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RESEARCH ARTICLE

DIMENSIONAL ACCURACY OF RINGLESS CASTING AND ACCELERATED WAX-ELIMINATION TECHNIQUE IN FABRICATING MULTIPLE UNIT CAST RESTORATIONS: AN IN-VITRO COMPARATIVE STUDY

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ABSTRACT

Aim: To evaluate and compare the marginal accuracy of multiple unit cast restorations fabricated by Conventional and Ringless casting technique.

Method: A forty standardized wax patterns are fabricated on a type IV stone replica of a multiple unit stainless steel die with standardized pontic space. The wax patterns are divided into four groups. Group IA: Ringless casting with conventional wax elimination method. Group IB: Ringless casting with accelerated wax elimination method. Group IIA: Metal ring casting with conventional wax elimination method. Group IIB: Metal ring casting with accelerated wax elimination method. The vertical marginal gap was measured at six sites per sample, using a digital optical microscope at 6.25_X magnification.

Result: The mean vertical marginal gaps of castings fabricated using ringless groups IA and IB (274.9±131.6 µm) were significantly less ($p < .004$) than those castings fabricated using the ring casting groups IIA and IIB (379.9± 106.9 µm). The conventional wax elimination groups (IA, IIA) showed higher vertical marginal discrepancies (393.8±116.6 µm) than the accelerated wax-elimination groups (IB, IIB) (215.9±73.02 µm); however, the difference was not statistically significant ($p < 0.05$).

Conclusion: The ringless casting technique can produce accurate and acceptable multiple-unit restorations in fixed prosthodontics.

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INTRODUCTION

Fixed cast restorations mainly aim to restore function and aesthetic of lost intra-oral structures without jeopardizing the oral or general health of the patients. Ill-fitting restoration is potentially harmful for abutment teeth and supporting periodontium. In addition; the restoration itself can be affected by the poor margin as variation in the fitting can create stress concentrations which may reduce the strength and long-term success of the restoration (Tuntiprawon and Wilson, 1995).

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Clinically acceptable marginal gap of fixed restorations is difficult to be precisely identified through the literature. Holmes *et al.* (1989) defined the internal gap as the measurement between the axial wall of the prepared tooth and the internal surface of the casting, while the same measurement at the margin is called "marginal gap" (Holmes *et al.*, 1989). The literature revealed that clinically acceptable marginal discrepancy for cast restorations ranges from 10 to 160 µm (Schwartz, 1986). There have been abundant reports on attempts to perfect casting procedure in dentistry by refining materials and technique (Alex *et al.*, 2015). The majority of these efforts deal with the so-called "conventional" investing and casting techniques (Alex *et al.*, 2015). Conventional casting technique which is routinely used in dentistry usually requires at least 1 hour 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 hours for completion (Konstantoulakis *et al*., 1998; Schilling *et al*., 1999; Blackman, 2000). Accelerated casting technique has been reported 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 (Konstantoulakis *et al*., 1998; Schilling *et al*., 1999). 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 and recently, for conventional fixed restorations. 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 favour Ni-Cr alloy to be used are their high yield strength, susceptibility, and the strain hardening, high modulus of elasticity, greater hardness, and greater resistance to sag deformation, low specific gravity and porcelain to metal bonding ability (Donovan *et al*., 1984). There are very few in-vitro studies done on ringless casting and accelerated wax elimination technique for single unit cast restorations, but there is hardly any study on multiple unit cast restoration in the literature. The present in-vitro study attempts to determine marginal accuracy of multiple unit cast restorations fabricated by combing ringless and accelerated wax elimination technique and to compare them with the conventional casting technique.

MATERIALS AND METHODS

This in-vitro study was carried out to evaluate the accuracy of ringless casting and accelerated wax-elimination technique in multiple unit cast restorations. This study was reviewed by the Institutional Ethical Committee and necessary approval was obtained. The study was conducted in the Department of Prosthodontics, including Crown and Bridge and Implantology, SDM College of Dental Sciences and hospital, Dharwad, in assistance with Department of Oral Pathology, College of Dental Sciences, Davangere.

