to ascertain the investment's maximum temperature before placement in a preheated oven. They concluded that the accelerated casting technique requires 30–40 min whereas, conventional casting technique requires 2–4 h.[4,5] Later, many studies were carried out to evaluate the marginal accuracy of complete crowns made with gold alloys using a phosphate-bonded investment and accelerated casting method, and they ended up with comparable results.[4,5,18] The casting shrinkage differs for the various alloys, presumably because of differences in their composition. The casting shrinkage of gold-based alloys is 1.42–1.56% and Ni-Cr alloy is 2.30%.[16] The accuracy of fit of casting is affected by the quality of the preparation (undercuts, taper of the preparation), the impression, the working cast, the quality of the wax that is used for the lost wax technique, and the accuracy of the castings. At this last step, it is essential to achieve compensation for the shrinkage of the solidifying alloy by investment expansion.[10] The metal casting ring restricts the thermal expansion of the investment because the thermal expansion of the ring is less than that of the investment. To compensate for this limitation, an asbestos liner was recommended.[20] The asbestos liner that was in use for many years was abandoned because asbestos is associated with carcinogenesis. Reports have stated that asbestos fibers in the casting ring liners can cause asbestosis, bronchogenic lung cancer or mesothelioma.[21,22] Paper ceramic liners are used as a substitute.[23] The introduction of ceramometal technology made the use of higher melting temperature alloys necessary to withstand the firing cycle of porcelain without noticeable distortion, and led to the development and use of investments that can resist higher temperatures and higher stresses during casting.[16] Initially, phosphate-bonded investments were treated with the same techniques as used with the gypsum-bonded investments. The need of the casting ring for the phosphate-bonded investments was not questioned because its use was a standard procedure.[24] The use of the casting ring was challenged with the introduction of a ringless technique initially for phosphate-bonded investments for removable partial denture frameworks and recently, for conventional fixed restorations and even experimentally for implant-connected frameworks.[24,25] The high strength of the material makes it possible to abandon the use of the casting ring. The ringless techniques are easier, less expensive, and give clinically acceptable castings.[24] In the literature, there are few studies comparing the two casting techniques for fixed restorations.[2] The purpose of this *in vitro* study was to compare the fit of single full-coverage restorations made with two investing techniques to ascertain whether the ringless technique can be routinely used for the fabrication of cast restorations and the marginal accuracy of full coverage single crowns fabricated following conventional casting technique and accelerated casting technique.

A standardized custom-made stainless steel die was made as recommended by Ushiwata *et al*.[2] in their study, with a deep chamfer margin which was used to obtain patterns from inlay casting wax and pattern resin material. The cast copings were divested, sandblasted, and steam cleaned. The fabricated cast copings were grouped as Group I, Group II, Group III and Group IV respectively.

The Ni-Cr cast copings were seated by the same operator on the stainless steel die with finger pressure until the resistance was met. The vertical marginal gap of the cast copings were evaluated microscopically and measured at four predetermined reference points using a stereo optical microscope. The results obtained were tabulated and statistically analyzed.

The vertical marginal gap of all the 40 copings obtained by four different pattern forming methods showed a statistically significant difference between the four test groups (Group II < Group IV < Group I < Group III). But no statistically significant difference between Group I and Group II, Group I and Group III, Group II and Group III, Group II and Group IV, and Group III and Group IV were found.

Konstantoulakis *et al*.[4] used a high noble metal ceramic alloy and phosphate-bonded investment to check the marginal fit and surface roughness of complete crowns made with a conventional and an accelerated casting technique. Schilling *et al*.[5] used a high noble alloy and a phosphate-bonded investment to measure the marginal gap and determined the clinical acceptability of single castings with the use of conventional and accelerated methods. The range of discrepancy was 0.00–85.0 μ and 0.00–121.0 μ for the conventional and accelerated castings respectively. Blackman[18] evaluated the dimensional changes and surface roughness of gold crowns cast with rapidly prepared phosphate-bonded investments, and the mean marginal loss for the conventional and accelerated casting when compared with the wax patterns was 17.3 ± 5.9 μ and 27.1 ± 3.7 μ respectively. All the studies carried out earlier, state that even though the accelerated castings show more marginal discrepancy when compared with the conventional technique, they can be routinely used for clinical purposes as the marginal loss is well within the maximum tolerable limit.[4,5,18] In spite of utmost care, the marginal discrepancies in wax patterns were found to happen.

