EFFECT OF PHOSPHATE-BONDED INVESTMENT MATERIALS AND THEIR MANIPULATION ON THE MARGINAL FIT OF CAST-METAL CROWN COPINGS

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A Thesis submitted in partial fulfilment of the requirements for a Master of Dental Surgery (MDS) in Prosthodontics Degree from The University of Nairobi

April, 2023

DECLARATION

I, Silas Mbeya Toka, declare that this thesis titled: **"Effect of Phosphate-Bonded Investment Materials and their Manipulation on the Marginal Fit of Cast-metal Crown Copings"** is my authentic work. It has not been submitted elsewhere for examination or award of a degree.

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Signed : .....

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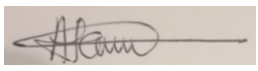
Signed:  Date: 30th April, 2023

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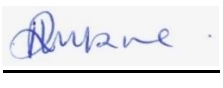
Signed:  Date: 30th April, 2023

DEDICATION

To Jebii and Ari

Without whom I'd have probably finished this in 2018.

But then what would I have done with the rest of my life?

To Allen (With an "E")

Who just came… and has no idea he's being talked about in scientific documents.

And to Hudson Alumera

Who will now find it harder to wire to me my money on the day I wed …

You promised.

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AAS: Atomic absorption spectroscopy

ANSI/ADA: American National Standards Institute/American Dental Association

NIH: National Institutes of Health

USA: United States of America

US $: United States Dollar

ISO: International Standardization Organization

SPSS: Statistical Package for Social Sciences

ANOVA: Analysis of variance

GPT 8: Glossary of Prosthodontic Terms, Version 8

CAD-CAM: Computer Aided Designing and Computer Aided Milling

BV: Bellavest T®

C: Castorit®-super C

R: Rema® cc

W: Wirofine®

mr: manufacturers' recommendation

ma: modified application

mm: modified manipulation

MPa: Mega-Pascals

μm: Micro-metres

g: Grams

ml: Millilitres

°C: Degrees Celsius

°F: Degrees Fahrenheit

Aqua dest.: Distilled Water

GmbH: German phrase “Gesellschaft mit beschränkter Haftung,” which means "company with limited liability."

Co-Cr: Cobalt-Chromium

Ni-Cr: Nickel-Chromium

min: minute

μm: Micro-metres

N/A: Not Applicable

SD: Standard Deviation

IQR: Inter-quartile range

vs: Versus

MgO: Magnesium oxide

Al_2O_3: Aluminium oxide

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Introduction: Dental practitioners are faced with the growing demand to provide fixed prostheses that offer long-term service to patients; prostheses that do not de-cement, create stagnation sites or develop marginal failure. The investment materials used in the laboratory stages of production of cast-metal crowns and retainers for fixed partial dentures, influence the dimensional fit of the resultant fixed dental prostheses.

Objective: 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.

The study was conducted in Nairobi, Kenya, in the year 2020, at the Kenyatta National Hospital Dental Prosthetics Laboratory and at Prime Dental Studios, a privately-owned Dental Prosthetics Laboratory.

Materials & Methods: This was a descriptive cross-sectional study, designed as a laboratory-based experiment. There were three control groups, and four experimental groups. Each of the seven groups had ten cast-metal crown copings fabricated using cobalt-chromium ingots. The groups of ten castings in the three control groups were fabricated according to the manufacturers' instructions for investing, using Bellavest T®, Castorit®-super C, and Rema® cc, for the ***BV-mr, C-mr***, and ***R-mr*** groups, respectively. The experimental group ***W-ma*** had a modified application of Wirofine®, manipulated according to the manufacturer's instructions, but applied to invest cast-metal crown copings, instead of removable partial denture frameworks. The cast-metal crown copings in the ***BV/W-mm***, ***C-mm*** and ***R-mm*** were fabricated after investment with the various investment materials, manipulated whilst utilizing modifications to the manipulation modalities that are in use by a section of dental laboratory technologists in Nairobi, Kenya.

Each of the seventy cast-metal crown copings were photographed at four sites using a digital single-lens reflex camera with a macrolens. The photographs were magnified (x150%) in order to facilitate measurement of the marginal gaps in micro-metres, using the ImageJ National Institutes of Health (NIH) software. A sample size of 280 measurements was obtained. The continuous data was analysed using STATA software, version 16 with Kruskal Wallis H statistical tests followed by post-hoc (Dunn's) tests being done to show relationships.

Results: The study determined that there were no significant differences (**χ^2(2)=1.286, p=0.526)** in the measurements of the marginal gaps, of crowns that were fabricated according to the manufacturers' instructions for Bellavest T®; ***BV-mr*** (**Mean: 133.8 µm; SD: 85.88**), Castorit®-super C; ***C-mr*** (**Mean: 152.5 µm; SD: 85.67**), and Rema® cc; ***R-mr*** (**Mean: 149.6 µm; SD: 98.83**). Crowns that were cast after investment with the modified manipulation modalities that are in common practice in Nairobi, Kenya, for Bellavest T®; ***BV/W-mm*** (**Mean: 152.5 µm; SD: 103.88; p=1.0**), Castorit®-super C; ***C-mm*** (**Mean: 175.4 µm; SD: 97.85; p=0.636**), and Rema® cc; ***R-mm*** (**Mean: 158.9 µm; SD: 105.03; p=1.0**), also yielded marginal gap measurements that were no larger than the control groups in any statistically significant way.

However, correct manipulation of Wirofine® phosphate-bonded investment, but incorrect application to cast crowns (***W-ma)***, resulted in cast-metal crown copings with significantly larger (**χ^2(6) = 18.681, p=0.0047)** marginal gap measurements; (**Mean: 236.8 µm; SD: 130.34**) when compared to the use of Bellavest T® (**Mean: 133.8 µm; SD: 85.88**), Castorit®-super C (**Mean: 152.5 µm; SD: 85.67**), and Rema® cc (**Mean: 149.6 µm; SD: 98.83**), phosphate bonded investment materials, manipulated according to their respective manufacturers' instructions (***BV-mr, C-mr***, and ***R-mr*** groups).

Wirofine® phosphate-bonded investment material (***W-ma)***, further yielded cast-metal crown copings with significantly larger (**χ^2(3)=11.817, p=0.008**) marginal gap measurements, compared to crowns cast after investment with the modified manipulation modalities for Bellavest T®; ***BV/W-mm*** (**Mean: 152.5 µm; SD: 103.88**), and Rema® cc; ***R-mm*** (**Mean: 158.9 µm; SD: 105.03**).

