

# Effect of Phosphate-bonded Investment Materials and their Manipulation on the Marginal Fit of Cast-metal Crown Copings

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## ABSTRACT

This study evaluated the marginal fit of cast-metal crown copings fabricated while adhering to the manufacturers' manipulation instructions for three phosphate-bonded investment materials, (1) Bellavest T<sup>®</sup>, (2) Castorit<sup>®</sup>-super C, and (3) Rema<sup>®</sup> cc, and when utilizing three modifications to their manipulation, and one modified application for Wirofine<sup>®</sup>, as practiced by a section of dental laboratory technologists in Nairobi, Kenya. Seventy fabricated crowns were seated on a metal die and four standardized photographs of each crown were taken to display the facial, palatal, mesial and distal aspects. The marginal fit was measured on each image using the ImageJ National Institutes of Health software. The results showed no significant differences in the marginal gap measurements of crowns fabricated according to the manufacturers' instructions for Bellavest T<sup>®</sup>, Castorit<sup>®</sup>-super C, and Rema<sup>®</sup> cc, as well as the crowns fabricated from the modified manipulation of Bellavest T<sup>®</sup> and Rema<sup>®</sup> cc. The modified application and manipulation of Wirofine<sup>®</sup> and Castorit<sup>®</sup>-super C, respectively, yielded crowns with marginal gap measurements beyond the clinically acceptable range (<150 µm).

**Keywords:** phosphate-bonded investment materials, marginal fit, cast-metal crown copings.

## INTRODUCTION

The marginal fit of a crown is an important prognostic indicator for the success and longevity of the fixed prosthetic restoration.<sup>1</sup> It is a factor that is determined by, among other things, the quality of the crown preparation and the accuracy of the cast-metal framework.<sup>2</sup> Whereas factors such as the impression material and impression technique used may have an implication on the accuracy of a cast-metal framework, the auxiliary materials used in the laboratory procedures are equally as critical.<sup>3, 4</sup> Such materials include gypsum, waxes and investment materials. The type of investment material used in a casting procedure should be able to accurately create a mould that would produce cast crowns and/or retainer copings of the desired dimensions.<sup>5</sup>

Casting procedures take place at very high temperatures; therefore, dimensional changes are inevitable.<sup>6</sup> Investment materials are generally designed to allow for varying degrees of expansion in order to compensate for the subsequent shrinkage of the alloy on cooling, with a resultant casting that fits the intended dimensions of the die.<sup>7</sup>

Commercially available investment materials vary in particle sizes even if they are of the same type. For example, some phosphate-bonded investment material brands can produce accurate castings because of their finer particle sizes compared to others that have larger particle sizes, and are recommended for casting removable partial denture frameworks.<sup>8</sup> Manufacturers often develop and recommend certain phosphate-bonded investment materials specifically for use in casting crowns and fixed partial dentures.<sup>9, 10</sup>

This study evaluated the marginal fit of cast-metal crown copings fabricated while adhering to the manufacturers' manipulation instructions for three phosphate-bonded investment materials, (1) Bellavest T<sup>®</sup> (BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany), (2) Castorit<sup>®</sup>-super C (Dentaurum GmbH & Co. KG, Ispringen, Germany), and (3) Rema<sup>®</sup> cc (Dentaurum GmbH & Co. KG, Ispringen, Germany), and when utilizing three modifications to their manipulation, and one modified application for Wirofine<sup>®</sup> (BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany), as practiced by a section of dental laboratory technologists in Nairobi, Kenya.

Whereas it may be assumed that dental clinicians' and technologists' adherence to manufacturers' instructions should be the norm, available anecdotal information seems to suggest that this may not always be the case. Research to document the extent of deviation from manufacturers' recommendations of various dental and

auxiliary dental materials, has not been explored. The main objective of this study was to determine the effect of four different phosphate-bonded investment material brands with various modifications to their manipulation, on the marginal fit of cast-metal crown copings.

## MATERIALS & METHODS

**Survey of manipulation modalities of phosphate-bonded investment materials by dental technologists in Nairobi, Kenya.** A survey of the various investment materials in use by dental technologists in Nairobi Kenya, as well as the manipulation modalities that they employ, was carried out, by administration of a questionnaire. The 16 respondents who participated were selected by convenience sampling. The survey identified three major deviations from the manufacturers' instructions for the manipulation of the various phosphate-bonded investment materials, namely: (1) investment with a mixture of 50% Bellavest T<sup>®</sup> and 50% Wirofine<sup>®</sup> powders (by weight), mixed in 100% expansion liquid (BegoSol<sup>®</sup>), (2) investment with Castorit<sup>®</sup>-super C investment material using the liquid at a ratio of 1:1 – Distilled Water: Expansion Liquid, and (3) investment with Rema<sup>®</sup> cc investment material using the liquid at a ratio of 2:3 – Distilled Water: Expansion Liquid.