In the present study, the wax patterns were fabricated directly on the metal master die. When the molten wax flows on a cool metal die the wax immediately adjacent to the die solidifies rapidly because the heat from the molten wax is rapidly dissipated. The wax adjacent to the air stays molten for a long period. As it solidifies and contracts, it pulls the previously congealed wax away from the metal.[16] To minimize the distortion of the wax pattern, it is advised to use low storage temperature, and it should be invested immediately after fabrication.[16,19,26] The mean vertical marginal discrepancies of conventional and accelerated castings were compared, and statistically significant differences were found between the mean vertical marginal discrepancies of conventional and accelerated castings ($P < 0.001$) using both metal ring and ringless investment method. Clinical tolerance limits for the fit and marginal adaptation of a cast restoration are actually not known. However, several investigations reported that marginal gaps in cast crowns of up to 74 μ, 104 μ, or 120 μ are considered to be clinically acceptable.[1,4,5] The metal ring casting technique is well-documented in the literature. Although the metal ring technique is clinically acceptable and allows for the fabrication of accurate casts, the metal ring restricts the setting and thermal expansion of the investment which is necessary to compensate for the shrinkage of the metal on solidification. To overcome this expansion restriction, a soft liner is used.[27] The molds of ringless technique will not be cracked or fractured on their own during or after the casting because of the absence of the metal ring if care is taken. Even if the casting of each group is adjusted on the internal surface after the original measurements are made in the ideal condition, no difference in the margin discrepancy should be found after the adjustment of the internal surface.[15]

The mean vertical marginal discrepancy in a study conducted to find the marginal discrepancy when using ringless, split ring, metal ring with single layer of ring liner and metal ring with double liner was done. The mean marginal discrepancies were 95 μm, 136 μm, 128 μm and 104 μm respectively.[28] The ringless investment showed least discrepancy, followed by the metal ring with double layered liner and then the metal ring with single layered liner. This shows that, more the space for the investment to expand, better the marginal fit.

In the present study, the vertical marginal accuracy of castings fabricated with ringless system (Group III and Group IV) was found to be statistically significant. The decreasing order of accuracy of fit of castings among groups was Group III > Group I for conventional casting and Group IV > Group II for accelerated casting. This can be explained on the ground that in the ringless technique, complete expansion of the mold during setting of the investment occurred uniformly in all directions without any restriction. The setting expansion was also not restricted as the plastic ring was opened up immediately on initial set of the investment. There is no statistically significant difference in investing a single crown per investment and multiple crowns per investment.[29]

Table 1: Basic data and the mean vertical marginal gap for Group I test samples

Point 1	Point 2	Point 3	Point 4	Mean
44.32	40.54	42.45	41.45	42.19
45.98	51.87	45.74	41.67	46.315
48.87	44.64	48.86	50.13	48.125
40.67	48.65	44.43	43.29	44.26
46.74	42.67	45.91	45.86	45.295
38.54	35.85	39.85	41.97	39.0525
43.67	46.86	49.76	42.77	45.765
46.67	48.87	50.63	42.59	47.19
42.63	45.74	48.75	40.82	44.485
43.86	48.87	46.63	42.97	45.5825
Mean vertical marginal gap for Group I test samples				44.8260

Table 2: Basic data and the mean vertical marginal gap for Group II test samples

Point 1	Point 2	Point 3	Point 4	Mean
49.54	52.84	54.79	48.98	51.5375
58.97	56.69	53.82	49.73	54.8025
57.05	49.32	54.54	55.73	54.36
48.53	55.76	49.64	54.55	52.12
53.69	57.79	50.78	51.49	53.4375
48.68	53.09	49.51	55.87	51.7875
48.52	53.86	58.68	52.47	53.3825
53.74	55.93	49.79	57.82	55
58.79	54.67	49.93	60.54	55.9825
55.69	58.42	48.6	56.84	54.8875
Mean vertical marginal gap for Group II test samples				53.6418

Table 3: Basic data and the mean vertical marginal gap for Group III test samples

Point 1	Point 2	Point 3	Point 4	Mean
28.05	33.45	32.76	38.56	33.025
35.45	31.23	39.65	36.75	35.77
39.63	36.73	32.43	33.78	35.6425
45.15	37.43	35.64	37.43	37.7425
36.41	38.03	30.74	32.75	37.1075
42.86	36.72	39.64	34.35	38.3925
50.56	41.32	38.58	39.45	42.4825
29.79	31.56	35.83	34.82	33
31.86	30.59	31.84	32.22	31.6275
28.42	27.93	32.54	31.06	29.9875
Mean vertical marginal gap for Group III test samples				35.3497