Conclusion: Modification of manufacturers' modalities for the manipulation of Bellavest T®, and Rema® cc phosphate-bonded investment materials, as is done by laboratory technologists in Nairobi, Kenya, yielded crowns that had marginal gap measurements within clinical acceptable range **(<150 µm)**.

The modified application and manipulation of Wirofine® and Castorit®-super C phosphate-bonded investment materials yielded crowns that had mean marginal gaps of **236.8 µm (SD: 130.34)**, and **175.4 µm** (**SD: 97.85)** respectively. These measurements fell beyond the clinically acceptable range. Therefore, these modifications should not be used to cast fixed prostheses.

CHAPTER ONE:

INTRODUCTION

1.1 Background

Loss of dental hard tissue can be ascribed to a number of reasons. These can be broadly classified into non-carious and carious aetiological factors. Dental erosion, attrition and abfraction are examples of non-carious causes of dental hard tissue loss. Dental erosion is defined as acid-related loss of tooth structure which does not involve microorganisms [(1)]. Attrition refers to the mechanical wear resulting from mastication or parafunction, limited to contacting surfaces of teeth, whereas abfraction is the pathologic loss of hard tooth substance caused by biomechanical loading forces, resulting in enamel or dentine loss due to their flexure and chemical fatigue degradation at some point distant from the actual point of loading [(2)]. Dental caries is however the most common cause of hard tissue loss. Caries is defined as a dental disease causing the destruction of enamel, dentine and/or cementum, which has its aetiology generally ascribed to acid producing bacteria [(2)]. The prevalence of dental caries ranges from at least 30% up to 65% in different groups according to a number of studies [(3, 4)].

1.2 Management Modalities of Dental Hard Tissue Loss

1.2.1 Direct Restorations

The management of dental hard tissue loss is either undertaken using direct restorations or indirect restorations. The building of a direct restoration is typically undertaken by applying the restorative material directly onto the tooth. This is made possible by the plasticity of the filling material at the time of manipulation and placement. Such a filling material sets after placement [(5, 6)].

1.2.2 Indirect Restorations

Indirect restorations however require several iterative steps to create the final product, including a laboratory procedure [(7)]. The laboratory step of fabricating some indirect restorations such as crowns, bridges, inlays and onlays, entails the utilization of a procedure that is referred to as the lost wax technique.

1.3 The Lost Wax Technique

1.3.1 Definition

The lost wax casting technique also known as investment casting is described as follows:

"The casting of a metal into a mould produced by surrounding (investing) an expendable (wax) pattern with a refractory slurry that sets at room temperature, after which the pattern is removed through the use of heat" [(2)].

1.3.2 Correlation Between The Lost Wax Technique and Investment Materials

The refractory slurry that surrounds the wax pattern in the lost wax technique is the investment material.

The laboratory stages of preparing and investing a wax pattern for the purpose of fabricating a framework for a dental prosthetic replacement, are very sensitive. The cast-metal or the ceramic that fill the mould space left after the wax burnout are prone to shrinkage. The dimensional changes that inevitably result from these procedures need to be predictable, anticipated and planned for so as to end up with the intended dimensions of fixed dental prosthetic replacements.

1.4 Fixed Prosthodontics in Modern Societies

1.4.1 Perception of Fixed Prosthodontics by Modern Societies

It is desirable that patients be provided with long lasting fixed dental prostheses. Retention of one's natural teeth or the creation of the impression that one still has their natural teeth, is a feat that is associated with youth and virility in many modern societies [(8)]. Many people consider loss of teeth as something that generally happens to elderly people. Individuals in the population generally prefer fixed prosthetic rehabilitation as opposed to removable prostheses. In fact, an association has been drawn between overall treatment dissatisfaction and negative attitudes towards dentures [(9)].

1.4.2 Fixed Prosthodontic Modalities and Relationship to Marginal Fit

Crowns and fixed partial dentures are the two principal entities in fixed prosthodontics. They need to be fabricated in a manner that will ensure preservation of the patient's natural dentition. The accuracy in their marginal fit is of key importance in meeting this requirement.

A crown is a type of an indirect restoration that is indicated for restoration of badly broken-down teeth or endodontically treated teeth. It is defined as:

"an artificial replacement that restores missing tooth structure by surrounding part or all of the remaining structure with a material such as cast metal, porcelain, or a combination of materials such as metal and porcelain" [(2)].

A "bridge" is a colloquial term for a fixed dental prosthesis known as a fixed partial denture. The Glossary of Prosthodontic Terms, Version 8 (GPT 8) defines a fixed dental prosthesis as:

"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. This may include replacement of one to sixteen teeth in each dental arch. If a metallic or ceramic component is included within the fixed dental prosthesis, that component is termed the framework" [(2)].

A conventional fixed partial denture is secured to the natural tooth abutment(s) through the utilization of retainers. The GPT 8 defines a retainer as "any type of device used for the stabilization or retention of a prosthesis" [(2)]. Retainers for conventional fixed partial dentures are essentially crowns that are attached to the pontic(s). The pontic is the artificial tooth that replaces a missing natural tooth [(2)].

Evidently, this means that both crowns and retainers for fixed partial dentures share similar features. By studying the features of a crown, inferences can be made to the features of a retainer of similar design. In this study, the marginal fit of cast-metal crown copings fabricated after investing with four different phosphate-bonded investment materials, manipulated in seven different ways, was investigated.

1.4.3. Relationship Between Marginal Fit and Investment Materials

The marginal fit of a crown (or a retainer) is a very important prognostic indicator for the success and longevity of the fixed prosthetic restoration [10]. 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 [11]. Whereas factors such as the impression material and technique used may have an implication on the accuracy of a cast-metal framework, laboratory auxiliary materials used in casting are equally as critical [12]. Such materials include gypsum, waxes and investment materials.

The GPT 8 defines an investment material (or a dental casting investment) as follows:

"a material consisting principally of an allotrope of silica and a binding agent. The binding substance may be gypsum (for use at lower casting temperatures) or phosphates and silica (for use at higher casting temperatures)" [2].

The type of investment material used in a casting procedure should be able to accurately create a mould that would produce cast crown and retainer copings of the desired dimensions [13]. Since the casting procedure takes place at very high temperatures, dimensional changes are inevitable [14]. 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 [15].