The results of the survey guided the design of the experiment, where 70 cast-metal crown coping were fabricated. Table 1 shows the grouping of the cast-metal crown copings in the control and experimental groups.

**Table 1: Grouping of the cast-metal crown copings in the control and experimental groups.**

EXPERIMENTAL GROUPS	CONTROL GROUPS
Group 1 (W-ma): Ten cast-metal crown copings fabricated after investment with Wirofine <sup>®</sup> investment material according to the manufacturer's instructions for the manipulation of Wirofine <sup>®</sup> .	Group 5 (BV-mr): Ten cast-metal crown copings fabricated after investment with Bellavest T <sup>®</sup> investment material according to the manufacturer's instructions.
Group 2 (BV/W-mm): Ten cast-metal crown copings fabricated after investment with a mixture of 50% Bellavest T <sup>®</sup> investment material and 50% Wirofine <sup>®</sup> investment material powders by weight. The mixture of the two powders was mixed in 100% expansion liquid	

(BegoSol®).	
Group 3 (C-mm): Ten cast-metal crown copings fabricated after investment with Castorit®-super C investment material using the liquid at a ratio of 1:1 – Distilled Water: Expansion Liquid.	Group 6 (C-mr): Ten cast-metal crown copings fabricated after investment with Castorit®-super C investment material according to the manufacturer's instructions.
Group 4 (R-mm): Ten cast-metal crown copings fabricated after investment with Rema® cc investment material using the liquid at a ratio of 2:3 – Distilled Water: Expansion Liquid.	Group 7 (R-mr): Ten cast-metal crown copings fabricated after investment with Rema® cc investment material according to the manufacturer's instructions.

**Typodont tooth preparation.** A maxillary first molar typodont tooth (Frasaco CmbH, Tettang, Germany) was prepared for a porcelain-fused-to-metal crown (Fig.1). The preparation was designed with five to ten percent total occlusal convergence, approximately two millimetres axial reduction on the buccal aspect, a shoulder finish line on the buccal aspect,

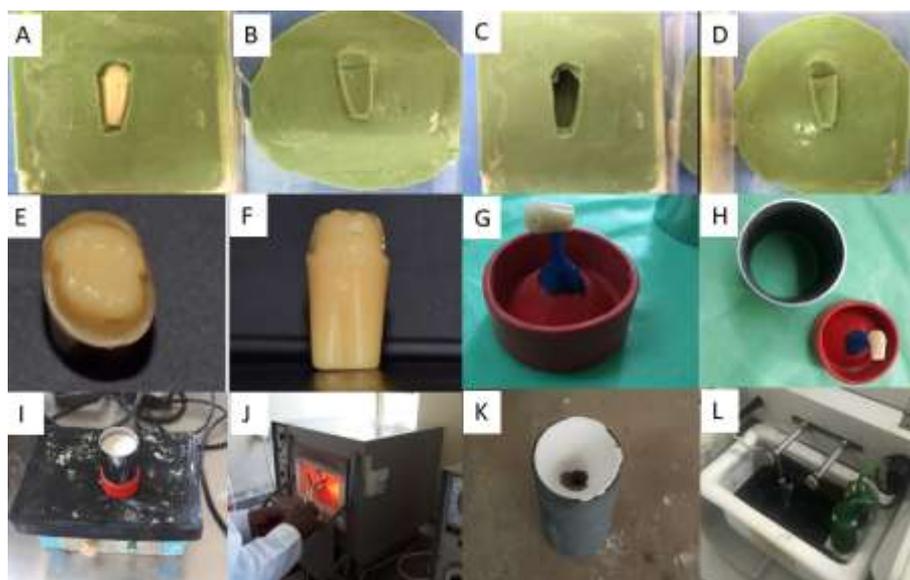
approximately 1.5 millimetres axial reduction on the palatal aspect, a chamfer finish line on the palatal aspect, and wings on the proximal margins in the intervening region between the chamfer and shoulder margins. The typodont tooth was marked just below the prepared margins at four points: mid-facial, mid-palatal, mid-mesial, and mid-distal.



**Figure 1: The prepared typodont tooth**

**Cast-metal die preparation.** The prepared molar typodont was invested in a light body addition cured elastomeric impression material (Affinis® Perfect Impressions, Coltène/Whaledent Ltd., United Kingdom) in a duplicating flask, and a complete impression of it was taken for the purpose of duplication in wax. After obtaining a

negative replica of the typodont, casting wax (Sybron/Kerr Romulus, Michigan) was heated and poured into the impression mould to obtain a wax die preparation. The wax die preparation was then sprued, invested and cast in cobalt-chromium alloy to form a cast-metal die preparation (Fig. 2 and 3).



**Figure 2:** Duplication of the typodont tooth and investing and casting of the metal die. (A) and (B): The prepared molar typodont invested in Affinis® Perfect Impressions light body elastomeric impression material. (C) and (D): The negative elastomeric impression mould after removal of the acrylic typodont tooth. (E) and (F): Wax die preparation poured out of casting wax (Sybron/Kerr Romulus, Michigan). (G) and (H): Sprued up wax die and casting ring. (I): Investment of wax die preparation with Rema® Exakt phosphate-bonded investment material. (J): Wax burn-out procedure. (K): Bench cooling before divesting. (L): Electropolishing of the metal die in an electropolishing unit.