Stainless steel die assembly

A stainless-steel model with two abutments simulating a second premolar and a second molar screwed tightly on a holder (40 mm long, 16 mm wide, and 8 mm thick) was machined (Figure1). The abutments were positioned on the platform to receive posterior three-unit FPDs. The preparation had a shoulder finish line with a 1.0 mm radius, a 6◦ angle of convergence of the axial walls with 6 mm height, and a 90◦ shoulder margin, there by simulating clinical conditions. The occlusal surfaces of both the abutments had reference markings for repositioning the wax patterns and castings. Reference marks were scribed on the master die abutments at six points 90◦ apart. A stainless steel wax pattern former was manufactured such that when assembled with the master die, it would have an occlusal opening to pout the molten wax into the mould and had a uniform space of 1mm from the axial and occlusal surfaces of master die. The master die was duplicated in a low expansion die stone (Ultrarock; Kalabhai, Mumbai, India) and the surfaces of this stone dies were treated with one coat of die hardener (Die hardener; Yeti, Engen, Germany). A single layer uniform thickness of die spacer was applied on the die 1mm above the margins of the die. Before waxing the die, a layer of die lubricant was applied for easy removal of wax pattern.

Wax pattern fabrication

The stainless steel former was placed on the lubricated stone die, and molten inlay casting wax (S-u-gnatho-wax; Schuler Dental, Ulm, Germany) was poured through the occlusal opening to form standard wax patterns. The die-former assembly was held together for 1 minute followed by immersion at room temperature water for 3 minutes, after which the assembly was removed and wax pattern retrieved. The intaglio surface of each wax pattern was carefully inspected using a magnification lens, to ensure it was smooth and free of defects. The wax patterns were repositioned on the respective stone dies and stored in a plastic container at room temperature for 24 hours prior to casting. Forty stone dies and wax patterns were fabricated. They were divided into four groups consisting of 10 wax patterns each (Table 1). The wax patterns were sprued using a 12-gauge sprue wax (Schuler Dental, Ulm, Germany) attached 45◦ to the thickest portion of occlusal surface.

Metal ring investment procedure

The wax patterns were sprued and individually cast using 1× casting rings. The casting rings were lined with a single layer of cellulose ring liner (PCT FlexVest Liner; IvoclarVivadent, Schaan, Liechtenstein) following the manufacturer's instructions. The wax patterns were invested in a phosphate-bonded investment material (PCT FlexVest; IvoclarVivadent) following the manufacturer's recommendations.

Ringless investment technique

A ringless system (Thermofix 2000; DFS, Reidenburg, Germany) was used. The wax patterns were sprued and attached to the base former. The plastic foil ring was confined to the rubber lip of the base former and secured with Velcro fasteners. The investment material (PCT FlexVest Liner) was mixed and poured following the manufacturer's recommendations. The plastic foil ring has a heat sensitive strip indicator which changes the colour from black to green and again from green to black depending upon the heat generated by exothermic reaction of the investment material. The investment ring in the ringless system has got three levels indicator, level 1, 2 and 3. Once the indicator reaches level 3 of indicator strip it turns to black colour (6-8 minutes). At this point the ring of ringless system was removed and separated from investment.

Investment setting time (bench setting)

For the conventional wax-elimination groups (groups IA and IIA), the invested molds were bench set for 1 hour, as per the manufacturer's recommendation. For the accelerated wax elimination groups (groups IB and IIB), the time taken by the investment material to reach maximum exothermic setting reaction temperature was used to calculate the bench setting time i.e. 6-8 minutes.

Table 1. Groups tested

Groups	Condition
IA	Ringless casting with conventional wax elimination
IB	Ringless casting with accelerated wax elimination
IIA	Metal ring casting with conventional wax elimination
IIB	Metal ring casting with accelerated wax elimination

Table 2. The mean vertical marginal gaps, standard deviations, minimum and maximum range, and p-values for the different groups

No	Group (µm ± SD)	Mean marginal gap (min – max, µm)	Range	p value
1	Ringless casting (IA, IB)	274.9±131.5	157.66-392.11	.004*
2	Ring casting (IIA, IIB)	379.9±106.9	229.68-530.08	.012*
3	Conventional-wax elimination (IA, IIA)	393.8±116.6	257.51-530.08	
4	Accelerated-wax elimination (IB, IIB)	215.9±73.02	157.66-274.25	

* Indicate that there is significant difference between the groups since p<0.05.

Table 3. Dependent Variable: Univariate ANOVA- Taking the total of all the samples

Source	Type III Sum of Squares	Df	Mean Square	F	P value
Groups	11.235	3	3.745	11.086	.000*
Surfaces	1.786	5	.357	1.057	.422

* Indicate that there is significant difference between the groups since p<0.05. There is no significant difference between Surfaces.