There are three types of investment materials available for dental casting procedures; namely, gypsum-bonded investments, phosphate-bonded investments, and silica-bonded investments [16]. These investment materials vary in particle sizes even if they are of the same type [17]. Phosphate bonded investment materials are used to cast base metal alloys used for the fabrication of cast crown and retainer copings for fixed prosthodontic treatment [15].

Within the various commercially available brands of phosphate bonded investment materials there are brands that are provided with their manufacturer's instructions for specific use in casting crowns and bridges [18, 19] . Some are postulated to be able to produce accurate castings because of their finer particle sizes [17] compared to other phosphate bonded investment materials that have larger particle sizes and are recommended for casting removable partial denture frameworks.

This study sought to find out the dimensional differences of the margins of cast-metal crown copings fabricated using four different phosphate-bonded investment materials, when adhering to the recommendations of the manufacturer, and when employing some of the compromises in common practice by dental technologists in Nairobi, Kenya.

As it is every clinician's wish to provide patients with long lasting fixed prostheses, this study is invaluable in advising dental practitioners and dental technologists about the possible correlation of the investment materials they use and the manipulation thereof, with the accuracy of the marginal fit of the final prostheses.

CHAPTER TWO:

LITERATURE REVIEW

A dental casting investment generally contains three distinct materials, namely [7]:

1. Refractory material: Usually a form of silicon dioxide such as quartz, tridymite or a mixture of these.
2. Binder material: Material used to enable the entire mix to form a coherent solid mass. Examples of these are gypsum (α-calcium sulphate hemihydrate), phosphate and ethyl silicate.
3. Other chemicals such as sodium chloride, boric acid, potassium sulphate, graphite, copper powder or magnesium oxide are incorporated in investment materials to improve various physical properties.

   Investigations using atomic absorption spectrophotometry (AAS) have revealed various elements present within investment materials. These elements include lead, copper, iron, zinc, manganese, sodium, calcium, magnesium and potassium [20].

Based on the type of binder material, the investment materials available for dental casting procedures are [16]:

1. Gypsum-bonded investments
2. Phosphate-bonded investments
3. Silica-bonded investments

Gypsum-bonded and phosphate-bonded investments are commonly used in the laboratory stages of fabricating cast restorations [15]. Silica-bonded investment materials are also used for casting alloys with high melting points [7], but are not in common use in the local set up of Nairobi, Kenya.

This study focused on four commercially available brands of phosphate-bonded investment materials in common use in the aforementioned study area. In the next sub-sections however, in addition to discussing the material properties of phosphate-bonded investment materials, a brief description of gypsum-bonded and silica-bonded investments shall be presented.

2.1 Gypsum-bonded Investments

These investment materials are used for casting conventional gold casting alloys with melting temperature ranges below 1000°C. They contain α-calcium sulphate hemihydrate (gypsum) as a binder to an allotropic form of silica; either in the form of quartz or cristobalite [16]. The gypsum matrix is a calcium sulphate hemihydrate and it comprises 30% to 35% of the investment. The quartz or the cristobalite act as the refractory material and provides for thermal expansion of the investment. These refractory materials make up 60% to 65% of the investment [15].

Gypsum-bonded investments are used with type I, II and III gold alloys and are themselves classified as type I for use with the high temperature technique and type II for use with the low temperature technique [15].

A high temperature burn-out technique utilizes temperatures of about 650°C, whereas the low temperature burnout utilizes temperatures of about 480°C followed by immediate immersion into a 38°C water bath to achieve adequate wax pattern expansion [15].

2.2 Phosphate-bonded Investments

This is the most common type of investment material for casting high melting point alloys. It contains three essential components which may vary in their exact composition depending on the desired physical properties that the manufacturer intended to develop. The three components are [7]:

1. A water-soluble phosphate ion
2. A component that reacts with phosphate ions at room temperature
3. A refractory component such as silica.

The reaction in the binding system of the typical phosphate-bonded investment material is an acid-base reaction between monoammonium phosphate ($NH_4H_2PO_4$) and basic magnesia (MgO) [7].

The reaction proceeds as follows [7]:

$NH_4H_2PO_4 + MgO + H_20 \rightarrow NH_4MgPO_4.6H_2O + H_2O$

In order to achieve higher expansion in the refractory system, a combination of different particle sizes of silica is used [7].

Whereas the investments can be mixed with pure water alone during its manipulation, manufacturers also supply a special liquid which is a form of silica in water, that can be used to mix with the phosphate bonded investments to produce a greater setting expansion [7].

Figure 1, below, illustrates the thermal expansion and hygroscopic expansion experienced by two phosphate-bonded investment materials. One phosphate-bonded investment material (labelled "A") predominantly displays thermal expansion. The phosphate-bonded investment material labelled "B" predominantly displays hygroscopic expansion. The solid lines indicate thermal expansion, whereas dotted lines indicate hygroscopic expansion for the two phosphate bonded investment materials.

The setting 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 and/or thermal expansion experienced when only plain water is used [7]. For the phosphate-bonded investment material labelled "B" in Figure 1, the amount of hygroscopic setting expansion it experiences at 100 % silica sol concentration, matches the thermal expansion experienced by the phosphate-bonded investment labelled "A". Whereas the hygroscopic setting expansion experienced by material "A" is still dependent on the concentration of the silica sol, it is still negligible compared to the thermal expansion it experiences at different concentrations of the silica sol liquid.

The strength of phosphate-bonded investments is also considerably increased when the silica sol is used for mixing instead of plain water [7].

Figure 2 illustrates the thermal expansion of two commercially available phosphate-bonded investment materials mixed according to the manufacturers' recommended liquid/powder ratio [7].

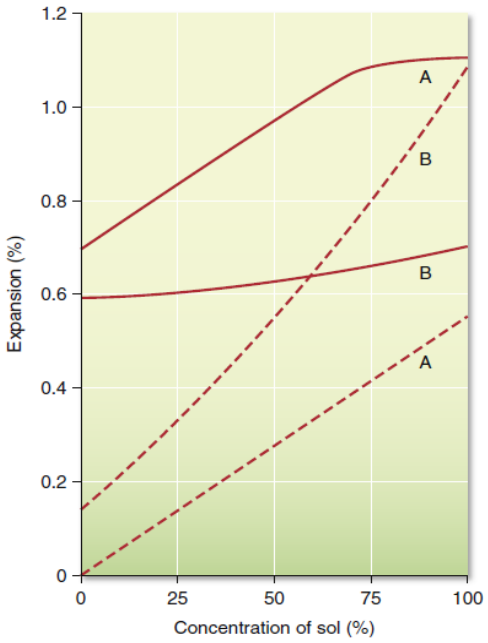

Figure 1: Effect of silica sol concentration on thermal expansion at 800°C and hygroscopic setting expansion of two phosphate-bonded investments – A and B. The solid lines indicate thermal expansion, whereas dotted lines indicate hygroscopic setting expansion for the two materials.