**Figure 3:** Cast-metal die preparation

**Fabrication of the crowns.** The cast-metal die preparation was scanned using a CAD-CAM scanner and a wax-up design was done using the scanner software, with the specifications of the fit for a cast-metal crown coping. The wax patterns were then milled in batches of ten patterns, using a CAD-CAM machine, using Yenadent® CAD-CAM wax blocks (Istanbul, Turkey). Each of the seven groups of ten wax

patterns were then sectioned out of the wax block, trimmed, sprued and invested in their respective mixtures of phosphate bonded investment materials on the same day for each set of ten. This was done in order to minimize any distortion to the wax patterns as a result of heat or long duration in storage. Spruing was done using Bego® (BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany) wax wires for sprues, with the individual wax patterns being attached to the wax wire and then to the main sprue using Bego® crown wax (Fig. 4).

The 70 maxillary molar cast-metal crown copings were then cast in batches of ten cast-metal crown copings per casting cycle, for each of the manipulation modalities of the phosphate-bonded investment materials in the 7 groups (W-ma, BV/W-mm, C-mm, R-mm, BV-mr, C-mr, and, R-mr) (Fig. 5).

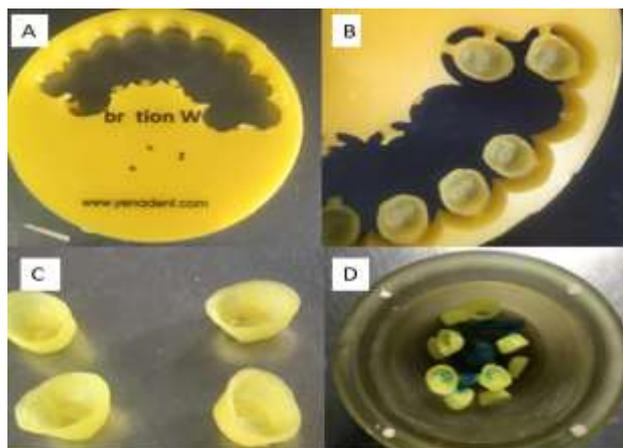


Figure 4: (A) and (B): Yenadent® CAD-CAM wax block with the milled wax patterns. (C): patterns after sectioning and trimming. (D): Sprued wax patterns.