Table 4. Multiple comparisons of total samples using Tukey's honest significant differences (Tukey's HSD) test

(I) GRP	(J) GRP	Mean Difference (I-J)	Std. Error	P value
IA	IB	1.3977*	.33556	.004*
	IIA	-.3015	.33556	.806
	IIB	.9174	.33556	.066
IB	IIA	-1.6992*	.33556	.001*
	IIB	-.4803	.33556	.500
	IA	-1.3977*	.33556	.004*
IIA	IIB	1.2189*	.33556	.012*
	IA	.3015	.33556	.806
	IB	1.6992*	.33556	.001*
IIB	IIA	-1.2189*	.33556	.012*
	IA	-.9174	.33556	.066
	IB	.4803	.33556	.500

* The mean difference is significant at the 0.05 level.

Figure 1. The customized stainless steel die assembly

Figure 2. Armamentarium for Investing and Casting technique

Figure 3. Optical stereomicroscope (Olympus, SZX 12, Japan), 3 Chip CCD Camera (Proview, Media Cybernetics, USA) with image Pro-Plus Software (Version 4.1.0.0)

The mean time interval required for the investment material to reach its maximum exothermic setting reaction temperature was determined with the help of strip indicator on ring less system (groups IB and IIB).

Conventional wax-elimination method

For groups IA and IIA, three-stage wax-elimination was performed as per the manufacturer's recommendation. The temperature increased at a constant rate of 7 to 10◦C per minute.

Accelerated wax-elimination method

For groups IB and IIB, the wax was eliminated in a single stage; the burnout furnance is preheated to 850□C, at this temperature the ringless mould is introduced in the furnance for 15 minutes, as per the manufacturer's recommendations.

Casting procedure

The molds were cast using two pellets of a nonprecious (62.9% Ni, 23.0%Cr,10%Mo) metal-ceramic alloy (Heranium S; Heraeus Kulzer, Hanau, Germany) in an induction casting machine (AsegGalloni, San Colombano al Lambro, Italy). The metal ring molds were bench cooled for 24 hours prior to divestment. The ringless molds were divested immediately after they cooled to room temperature. The castings were carefully sand blasted with alumina-oxide (50 µm) under 30 psi pressure. The intaglio surfaces of the castings were examined under magnification for defects and nodules. Minor nodules were removed using a no.1 round carbide bur. Castings with gross defects were discarded. The wax-pattern fabrication, investment, wax elimination, casting, recovery, and minor refinement of copings were performed by the same "blind" operator throughout the study.

Measurement of vertical marginal gap

Each cast coping was seated on the stone master 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 6.25_X, under a stereo optical microscope (Figure 3). Marginal gaps were measured to the nearest micron on each cast coping at the six predetermined reference points as shown in the figure 6 (A=mesial, B=mesio-buccal, C=disto-buccal, D=distal, E=disto-lingual and F=mesio-lingual) on the master stone die. The same procedure was followed to record the vertical marginal gap for each of the 10 samples of the four test groups (IA, IB, IIA, and IIB). The measurements thus obtained were tabulated and statistically analysed for means and standard deviation. A parametric test like ANOVA and Tukey tests was performed using SPSS19 software to compare and determine the presence of statistical significance between and within the different groups.

RESULTS

The mean vertical marginal gaps, standard deviations, minimum and maximum range, and p-values for the different groups are listed in Table 2**.** The values presented signify the mean difference in µm, between the margins of the casting and die measured at six locations. The mean vertical gaps were significantly larger for the metal ring casting groups IIA and IIB (379.9± 106.9 µm) than those for the ringless groups IA and IB (274.9±131.6 µm). The conventional wax elimination groups (IA, IIA) showed higher vertical marginal discrepancies (393.8±116.6 µm) than the accelerated wax-elimination groups (IB, IIB) (215.9±73.02 µm); however, the difference was not statistically significant ($p > 0.05$).