(Reproduced with permission from Craig RG. Craig's Restorative Dental Materials. 13 ed. St. Louis, Missouri: Mosby, an imprint of Elsevier Inc.; 2012. [7]*)*

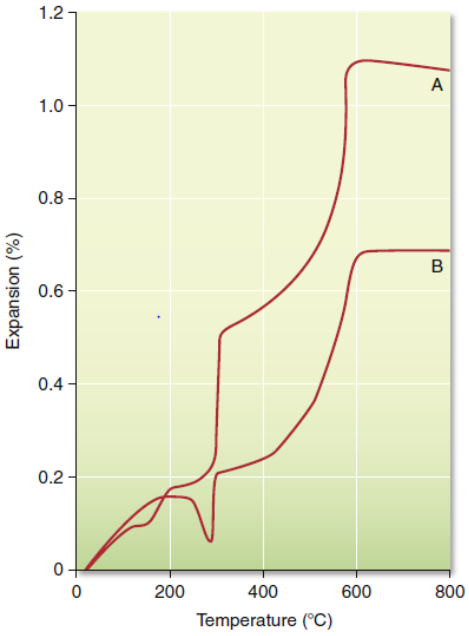

Figure 2: Thermal expansion curves of two phosphate-bonded investments mixed at recommended liquid/powder ratios.

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The illustration in Figure 2 is apt because it shows that various commercially available products have got different ranges of expansion capabilities and so the resultant castings obtained after investing with the various phosphate-bonded investments may vary with different products. This study investigated this and other aspects of phosphate-bonded investments.

The ANSI/ADA specification No. 126 (ISO 9694) specifies two types of dental phosphate-bonded investment materials for alloys having a solidus temperature above 1080°C. These are [7]:

1. Type 1: For inlays, crowns, and other fixed restorations.
2. Type 2: For removable dental prostheses.

The specification describes the following properties [7]:

- Fluidity
- Initial setting time
- Linear thermal expansion
- Compressive strength

The specification states that the fluidity at working time for type 1 investments should be a diameter of 90 millimetres, whereas that for type 2 phosphate bonded investments should be a diameter of 70 millimetres. It further states that the setting time should be within 30% of the time stated by the manufacturer, whereas the linear thermal expansion must not differ by more than 15% from the value stated by the manufacturer. The compressive strength at room temperature for type 1 investments (for fixed prosthodontics) should not be less than 2.5 MPa, whereas that for type 2 investments (for removable prostheses) should not be less than 3.0 MPa [7].

2.3 Silica-bonded Investments

This type of investment material utilizes either an aqueous dispersion of colloidal silica or sodium silicate to impart a silica bond to a refractory silica [7].

Ethyl-silicate-bonded investment material consists of silica refractory bonded by the hydrolysis of ethyl silicate in the presence of hydrochloric acid resulting in a colloidal solution of silicic acid and ethyl alcohol. The reason this investment material is uncommonly

used is because this method of processing is expensive. It entails the mixing of the powder with two bottles of special liquid instead of water. One bottle contains properly diluted water-soluble silicate solution. The other contains a properly diluted acid solution such as that of hydrochloric acid. The investment also gives off flammable components during its processing and so the use of sodium silicate and colloidal silica as binders is preferred [7].

Whereas ethyl-silicate bonded investment materials are losing popularity because of the complicated and time consuming procedures that are involved in their use, they are still used in the construction of high fusing, base-metal partial denture alloys [16].

2.4 The Lost Wax Technique

The lost wax technique was introduced by William H. Taggart in 1907 [16]. It was supposed to be a novel "accurate" way of making gold inlays, but he noted that the resultant restorations were undersized [14, 21, 22]. His findings have been shared by many subsequent studies, all of which have shown that molten alloys used for the fabrication of fixed prostheses, shrink upon solidification [15]. Gold alloys contract by 1.5% [23], whereas the contraction of nickel-chromium alloys is as much as 2.4% [24].

Shrinkage of a cast-metal crown is an undesirable change that may end up causing incomplete seating on the tooth preparation.

The success of a fixed prosthetic replacement depends on the quality of the preparation, the dimensional accuracy of the impression material and impression technique, the quality of the working cast, the quality of the wax used in the lost wax technique, and the accuracy of the castings [25]. The accuracy of the casting will depend on the compensation that is provided for the solidification shrinkage. This is done by investment expansion. There are four methods of achieving an expanded mould, namely: (1) setting expansion of the investment, (2) hygroscopic expansion of the investment, (3) thermal expansion of the investment, and (4) wax pattern expansion [15]. The first three are regularly used in modern laboratory set-ups to achieve an expanded mould [26].

2.5 Setting Expansion

This occurs as a result of normal crystal growth of the investment material. Silica particles in the investment interfere with the forming crystalline structure of the gypsum causing it to

expand outwards [27]. In air, the setting expansion is normally about 0.4%, but the full achievement of this is restricted by a metal casting ring [15].

2.6 Hygroscopic Setting Expansion

Hygroscopic setting expansion results when an investment is allowed to set in the presence of water to produce an additional expansion. The theory is that the expansion results from the maintenance of space between the growing crystals as a result of the water in which the investment is soaked, replacing the water used by the hydration process. Replacing the water of hydration allows crystals to expand outwards, rather than restricting them. Typically, the investment filled ring is placed in a 38°C water bath or by adding measured amounts of water to a setting investment, resulting in hygroscopic setting expansion ranges from 1.2% to 2.2%. Hygroscopic setting expansion takes place unimpeded if the investment is not restricted by a trough or an expandable investment ring. If restricted though, the expansion that takes place is due to the expansion of the wax pattern [15].

Figure 1, above, illustrated the amount of hygroscopic setting expansion experienced by a commercially available brand of a phosphate-bonded investment material. It shows that if the manufacturer's recommendations 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 would be significant [7].

As it was outlined earlier, 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 [7].