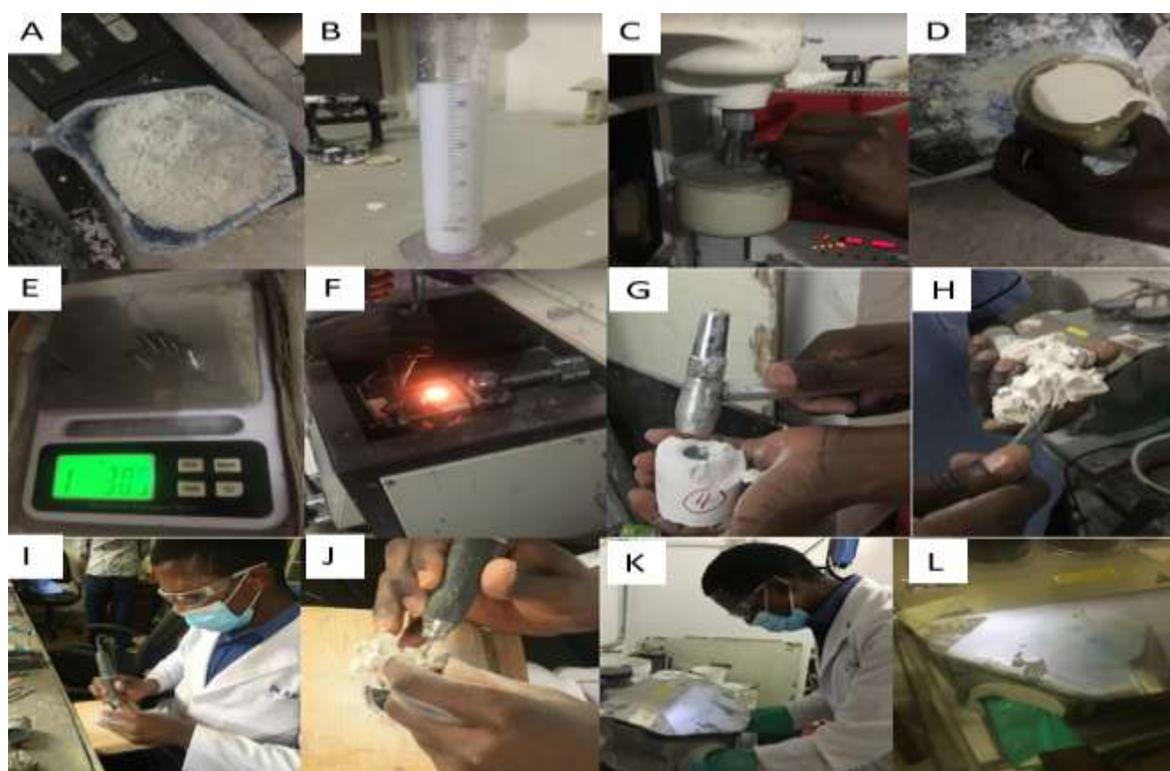


Figure 5: Investment, casting and divesting processes. (A) and (B): Measurement of the powder and liquid for Castorit super C phosphate bonded investment materials for casting the crown copings in the C-mr group. (C): Mixing the powder and liquid using a vacuum mixer. (D): Pouring the investment material into the rubber casting ring, while holding it against a dental vibrator. (E): Measurement of the weight of the cobalt-chromium metal ingots. (F): Placement of the investment mould into the induction casting machine after the wax burn-out procedure and melting of the metal alloy ingots. (G) and (H): Divesting the castings in the C-mm group. (I) and (J): Removal of investment material from the fitting surface of the crowns. (K) and (L): Sand blasting using 50 µm alumina particles.

**Divesting and preparation for digital photography analysis.** The cast-metal crown copings were sectioned out from the casting formation and trimmed on the occlusal aspect to create a near flat occlusal

surface. Modifications using a bur were only made where irregularities impeded proper seating of the casting on the metal die (Fig. 6).



Figure 6: Cast-metal crown copings sectioned out from the casting formation. Arrow shows example of extensions that had to be modified with a bur before seating onto the master metal die.

**Digital photography of the cast-metal crown copings.** A custom-made jig for securing the metal die was fabricated by mounting the metal die using Portland cement onto a plastic Lego® (toy), with the metal die centered on the jig. The cast-metal crown copings were then seated on the metal die and a 50-gram metal weight was placed on the castings to apply a force of approximately five Newton (Fig. 7). Images of the cast-metal crown copings sat on the metal die preparation, positioned against a black background for increased contrast,

were captured using digital photographs. A digital single-lens reflex camera (D3300; Nikon, USA) with a macro lens (Nikkor AF-S 105 mm f/2.8G IF-ED; Nikon USA), was set on a tripod stand, with the distance from the centre of the jig, up to the rim of the macro lens set at 30 centimetres. Photographs of the cast-metal crown copings, were taken to capture the four positions, initially documented on the original typodont tooth; mid-facial, mid-palatal, mid-mesial and mid-distal, for each of the 70 cast-metal crown copings (Fig. 8).



Figure 7: Seating of the cast-metal crown copings on the metal die preparation.



Figure 8: Photography set for the cast-metal crown copings.

**Image and data analysis.** The images were transferred to a computer and analyzed using the ImageJ National Institutes of Health (NIH) software (Fig. 9). The images were magnified by a factor of 150%. The vertical distance between the margin of the cast-metal crown coping and the finish line of the cast metal die preparation was then measured at the four pre-marked positions; mid-facial, mid-mesial, mid-palatal and mid-distal. Each individual measurement was taken three different times, in three different sittings, and the average measurement calculated from the three readings of each of the four pre-marked positions. The observer was blinded from having knowledge of the previous measurement to eliminate bias while taking the second and third marginal gap measurements. This was achieved by having each of the three sets of measurements taken

on different days and by not cross-checking the records of the previous measurements for the same point. A second observer was used to calibrate the main observer. His measurements were not included in the data but analysis of inter-rater reliability was carried out, where, the intra-class correlation coefficient was  $r=0.978$ ,  $p<0.001$ , showing agreement between the two observers.

Raw data was cleaned and subjected to analysis using STATA software version 16. Statistical tests [Kruskal Wallis H followed by post-hoc (Dunn's) tests] were undertaken to show the relationships between the manipulation and application of the various phosphate-bonded investment materials and the accuracy of marginal fit of cast-metal crown copings. Significant differences between the groups were assumed where  $p<0.05$ .



Figure 9: Image analysis using the ImageJ software.

## RESULTS

There were no significant differences in the measurements of the marginal gaps of crowns that were fabricated according to the manufacturers' instructions for Bellavest T<sup>®</sup>, Castorit<sup>®</sup>-super C, and Rema<sup>®</sup> cc ( $\chi^2(2)=1.286$ ,  $p=0.526$ ). The crowns that were cast after investment with the modified manipulation modalities that are in common practice in Nairobi, Kenya, for Bellavest T<sup>®</sup> ( $p=1.0$ ), Castorit<sup>®</sup>-super C ( $p=0.636$ ), and Rema<sup>®</sup> cc ( $p=1.0$ ), also yielded marginal gap measurements that were not statistically larger than the control groups. However, correct manipulation of Wirofine<sup>®</sup>