A hypothesis can be made that the ringless technique allows for more expansion of the investment and, therefore, produces castings that bind less on the die.[30] Though the vertical marginal accuracy of castings fabricated with ringless system is found to be better than the castings fabricated using metal ring, the castings fabricated using metal ring shows more consistent type of results compared to restorations fabricated using ringless system.[30] In the present study, it was found that the marginal gap was of 44.8260 (Group I) microns and 35.3497 (Group III) microns for castings obtained by conventional casting with and without metal ring respectively and 53.6418 (Group II) microns and 47.6192 (Group IV) for casting obtained by accelerated casting with and without metal ring for investment. These values are well within the clinical tolerance limits and were consistent with earlier research.

Table 4: Basic data and the mean vertical marginal gap for Group IV test samples

Point 1	Point 2	Point 3	Point 4	Mean
42.58	39.79	49.84	45.75	44.49
45.38	47.68	49.89	47.53	47.62
50.54	48.39	48.67	46.73	48.5825
51.48	48.54	43.64	45.86	47.38
46.82	45.63	44.9	49.59	46.735
47.09	53.85	50.76	46.94	49.66
43.75	50.48	44.91	45.68	46.205
51.94	50.52	49.85	49.89	50.55
44.78	46.74	43.68	49.87	46.2675
48.05	50.86	48.04	47.86	48.7025
Mean vertical marginal gap for Group IV test samples				47.6192

Table 5: Mean vertical marginal gap and SD of Groups I, II, III and IV (ANOVA test)

	n	Mean	SD	Minimum	Maximum
1.00	10	44.8260	2.60515	39.05	48.13
2.00	10	53.6418	1.46809	51.54	55.98
3.00	10	35.3497	3.74909	29.99	42.48
4.00	10	47.6192	1.80474	44.49	50.55

$P<0.001$ VHS; SD: Standard deviation, ANOVA: Analysis of variance, VHS: Very highly significant

Table 6: Dependent variable: vertical gap multiple comparisons

Group (I)	Group (J)	Mean difference (I–J)	*P*
1.00	2.00	−8.8158	<0.001 VHS
	3.00	9.4763	<0.001 VHS
	4.00	−2.7932	0.088 NS
2.00	3.00	18.2920	<0.001 VHS
	4.00	6.0225	<0.001 VHS
3.00	4.00	−12.2695	<0.001 VHS

NS=$P>0.05$; HS=$P<0.01$; Tukey HSD. P: Probability, NS: Not significant, HS: Highly significant, VHS: Very highly significant

However, there are few limitations in this study. The laboratory testing cannot exactly reproduce the clinical situation. In this study, the marginal discrepancy was measured without permanent cementation of the cast copings, and it could potentially affect the marginal adaptation. Previous studies have demonstrated that the marginal discrepancy had been increased significantly after cementation.[31,32] Sorensen[33] introduced a standardized method for determination of marginal adaptation of crowns like direct view, cross-sectional view, impression technique, explorer and visual view. This study used direct view to evaluate the vertical marginal discrepancy. The direct view method is convenient, easy, and rapid because the crown is retrievable, unlike the cementation, embedment, and sectioning method, which causes destruction of the crown. However, it is difficult to determine the repeatable measuring point of reference with a rounded margin and to assess over contouring of the crown margin. Although clinically prepared crown margin seems to be sharp, it is seen rounded under microscope. In this study, it was difficult to determine the measuring points of rounded margin and over-contoured margin and also it could affect the results.

Groten *et al*.[34] reported that approximately 50 measurements are required for clinically relevant information about gap size regardless of gap definition or cementation condition. In this study, the vertical marginal discrepancies were measured only at four predetermined points. More number of reference points for marginal gap measurements for each coping could yield a better confirmative result. Also, there is no literature to compare the marginal accuracy of Ni-Cr crowns/coping obtained by accelerated casting using ringless investment system.

In spite of several limitations mentioned above, this *in vitro* study suggested that the marginal fit of cast copings with four different pattern forming methods were within the range of clinically acceptable values for longevity of restorations.

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How to cite this article: Alex D, Shetty YB, Miranda GA, Prabhu MB, Karkera R. Marginal accuracy of nickel chromium copings fabricated by conventional and accelerated casting procedures, produced with ringless and metal ring investment procedures: A comparative *in vitro* study. J Indian Prosthodont Soc 2015;15:58-64.

Source of Support: Nil, **Conflict of Interest:** None.