This study sought to establish the extent to which deviations from manufacturers' recommendations on the use of the special silica sol liquid, have on the marginal fit of the resultant cast-metal crown copings.

Since it has already been established that these deviations will interfere with the setting expansion as well as the hygroscopic expansion of the investment material, the study sought to find out what impact this impaired expansion has on the cast-metal crown copings that were fabricated after investment with those investment materials.

2.7 Thermal Expansion

This 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 [15].

A metal casting ring was not used in this study, and so it was expected that the other two means of achieving thermal expansion were of significance in this study.

2.8 Wax Pattern Expansion

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 [15].

The dental wax that is invested and utilized in the lost wax technique is known as inlay wax [16]. 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 x 10^{-6}/°C [16].

2.9 Investment Procedures and Materials Used for Investing Base Metal Alloys

Unmodified gypsum can withstand temperatures up to 1200°C without decomposing [14, 28-29]. However, because of the notable shrinkage that it undergoes at this temperature, a refractory material such as silica is added to it. Whereas silica does compensate for the dimensional changes of gypsum, it reduces both the heat resistance of and the compressive strength of gypsum, making it necessary to use a metal casting ring that serves to protect the investment material from casting forces [14, 21, 30-32].

Phosphate bonded investment materials are ideal for casting base metal alloys that are used in the fabrication of crown and retainer copings for fixed prosthodontic work. The refractory filler in these investments is silica in the form of cristobalite, quartz or a mixture of the two in the concentration of about 80%. The binder consists of magnesium oxide and

monoammonium phosphate [16]. Phosphate bonded investment materials are able to withstand higher temperatures and higher casting stresses that are experienced in the casting of alloys with higher melting temperatures [27, 7]. The base metal alloys used for fabricating the cast metal crown and retainer copings include cobalt-chromium and nickel-chromium-beryllium alloys. The commercial brands available contain other constituents in their composition, including Beryllium, Molybdenum, Tin, Aluminium and Gallium [16].

Base metal alloys experience a high degree of shrinkage on cooling. When investing them, the set investment with the invested pattern is placed in a water bath at 38°C for one hour. The setup is then allowed to cure overnight with the wax burnout procedure being carried out the next day. The wax pattern is then eliminated from the mould using a high temperature burnout technique, where the set investment is brought to 815°C in one hour and then allowed to heat for another two hours. This ensures that all traces of carbon are eliminated [15].

When using a centrifugal casting machine, the process of casting entails preheating the quartz crucible in the burn-out oven. The casting machine is wound, allowing it one or two extra winds to compensate for the light density of the base metal alloy. The quartz crucible is then removed from the oven with casting tongs and placed in the bracket on the casting machine. The metal ingots are placed in the crucible and melted using a gas oxygen torch, taking care not to overheat the alloy. Casting is then done and once complete, bench cooling is done at room temperature. The divested casting is air blasted using 50 μm alumina. No pickling is done for base metal castings [15]. Modern induction casting machines have their own internal mechanism of heating the quartz crucible and melting the metal alloy ingots.

In this study, cobalt-chromium ingots were cast, first according to the manufacturers' instructions for the various phosphate-bonded investment materials, and then by employing compromises made in our local set-up in the manipulation of the various phosphate-bonded investment materials.

The manufacturers' instructions for the use of Bellavest® T, Wirofine®, Castorit®-super C and Rema® cc are outlined Appendices III to VI.

2.10 Modifications to Manipulation Procedures Practiced 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 (Appendix I). The respondents were selected by convenience sampling. Dental technologists who practice their profession in either public or private laboratories that have the equipment needed to cast metal copings for fixed prosthodontic work, were included in the survey. Dental technologists who do not routinely fabricate cast-metal copings for fixed prosthodontic work were excluded from participating in the survey.

An example of a manipulation modality employed by the dental technologists, who participated in the survey, is the use of Wirofine® phosphate-bonded investment material, for casting metal copings for crowns and retainers for fixed partial dentures. Out of 16 dental technologists interviewed, all of them reported that they use Wirofine® for investing wax-patterns for the purpose of fabricating cast-metal copings for crown and bridge work. About 60% of them (ten respondents) further reported that they use Wirofine® "often" or "very often", for that same purpose of investing wax-patterns for crown and bridge work. Wirofine® phosphate-bonded investment material is recommended by its manufactures for casting base metal alloys for removable partial dentures [33]. The material recommended by the same manufacturer for casting crowns and retainers for fixed prosthodontic work is Bellavest T® phosphate-bonded investment material.

The manufacturer's dealer's website for BEGO, the company that produces the two materials suggests why Wirofine® may be preferred by some dental laboratories. At the time of the development of this study's proposal, 15 kilograms of Wirofine® retailed at US $ 145.85 whereas the same amount of Bellavest® T retailed at US $ 168.40 [36]. Evidently, Wirofine® may have been used and found to be able to achieve *similar* results as Bellavest® T and therefore it became an option for technicians in order to provide more affordable cast-metal crowns and bridges to the local populace. The accuracy of using either of the materials had not yet been compared in any study prior to this current study.

Wirofine® has a reported compressive strength of approximately 15 MPa, measured two hours after the initial mixing is done according to the manufacturer's instructions [33]. Bellavest® T has a compressive strength of 7 MPa when mixed with 50% expansion liquid (BegoSol®) and that of 10 MPa when the expansion liquid is mixed in the ratio of 9:1 with

distilled water [18]. Wirofine® is generally able to withstand higher temperatures than Bellavest® T, which is apt for cobalt chromium alloys, which are cast at recommended casting temperatures of between 950°C to 1050°C [33]. The final temperature that Bellavest® T is subjected to when casting non-precious metal and non-precious metal to ceramic alloys is between 900°C to 950°C [18].

Bellavest® T however produces a smoother mix and a mixture of the two reportedly avails similar properties to the mix. In the survey of manipulation modalities employed by dental technologists in Nairobi, 50% of respondents reported that they mix Wirofine® and Bellavest® T powders as one of their manipulation modalities for investing wax-patterns for crown and bridge work. Amongst these respondents, 50% of them reported mixing the two powders at a ratio of 1:1. In this study, the mixing of Wirofine® and Bellavest® T was done in the ratio of 1:1 by weight, for the purpose of investing ten wax-patterns for casting cast-metal crown copings. The mixture of the two powders was mixed in 100% expansion liquid (BegoSol®).

Two other phosphate bonded investment materials in use in dental laboratories in Nairobi are Castorit®-super C and Rema® cc, both products of Dentaurum.