phosphate-bonded investment, but incorrect application to cast crowns, resulted in cast-metal crown copings with significantly larger ( $\chi^2(6) = 18.681$ ,  $p=0.0047$ ) marginal gap measurements; (Mean: 236.8  $\mu\text{m}$ ; SD: 130.34) when compared to the use of Bellavest T<sup>®</sup> (Mean: 133.8  $\mu\text{m}$ ; SD: 85.88), Castorit<sup>®</sup>-super C (Mean: 152.5  $\mu\text{m}$ ; SD: 85.67), and Rema<sup>®</sup> cc (Mean: 149.6  $\mu\text{m}$ ; SD: 98.83), manipulated according to their respective manufacturers' instructions. Wirofine<sup>®</sup> phosphate-bonded investment material also yielded cast-metal crown copings with significantly larger ( $\chi^2(3)=11.817$ ,  $p=0.008$ ) marginal gap

measurements, compared to crowns cast after investment with the modified manipulation modalities for Bellavest T<sup>®</sup> (Mean: 152.5 µm; SD: 103.88), and Rema<sup>®</sup> cc (Mean: 158.9 µm; SD: 105.03). The modified application and manipulation of

Wirofine<sup>®</sup> and Castorit<sup>®</sup>-super C phosphate-bonded investment materials yielded crowns that had mean marginal gap measurements of 236.8 µm (SD: 130.34), and 175.4 µm (SD: 97.85) respectively, as illustrated in figure 10.

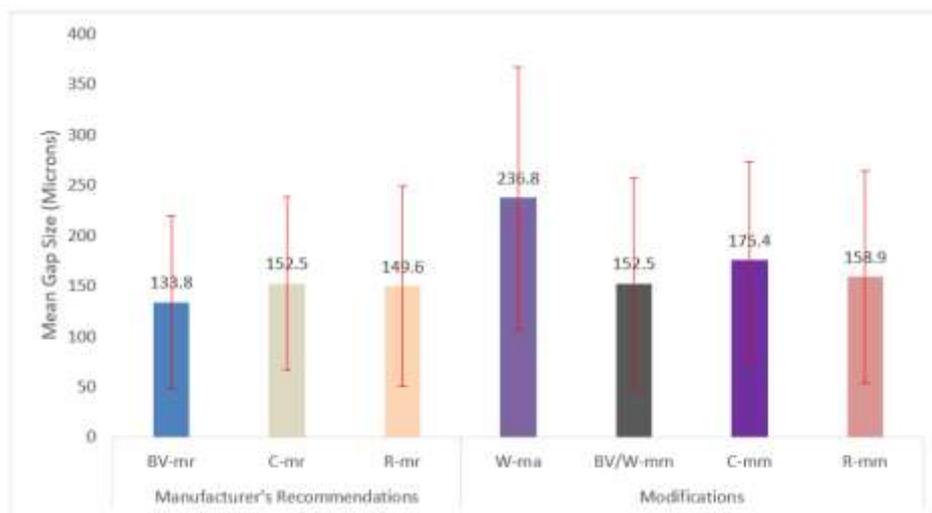


Figure 10: Overall mean marginal gap measurements for the different cast-metal crown coping groups

A test for homogeneity of variance (Levene test) accompanying the preliminary ANOVA test was done as shown in Table 1. The data violated the assumptions of ANOVA and so the non-parametric, Kruskal-Wallis H test was selected for subsequent analysis ( $F(6, 273) = 3.058, p = 0.006$ ). The Kruskal Wallis H test conducted on all the marginal gap measurements across the seven groups (Table 32), showed that the medians of the seven protocols are not equal statistically;  $\chi^2(6) = 18.681, p = 0.0047$ .

A post-hoc (Dunn's) test was conducted on all the seven groups of measurements, as shown in Table 3. The differences in median were found to be: (1) between W-ma against BV-mr ( $p = 0.002$ ), (2) between W-ma and R-mr ( $p = 0.013$ ), (3) between W-ma and BV/W-mm ( $p = 0.020$ ), and (4) between W-ma and R-mm ( $p = 0.047$ ).

A Kruskal-Wallis H test was conducted to determine if marginal gap measurements

were different for the four experimental groups (Table 4): W-ma ( $n = 40$ ); BV/W-mm ( $n = 40$ ); C-mm ( $n = 40$ ), and R-mm ( $n = 40$ ). The Kruskal-Wallis H test showed that there was a statistically significant difference in measurements between the four groups,  $\chi^2(3) = 11.817, p = 0.008$ .

A post-hoc (Dunn's) test was done on the experimental groups (Table 5). It revealed that the statistically significant difference in median was between W-ma and BV/W-mm, and between W-ma and R-mm.

A Kruskal-Wallis H test was conducted to determine if marginal gap measurements were different for the three control groups (Table 6): BV-mr ( $n = 40$ ); C-mr ( $n = 40$ ); and R-mr ( $n = 40$ ). The Kruskal-Wallis H test showed that there was no statistically significant difference in measurements between the three groups,  $\chi^2(2) = 1.286, p = 0.526$ .