DISCUSSION

In dentistry, lost wax process of casting metals became common practice after it was introduced by Taggart in 1907 (Taggart, 1907). The marginal integrity of cast restorations is an important factor in the clinical success of fixed prosthodontics. The casting process used in dentistry based on the lost wax technique has been receiving continuous investigations exploring the behavior of the materials involved (Goshi *et al*., 2004). The majority of the fixed partial dentures are fabricated using "conventional" investing and casting techniques, which usually require at least 1 hour setting time for the investment, followed by a two stage for wax elimination procedure before casting is done. The whole process requires approximately 2–4 hours for completion and is time consuming (Blackman, 2000; Schneider, 1994; Ushiwata and de Moraes, 2000; Ushiwata *et al*., 2000; Campagni and Majchrowicz, 1991). Accelerated casting techniques have been reported in an effort to achieve similar quality result in significantly less time. These techniques have the ability to shorten the investing and casting process, thereby improving productivity. Although the ringless casting technique is in use in fixed prosthodontics and implant prosthodontics, there are few investigations about the technique in the literature, and the accuracy of the castings depends on the skills of the technicians and is clinically determined by the dentists. There are no scientific data to support the use of this technique in the multiple crown fabrication. This study is clinically oriented, which determines and compares, whether the technique produces acceptable results in fabricating multiple unit cast restorations. The ringless technique for investing and casting has been in use for many years for the fabrication of frameworks for removable partial dentures. It was introduced in fixed prosthodontics technology (Morey, 1992). With the use of a ringless technique; the restriction of thermal expansion that is associated with the presence of the metal ring is avoided. 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. The phosphate-bonded investments fulfil these requirements. Phosphate-bonded investment mixed with 100% special liquid resulted in higher heat and higher setting expansion (Ito *et al*., 2002). The use of silica sol (colloidal silica) additionally increases the strength of phosphate-bonded investments considerably. As per the manufacturer's recommendation, the phosphate□bonded investment can be used for an accelerated as well as for the conventional casting technique with three□stage wax elimination. Hence, this material was chosen for investing the wax patterns for all the test groups in the present study. Also, using a single investment material for all the test groups helps to eliminate any variability in the test results.

Nickel chromium (Ni□Cr) base metal alloy has been chosen for this study to fabricate the test sample of multiple-unit cast restoration since it is the most widely used alloy for the fabrication of dental cast restorations in the field of fixed prosthodontics. The factors which favour Ni□Cr alloy to be used are their high yield strength, susceptibility, and the strain hardening, high modulus of elasticity, greater hardness, and greater resistance to sag deformation, low specific gravity and porcelain to metal bonding ability (Donovan *et al*., 1984). In the present study, the vertical marginal gaps obtained were between 157.66µm and 530.08 µm. The average vertical marginal discrepancy and standard deviation was minimal for surface "C" followed by "A", "F", "E", "D" and "B". As regard the groups, Group-IB generated the least marginal discrepancy followed by Group-IIB, Group-IA and Group-IIA. However, the Group-IB had the least variability (SD = 29.19µm). This means that Group-IB produced castings with more consistent results. The wax patterns cast with the metal ring (groups IIA, IIB) showed greater vertical marginal gaps than those cast with the ringless technique (groups IA, IB). The difference was statistically significant ($p < 0.05$). The conventional wax elimination groups (groups IA, IIA) showed higher vertical marginal gaps than the accelerated wax-elimination groups (groups IB, IIB); however, the difference was not statistically significant (Table 2).

The difference in the vertical marginal gaps in the present study could be attributed to the compositional differences of the investments formulations. Investments may differ in terms of composition, particle size, heat transmission, wettability and so forth, and as a consequence, the castability of the dental casting alloys could be affected, which agreed with Cohen et, al.1996 findings (Cohen *et al*., 1996). In general, it has been reported that incomplete castability results in an incomplete cast crown margins and therefore an increase in marginal discrepancy (Thiab and Zakaria, 2004). 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 (Schwartz, 1986). In the present study, the mean vertical gaps were significantly larger for the metal ring casting groups IIA and IIB (379.9± 106.9 μm) than those for the ringless groups IA and IB (274.9±131.6 μm). This can be attributed to the restrictive effect of the metal ring on the thermal and setting expansion of the investment material (Lombardas *et al*., 2000; Hollenback, 1962; Van Horn, 1911; Hollenback and Rhoads, 1960). The solid metal ring confines and restricts the lateral expansion of the investment, causing a negative pressure, which in turn reduces the mold cavity (Anusavice, 2003). This lack of compensation by the investment, coupled with the solidification shrinkage of alloy, leads to undersized castings with increased vertical marginal gaps. The above problems can be partially overcome with the use of a ring liner (Van Horn, 1911; Morris, 1992). The liner provides the needed resilience against the rigid metal ring and permits setting and thermal expansion of investment, allowing mold cavity enlargement. The thermal expansion of the metal casting ring also undergoes expansion during heating and may additionally account for the increased marginal gaps obtained in the metal ring casting groups (IIA and IIB) in the present study.