According to the manufacturer's instructions when using Rema® cc for casting Co-Cr and Ni-Cr alloys, 90% of the liquid used should be the expansion liquid, and 10% distilled water [19, 35]. The survey of dental technologists in Nairobi indicated that only 31% of respondents (Five out of sixteen respondents) indicated using Rema® cc phosphate-bonded investment material for investing wax-patterns for crown and bridge work. Of the five respondents, one reported mixing the Rema® cc powder with 100% expansion liquid. Another respondent utilized a liquid composition of 40% water mixed with 60% expansion liquid. For the purpose of this study, one study group of ten cast-metal crown copings had the wax-patterns invested in Rema® cc powder, mixed with a liquid composition of 40% water and 60% expansion liquid.

For the casting of cobalt chromium and nickel chromium alloys while investing with Castorit®-super C, the manufacturer recommends using 100% expansion liquid. However according to the survey of manipulation modalities employed by dental technologists in Nairobi, casting has been done for crowns and bridges while investing with a mix of Castorit®-super C powder and a liquid mix composed of a ratio of approximately 1:1, distilled water to expansion liquid, in 33% of Castorit®-super C investment material users.

Out of the nine respondents who reported that they use Castorit®-super C phosphate-bonded investment material, two indicated that they mix the powder with 100% expansion liquid. One respondent indicated that he uses 100% water. One user indicated that he uses 1:1, distilled water to expansion liquid. Another user indicated that he uses 1:2 distilled water to expansion liquid, whereas another technologist reported using a liquid mix of 40% water to 60% expansion liquid. For the purpose of this study, one study group of ten cast-metal crown copings had the wax-patterns invested in Castorit®-super C powder, mixed with a liquid composition of 1:1, distilled water to expansion liquid.

2.11 Marginal Design for Metal Ceramic Crowns

Metal-ceramic crowns are still a preferred form of complete veneer restoration in modern prosthodontics. They have been found to deliver acceptable aesthetics from the overlying highly translucent, naturally appearing porcelain, and have optimum mechanical properties because of the metallic substructure [(37)].

The margins of porcelain-fused-to-metal crowns may be of different designs. They may be designed to be porcelain faced or they may have a metal cervical collar on the facial margin [(37)]. For a long time, there was speculation that porcelain margins demonstrate inferior properties [(38)]. However, studies were undertaken in the 1980's that showed that porcelain margins have marginal openings that are clinically acceptable just as are, metal margins [(39, 40)].

Gardner *et al.* in 1997 compared the in vitro failure load of metal-collar margins with porcelain facial margins of metal-ceramic crowns. They reported that greater loads were required to fracture porcelain from crowns with porcelain margins compared to crowns with metal collar margins [(37)].

These findings are consistent with those of a more recent study by Bulbule and Motwani who in 2014 compared the fracture resistance of porcelain in different metal ceramic restorations fabricated using the following metal coping designs:

a. Metal coping extending up to the gingivoaxial line angle of the finish line,
b. Metal coping extending one millimetre short of the gingivoaxial line angle of the finish line, and
c. Metal coping having a 0.4-millimetre-wide labial metal collar.

They reported the highest mean fracture strength in the samples having the metal coping design extending up to the gingivoaxial line angle [41]. The findings of these studies suggest that it may be imprudent to fabricate a crown with the incorporation of a metal collar.

Literature is replete with compelling reasons as to why metal collar designs may not be the most ideal for porcelain-fused-to-metal crowns. Incorporation of a metal collar on the labial face of a crown coping usually necessitates that the finish line should have been placed subgingivally so as to conceal the metal [42].

However, the validity of this aforementioned proposition that was made in the year 1981 by Wilson, that margins be placed subgingivally has been overtaken by research in periodontology. The adverse effect of subgingival crown margins cannot be overemphasized. Indeed, just a year after Wilson proposed the use of subgingival margins to conceal metal collars, a literature review was carried out by Gardner and he noted that:

"most of the investigative proof shows that supragingival margins are kinder to the gingiva than are subgingival margins" [43].

A longitudinal study carried out in 2002 followed up patients who had had different margin placements on their crowns, one-year post cementation. It was noted that crowns with intra-sulcular margins demonstrated twice the risk of gingival bleeding as compared with crowns with supragingival margins [44].

If placed supragingivally however, a metal collar design for a metal ceramic crown may compromise its aesthetic properties [37]. A further reason as to why metal collar designs are not advocated for was demonstrated in a study by Sozio. He showed that the nature of force distribution upon the labial margin of a collarless metal-ceramic crown or retainer is mainly compressive and not tensile [45].

However, metal ceramic crowns in many instances still preserve a metal face and margin on the palatal or lingual surface. The preparation for these margins is usually achieved by the use of a torpedo bur that accentuates the chamfer on the lingual and proximal surfaces [15].

A 2015 study by Nemane *et al.* evaluated the effect of various finish line configurations on the marginal seal and occlusal discrepancy of cast full crowns after cementation. They reported that crowns fabricated with feather edge and long chamfer margins had the best marginal seal. However, since these margins do not allow adequate escape of the luting cement during crown seating, it was reported that they had the highest occlusal discrepancy

after cementation. The occlusal seat afforded by the rounded shoulder margin after crown cementation was the best, followed by the ninety-degree shoulder. The findings of this study point to a subtle superiority of the chamfer margin. It performed well on two parameters that were evaluated. First of all, it had a better marginal seal than that of shoulder preparations. Secondly, the occlusal seat discrepancy, although greater than that of the shoulder preparation, was still less than the high occlusal discrepancy noted after cementation of the crowns with feather edge and long chamfer margins [(46)].

Factoring in all the evidence obtained from literature, the marginal design employed in this study was in tandem with current practices in crown preparations. A shoulder margin on the buccal face of the preparation was prepared with the intention of fabricating a cast-metal crown coping that extended up to the gingivo-axial line angle of the finish line. The amount of reduction on the buccal face was designed to allow an eventual placement of a porcelain face over the cast-metal crown coping, on the buccal face of the eventual crown. The placement of porcelain was however not undertaken in this study. The amount of axial reduction on the buccal aspect recommended if the metal is to be veneered with ceramic is two millimetres. If the coverage is going to be metal only, the recommended axial reduction is 1.5 millimetres [(15)]. Figure 3, below, illustrates the features of a preparation for a metal ceramic crown on a posterior tooth and the functions served by each.