**Table 2: Comparison of the marginal gap measurements on all the cast-metal crown copings groups.**

Source	Partial SS	df	MS	F	Prob>F
Model	272396.1	6	45399.35	4.36	0.0003
Group	272396.1	6	45399.35	4.36	0.0003
Residual	2841801	273	10409.53		
Total	3114197	279	11162		

Levene test  $F(6, 273) = 3.058, p = 0.006$

**Table 3: Comparison of the medians of the seven groups.**

Group	Observation	Rank Sum
W-ma	40	7446
BV/W-mm	40	5198
C-mm	40	6059
R-mm	40	5388
BV-mr	40	4700
C-mr	40	5441
R-mr	40	5108

**Table 4: Post-hoc (Dunn's) test after Kruskal-Wallis test for all the seven groups.**

Row Mean	BV-mr	C-mr	R-mr	W-ma	BV/W-mm	C-mm
C-mr	-1.023 1.000					
R-mr	-0.563 1.000	0.460 1.000				
W-ma	-3.792 <b>*0.002</b>	-2.768 0.059	-3.228 <b>*0.013</b>			
BV/W-mm	-0.688 1.000	0.336 1.000	-0.124 1.000	3.104 <b>*0.020</b>		
C-mm	-1.876 0.636	-0.853 1.000	-1.313 1.000	1.915 0.583	-1.189 1.000	
R-mm	-0.950 1.000	0.073 1.000	-0.387 1.000	2.842 <b>*0.047</b>	-0.262 1.000	0.926 1.000

**Table 5: Comparison of the marginal gap measurements on the experimental groups.**

Group	Observation	Rank Sum
W-ma	40	4046.00
BV/W-mm	40	2760.00
C-mm	40	3201.00
R-mm	40	2873.00

**Table 6: post-hoc test (Dunn’s test) on the experimental groups.**

	W-ma	BV/W-mm	C-mm
<b>BV/W-mm</b>	3.103 *0.006		
<b>C-mm</b>	2.039 0.124	-1.064 0.862	
<b>R-mm</b>	2.830 *0.014	-0.273 1.000	0.791 1.000

**Table 7: Comparison of the marginal gap measurements on control groups.**

Group	Observation	Rank Sum
BV-mr	40	2237.00
C-mr	40	2589.00
R-mr	40	2434.00

## DISCUSSION

Several commercially available investment materials have got variable ranges of expansion capabilities and so the resultant castings obtained after investing with the various phosphate-bonded investments may vary with different products.<sup>11</sup> In this study, the accuracy of different phosphate-bonded investment material brands manipulated in various ways was investigated. This was motivated by the practice of dental technologists in Nairobi Kenya, who have adopted various modifications to the manipulation modalities of phosphate-bonded investment materials. These alternative manipulation approaches are spurred by limited supplies of some of the investment material components on the local market, and also as a cost cutting measure. Similar challenges have been experienced in other parts of the world by countries that are net importers of dental material supplies. In Ukraine, a paradigm shift from dependence on imported materials, to local manufacture and use of dental materials is underway. Iurii Mochalov, an Associate Professor from Uzhhorod National University, Ukraine, presented a paper entitled “Predicted consequences of the system of import substitution of dental materials in Ukraine,” at the International Scientific and

Theoretical Conference, in Lisbon, Portuguese Republic, on June 4, 2021. He outlined the many benefits that would accrue if Ukraine became less dependent on importation of dental materials. Besides increasing the industry of local dental materials production in Ukraine, he also postulated that the move would reduce the cost of dental service provision.<sup>12</sup>

With the results of this study, it was demonstrated that some of the modifications to the manipulation modalities of phosphate-bonded investment materials, employed by dental technologists in Nairobi, Kenya, impacted the marginal fit of the cast-metal crown copings fabricated. The overall marginal gap measurements for the castings ranged from 133.8  $\mu\text{m}$  ( $\pm 85.88$ ) [for BV-mr] to 236.8  $\mu\text{m}$  ( $\pm 130.34$ ) [for W-ma]. Fransson et al. showed that a marginal gap of up to 150  $\mu\text{m}$  was clinically acceptable.<sup>13</sup> Two groups of castings (W-ma [236.8  $\mu\text{m}$  ( $\pm 130.34$ )] and C-mm group [175.4  $\mu\text{m}$  ( $\pm 97.85$ )]) recorded marginal gap measurements that were significantly higher than this. Where modifications to manipulation modalities were introduced (W-ma, BV/W-mm, C-mm, and R-mm), certain differences emerged. There was a statistically significant difference in median between W-ma and BV/W-mm, and between W-ma and R-mm. This meant that