In the present study, the conventional wax elimination groups (IA, IIA) showed higher vertical marginal discrepancies (393.8±116.6 μm) than the accelerated wax-elimination groups (IB, IIB) (215.9±73.02 μm); however, the difference was not statistically significant (Table 2). This suggests that the accelerated method can replace the conventional method of wax-elimination to produce cast restorations with comparable accuracy; however, the accelerated casting method requires strict adherence to protocol and manufacturer's recommendations. There are several studies in the literature favouring Ringless casting technique similar to the present study: Lombardas *et al*. 2000, Zakaria and Al-Obaidi, 2014; Yadav, 2009 and Alex *et al*., 2015 showed that the castings produced by the ringless technique can improve marginal seating of castings better than the conventional metal ring technique. Accelerated technique may take advantage of characteristic exothermal setting reaction of phosphate bonded investments. Heat enhanced setting expansion continues uninterrupted as the mold is transferred into a preheated furnace for thermal expansion (Schilling *et al*., 1999). This may probably be the reason for the marginal gap of cast copings by accelerated technique to be within the clinically acceptable limit. In ringless technique, a soft plasticized PVC or elastomeric ring is used to support and confine the investment material until it attains sufficient green strength. Thereafter, the restrictions are removed to allow isotropic thermal and setting investment expansion. This allows the mold cavity to adequately compensate for alloy solidification shrinkage, resulting in castings with lesser marginal gaps and discrepancies (Lombardas *et al*., 2000).

Reddy *et al*. 2013 and Tannamala *et al*. 2013 showed the castings fabricated using conventional casting technique with less vertical marginal discrepancy than the castings fabricated by accelerated casting technique favouring Ring casting and conventional wax-elimination technique in the literature. Konstantoulakis *et al*. 1998; Schilling *et al*.1999; Vaidya *et al*. 2014 and Tandon *et al*. 2014 reported that crowns fabricated with the accelerated casting technique were not significantly different from those fabricated with conventional technique. The castings produced by accelerated casting technique showed the same fit as conventional casting technique with two-stage wax elimination technique. The marginal fit between the two casting techniques showed no statistical difference. In the present study since the interest lies in determining if the four groups differ significantly from one another with respect to mean discrepancy over all six locations, Multivariate Analysis of Variance (MANOVA) with multiple observations was carried out. The majority of variables are normally distributed since $P > 0.05$ when Kolmogorov-Smirnov and Shapiro-Wilk tests were used. Hence, parametric tests like ANOVA and Tukey HSD tests were performed. To see, if the group differences were statistically significant from surface to surface, one-way ANOVA was also applied for each sample. The mean vertical marginal differences between the groups were significant since p-values are < 0.05 in all samples. A Univariate ANOVA was done after taking the total of all the samples to see the differences between the groups and surfaces. The results of this analysis showed highly significant difference between the groups since $p < 0.00$ and there is no significant difference between the surfaces (Table 3). Multiple comparisons had been made by using Tukey's honest significant difference (Tukey's HSD) test as this is an exact test and therefore provides more accurate results. The results showed the Group IA differ significantly from Group IB with p-value 0.004. This means that ring-less casting and accelerated wax-elimination produced significantly low marginal discrepancy compared to ringless casting with conventional wax-elimination. Group IB differ significantly from Group IIA and IA (p-values 0.001 and 0.004 respectively). This means that ringless and ring casting with conventional wax-elimination produced significantly low marginal discrepancy when compared with ringless casting with accelerated wax-elimination. Group IIA differ significantly from Group IB and IIB (p-values 0.001 and 0.012 respectively). This means that ringless and ring casting with accelerated wax-elimination produced significantly low marginal discrepancy when compared with ring casting with conventional wax-elimination. Group IIB differ significantly from Group IIA with p-value 0.012. This means that ring casting and conventional wax-elimination produced significantly low marginal discrepancy compared to ring casting with accelerated wax-elimination (Table 4). Higher values of vertical marginal gap were found with ring casting technique with conventional wax-elimination when compared to the ringless casting technique with accelerated wax elimination and this difference was statistically significant. The results indicated that within the conditions of the study, the castings produced by accelerated casting technique fit better than the castings produced using conventional casting with three stage wax elimination technique. The results of this study encourages for further research with accelerated technique and reinforce the need to identify the factors that facilitate better marginal fit of multiple unit cast restorations in fixed prosthodontics.

In conclusion, under the conditions and limitations of the study, the following conclusions were drawn. The vertical marginal gaps obtained in the ringless casting groups were significantly less than those of the metal ring casting groups. There was no statistically significant difference in the marginal gaps of castings obtained by the accelerated and conventional wax-elimination methods. The ringless casting technique can produce accurate and acceptable multiple-unit restorations in fixed prosthodontics. The accelerated wax-elimination method can be used as a viable, time-saving alternative to the conventional wax-elimination method, provided that a protocol for its use is developed and strictly followed. The ringless casting technique can be combined with the accelerated wax-elimination method to offer a cost effective, clinically acceptable, and time-saving alternative for fabricating multiple-units castings in fixed prosthodontics.

Conflicts of interest: None

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