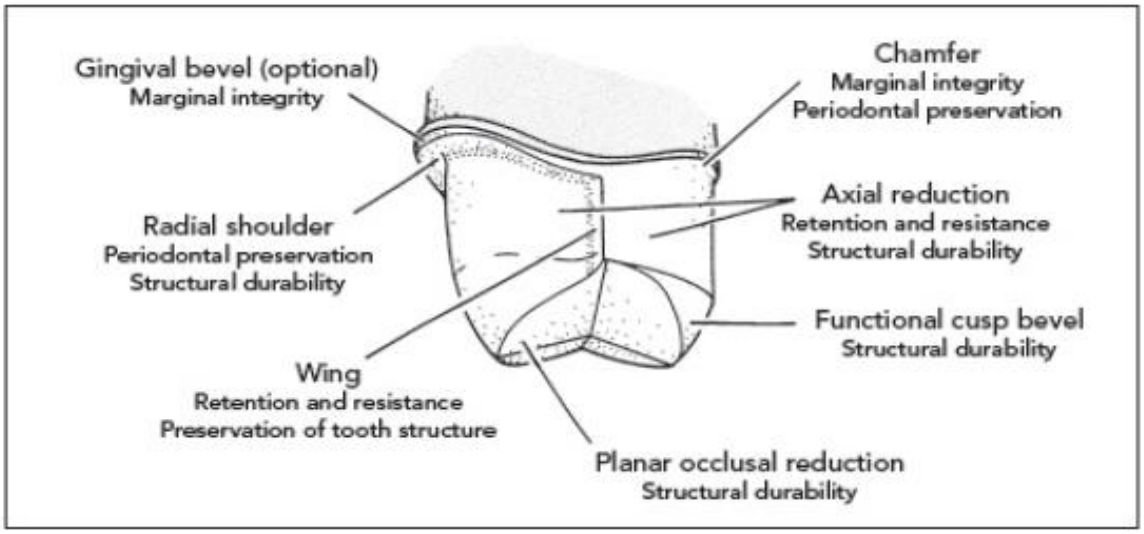

Figure 3: Features of a preparation for a metal ceramic crown on a posterior tooth

(Reproduced with permission from Shillingburg HT. Fundamentals of Fixed Prosthodontics. 4 ed. Chicago, Illinois: Quintessence Publishing Co.; 2012. [(15)])

In this study, the preparation of the metal die on which all the cast crown copings were fabricated was tailored to resemble the ideal preparation as closely as possible. The cast-metal crown copings were fabricated with the intention of obtaining porcelain-fused-to-metal crowns. However, as earlier outlined, for the purposes of this study, the porcelain facing was not applied to complete the crowns. However, the intention of the preparation was to leave the palatal aspect of the completed crowns in metal with a metal margin sitting on a chamfer margin. This is in tandem with the best practices of preparing a tooth to receive a restoration that will preserve the remaining tooth structure, considering the findings of a 1991 study that reported metal-ceramic crowns to be 2.8 times as strong as all ceramic restorations [(47)].

It is however recognized that the application of porcelain on the metal substructure of cast porcelain-fused-to-metal crowns, does affect the final marginal fit of the prostheses. This was the conclusion of a study conducted by Pettenò *et al.* in the year 2000. In that study, a total of 75 crowns were fabricated and the marginal gap measured at eight different points. The measurements were done before and after application of the ceramic material, and it was concluded that although all the values obtained were within the limits of clinical acceptability, a difference in the marginal gap was still noted after the application of the ceramic material. In the case of that particular study, all recorded measurements of the marginal gaps fell within 70 μm [(48)].

In this study, the measurement of the marginal gap was done at four different points of which the point on the palatal aspect of the preparation was on a chamfer margin, whereas that on the buccal aspect was on a shoulder margin. The aim was to obtain measurements that were as close as possible a reflection of the outcomes achieved in Nairobi, Kenya.

2.12 Evaluation of Margins

Various studies have been carried out evaluating the marginal fit of various types of crowns. One such study that was carried out by Groten *et al.* in 1997, employed the use of a light microscope and a computerized video image analysis system to evaluate the marginal fit of copy-milled Celay In-Ceram crowns after different steps of their fabrication. The recorded readings were then compared to those taken by a scanning electron microscope. They found that the data recorded by the light microscope system was confirmed by scanning electron microscopy [(49)].

The year 2000 study by Pettenò *et al.* aimed to compare the marginal adaptation of metal-ceramic crowns made with three different metal substructures. The method of marginal analysis employed by them was the use of a stereomicroscope at 200x magnification [48].

Groten *et al.* [49] and Pettenò *et al.* [48] are apt examples of researchers that utilized the direct view technique of measuring the marginal gap between the crown margin and the prepared margin of a die in an in-vitro set-up.

Another study in which a similar method of marginal fit evaluation was utilized is that by Olivera and Saito, carried out in the year 2006. In this study, one group of complete cast crown specimen were examined before and after cementation using optical microscopy with 0.001 mm resolution. Another group of complete cast crown specimen were examined after cementation using scanning electron microscopy. Although the main purpose of their study was to evaluate the effect of die spacer on the fit and retention of complete cast crowns by use of three different cements, of interest to note is that Olivera and Saito also concluded that optical microscopy and scanning electron microscopy correlate well [50].

Other researchers have utilized the cross-sectional method of evaluating the marginal gap and the space between the cast crown coping and the prepared tooth surface. Kunii *et al.* carried out such a study in 2007, seeking to establish the effect of sintering on the marginal and internal fit of CAD/CAM-fabricated zirconia frameworks. They fabricated the pieces and cemented them onto their respective master abutment models using a resin luting cement. The cemented copings and frameworks along with their master abutment models were then embedded in an acrylic resin and then sectioned in a mesio-distal direction using a low speed diamond cutting machine. The thickness of the cemented layer was then measured using a digital microscope at x40 magnification [51].

Figure 4 illustrates this method of marginal gap measurement. It is worth noting that this methodology necessitates the availability of equipment for sectioning the castings and that the master abutment models be fabricated out of a material that can be sectioned using the diamond cutting machine without interfering with the marginal gap. Kunii *et al.* prepared their master abutments by numeric control (NC) machining using stainless steel (SUS304), as shown in Figure 5 [51].