the marginal gap measurements for the cast-metal crown copings fabricated after investment with Wirofine<sup>®</sup> phosphate bonded investment material, manipulated according to the manufacturer's instructions (W-ma), differed significantly from the marginal gap measurements of cast-metal crown copings fabricated in the BV/W-mm, and R-mm groups, but not the C-mm group. Wirofine<sup>®</sup> phosphate bonded investment material is indicated for casting metal frameworks for removable partial dentures. The manufacturer of these investment materials (BEGO GmbH & Co., Bremen, Germany) recommends the use of Bellavest T<sup>®</sup> for the investment of cast-metal crown copings and frameworks for fixed partial dentures. Therefore, the copings in the BV-mm group were used as the control group for the W-ma and BV/W-mm groups. It is not surprising, that despite the correct manipulation of Wirofine<sup>®</sup> in the W-ma group, inappropriate application of the investment material yielded crown copings with unacceptably wide marginal gaps. This is consistent with the general sensitivity of material performance to incorrect handling, as was exemplified by Vande et al. who in 2021, carried out a survey to assess the knowledge about routine laboratory procedures in the fabrication of fixed dental prostheses, amongst dental laboratories in Western Maharashtra, India. Noteworthy amongst their findings, was that 47.1% of dental laboratories did not prepare dies, leading to their conclusion that such omissions were tied to fixed partial denture failure rates observed in their locality.<sup>14</sup>

The practice of veering away from the manufacturers' instructions and/or recommendations is not unique to Nairobi, Kenya. Laboratory technologists in other countries have their own justifications for adopting practices that work favourably for them. For example, in Brazil, Rocha et al. determined that the use of Castorit<sup>®</sup>-super C, mixed with 100% special liquid, for casting titanium at 70°C, yielded castings with low marginal misfits, due to the high levels of setting expansion that are achieved

by the manipulation modality. In their set-up, the investment material that was recommended for casting titanium was Rematitan<sup>®</sup> Plus (Dentaurum J. P. Winkelstroeter KG, Pforzheim, Baden-Württemberg, Germany). However, the use of Rematitan<sup>®</sup> Plus was undesirable because it required heating up to 430°C to achieve desired expansion, whereas similar expansion was achieved with Castorit<sup>®</sup>-super C at 70°C.<sup>15</sup>

Literature is replete with studies that have investigated the casting of titanium, presumably because many researchers are endeavouring to overcome the challenge of titanium contamination during casting. Modifications to the casting process of titanium includes the combination of Rematitan<sup>®</sup> Plus with an investment material that is referred to as "spinnel-based." This is an investment that contains MgO and Al<sub>2</sub>O<sub>3</sub>, and forms a reduced  $\alpha$ -case thickness, which is a stable high temperature resistance oxide that serves as a barrier for the reducing activity that causes titanium contamination during casting. Perialini et al. coated the wax patterns with this spinnel-based investment (Rematitan<sup>®</sup> Ultra, Dentaurum, Ispringen, Germany) before eventual investment with Rematitan<sup>®</sup> Plus, Rema<sup>®</sup> Exakt, and Castorit<sup>®</sup>-super C. They found that coating wax patterns with Rematitan<sup>®</sup> Ultra improved the castability of all the phosphate-bonded investments under investigation.<sup>16</sup>

The materials that are utilized in the lost wax technique include wax, investment materials, the metal alloy for casting, and the optional use of a casting ring. All of these materials undergo dimensional changes, and thus become part of the variables that may affect the marginal fit of a cast-metal crown or fixed partial denture retainer.<sup>17</sup> In this particular study, the same casting wax (Yenadent<sup>®</sup> CAD-CAM wax blocks; Istanbul, Turkey) and cobalt chrome alloy ingots, were used for all study groups. A casting ring was not employed. Therefore, any variations in the accuracy of marginal fit can be attributed to the specific factors

that impact the dimensional changes in the investment material during casting namely; thermal expansion, factors related to the wax pattern handling, and the hygroscopic expansion of investment material.

Thermal expansion refers to expansion that occurs when the investment is heated in a burnout oven, typically achieved by a high temperature burnout technique, which serves the three-fold purpose of (1) expanding the metal casting ring and the investment material enough to compensate for alloy shrinkage, (2) elimination of the wax pattern and (3) enabling the alloy to completely fill the mould before solidifying.<sup>7</sup>

Metal casting rings, when used, are most commonly made of stainless steel. The rigid nature of metal casting rings results in the restriction of dental casting investments' setting expansion in the radial direction.<sup>18</sup> Furthermore, the thermal expansion experienced by the metal casting ring is typically less than that undergone by the investment material. This results in a further restriction of the investment material during the process of high-temperature casting.<sup>19</sup> Since compensation for the metal ring thermal expansion using a ring liner is of limited value, current practice has moved to ringless casting that accommodates the anisotropic expansion of the investment material.<sup>20, 21</sup> Since a metal casting ring was not used in this study, the expansion that was recorded in this study may be attributed to wax pattern expansion and the hygroscopic setting expansion of the investment material.

Expansion of the wax pattern occurs when its temperature rises either because of the heat from the exothermic chemical reaction of the investment or from a water bath in which the investment is immersed. Wax pattern expansion occurs when the investment is still fluid and the wax is heated above the temperature at which it was formed.<sup>7</sup> The dental wax that is invested and utilized in the lost wax technique is known as inlay wax. An increase in temperature of about 20°C may

result in inlay wax expansion of up to 0.7%. Conversely, a reduction in temperature from 37°C to 25°C causes a contraction of up to 0.35%. Within this temperature range, the average linear co-efficient of thermal expansion of inlay wax is  $350 \times 10^{-6}/^{\circ}\text{C}$ .<sup>22</sup>

Whereas it cannot be postulated to what extent the marginal fit of the castings in this study was affected by wax pattern expansion, it is noteworthy that all wax patterns were CAD-CAM milled and were thus identical. This meant that any degree of wax pattern expansion that was experienced was uniform. Therefore, it can be concluded that differences in marginal gap measurements across the different groups of castings, was because of differences in the degree of hygroscopic setting expansion, stemming from the different manipulation modalities of the investments.

If the manufacturer's recommendations for manipulation of a phosphate-bonded investment material are adhered to as regards the powder: liquid ratios as well as the concentration of the special liquid, the amount of hygroscopic setting expansion experienced by the investment is significant. The expansion experienced by phosphate-bonded investment materials is greater when the powder is mixed with the special silica sol liquid than when it is mixed with plain water. This is because the silica sol liquid enables the investment to expand hygroscopically, as opposed to the negligible setting expansion experienced when only plain water is used.<sup>11</sup> The findings in this study showed that not using 100% pure expansion liquid, particularly while manipulating Castorit<sup>®</sup>-super C investment material resulted in castings that had significantly larger marginal gap measurements [175.4  $\mu\text{m}$  ( $\pm$  97.85)]. Dental technologists in Nairobi, Kenya reported using a ratio of 2:3 – Distilled Water: Expansion Liquid, in the manipulation of Rema<sup>®</sup> cc investment material. This deviation from the manufacturers' instructions (by not using 100% pure expansion liquid) did not however yield

castings with significantly larger marginal gap measurements [158.9  $\mu\text{m}$  ( $\pm$  105.03)]. In this study the average marginal gap measurements recorded were between 133.8  $\mu\text{m}$  ( $\pm$  85.88) for BV-mr and 236.8  $\mu\text{m}$  ( $\pm$  130.34) for W-ma. The acceptable marginal gap opening reported in this study was 150  $\mu\text{m}$ , citing the 1985 paper by Fransson et al.<sup>13</sup> The only two groups that recorded measurements that were significantly larger than this figure, were the cast-metal crown copings fabricated using the modified application of Wirofine<sup>®</sup> [W-ma: 236.8  $\mu\text{m}$  ( $\pm$  130.34)] and those fabricated using the modified manipulation of Castorit<sup>®</sup>-super C [C-mm: 175.4  $\mu\text{m}$  ( $\pm$  97.85)].

## CONCLUSION

Within the limits of this study, it can be concluded that: (1) there are significant differences in the accuracy of marginal fit of the cast-metal crown copings fabricated according to the manufacturers' instructions for investment or by utilizing the modifications in the handling of the investment materials, (2) modification of manufacturers' recommendations for the manipulation of Bellavest T<sup>®</sup>, and Rema<sup>®</sup> cc phosphate-bonded investment materials, as is done by laboratory technologists in Nairobi, Kenya, yields crowns that have marginal gap measurements within clinical acceptable range (<150  $\mu\text{m}$ ), (3) the modified application and manipulation of Wirofine<sup>®</sup> and Castorit<sup>®</sup>-super C phosphate-bonded investment materials yields crowns with marginal gaps beyond the clinically acceptable range. Therefore, these modifications should not be used to cast metal crowns.

This study is invaluable in advising dental clinicians and technologists about the possible correlation of the investment materials they use, and the manipulation thereof, with the accuracy of the marginal fit of the resultant metal crowns. Further research needs to be carried out on other phosphate-bonded investment material brands used by dental laboratories in Kenya, such as S.P.E<sup>®</sup> Phosphate Bonded Dental

Investment Material (Henan Shengbang Medical Technology Co., Ltd, Zhengzhou, Henan, China), Elite Vest Plus<sup>®</sup> (Zhermack, GmbH, Badia Polesine, Italy) and Yetinvest<sup>®</sup> (Yeti GmbH, Berlin, Germany). Such research should establish whether dental technologists in Kenya adhere to the manufacturers' instructions for manipulation of these material brands, as well as evaluate the accuracy of castings obtained from these products, whilst correlating the marginal gap and internal fit measurements obtained, to the manipulation modalities. With subsequent studies, it should be endeavoured to achieve absolute blinding when evaluating marginal gap measurements, in order to increase the power of the study, since this was a limitation in this study.

## Declaration by Authors

**Ethical Approval:** Approved.

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