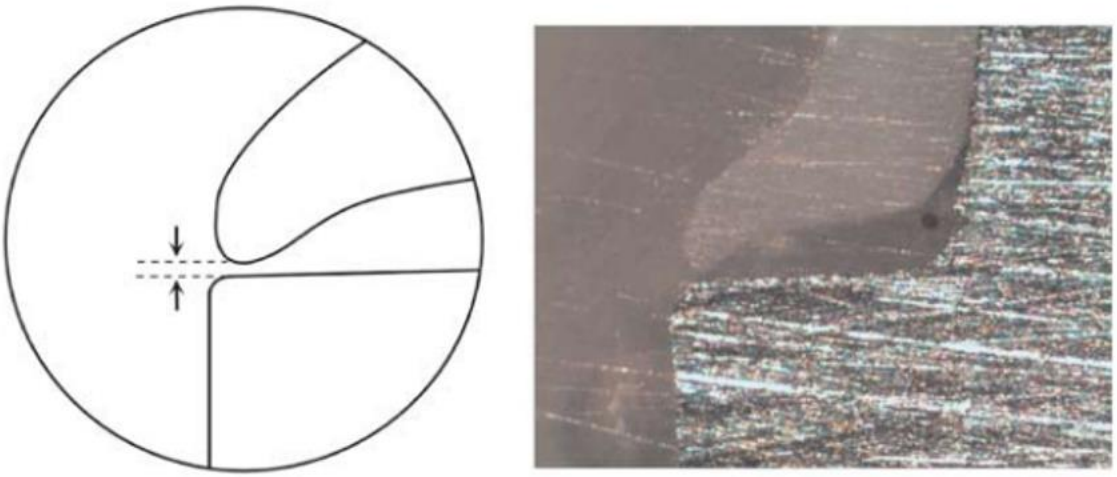

Figure 4: Marginal gap measurement by Kunii *et al.* (2007)

[*Reproduced with permission from* Kunni *et al*. (2007) [51]]

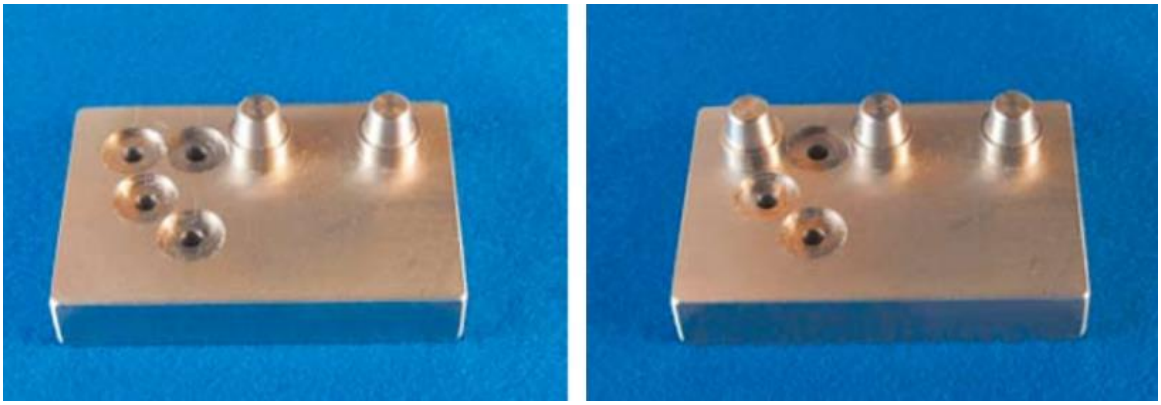

Figure 5: Master abutment model for the three-unit and five-unit bridge

[*Reproduced with permission from* Kunni *et al*. (2007) [51]]

Another method that has been employed for the evaluation of margins is known as the impression replica technique. This method was employed by Coli and Karlsson in their 2004 in vitro study evaluating the internal and marginal fit of zirconium dioxide ceramic copings manufactured using the "Denzir" CAD/CAM-based technique. They fabricated two metal master models representing a maxillary right central incisor and the first premolar. Silicone impressions were made of the metal models and from them, gypsum dies were poured. A total of 20 ceramic copings were produced from the dies. They then proceeded to make silicon replicas of the entire gap between the ceramic coping and the corresponding stone

die, and that between the ceramic coping and the metal master model. The silicon replicas were then sectioned bucco-lingually and mesio-distally. The sections that were obtained were measured at occlusal, axial and marginal locations under light microscopy. They concluded that the marginal fit was superior to the occlusal fit and the axial fit and that the Denzir manufacturing process was well within the range of clinical acceptability [(52)].

A variation of the impression replica technique was used in the 2003 study by Wolfart *et al.* In that study, the researchers sought to carry out an in vivo evaluation of the marginal fit of inlay and crown abutments for fixed partial dentures made from an all-ceramic material. The method of marginal evaluation entailed the taking of impressions of the restoration margins before and after cementation of the cast prostheses. Replicas of theses margins were then evaluated by scanning electron microscopy [(53)].

According to the fourth edition of the renowned fixed prosthodontics textbook, Fundamentals of Fixed Prosthodontics, a margin is considered open if the distance between the metal coping and the prepared margin on the tooth is greater than 50 μm. An open margin will thus allow the tip of a sharp explorer to pass through the intervening gap between the restoration and the tooth [(15)].

Mc Lean and von Fraunhofer in 1971 reported about the 1000 fixed restorations that they had studied over a 5-year period. They found that a marginal gap of 80 μm was difficult to detect clinically and gave a leeway of a gap of up to 120 μm between the crown margin and the prepared margin of the tooth as being clinically acceptable [(54)]. Fransson *et al.* in 1985 increased this value by another 30 μm and stated that a marginal gap of up to 150 μm was clinically acceptable [(55)].

In this study a variation of the direct view technique of marginal evaluation was employed. The methodology that was used was an adaptation of that used by Yoon *et al*. in their 2014 study that purposed to compare the total occlusal convergence of dental students' typodont crown preparations. Yoon *et al*. evaluated 165 typodont teeth prepared by dental students by placing individual typodont teeth in a custom-fit die base to ensure that the position of the die was stable and reproducible. They then proceeded to capture the images of the typodont teeth using a digital single-lens reflex camera (D3100; Nikon) with a macro lens (Nikkor AF-S 105 mm f/2.8G IF-ED; Nikon USA), set up on a tripod (Dolica) at a distance 30 centimetres from the base (as shown in Figure 6). The images were then uploaded onto a

computer, magnified at least 30 times and evaluated with an on-screen protractor software by Iconico Inc. (New York, USA) [56].

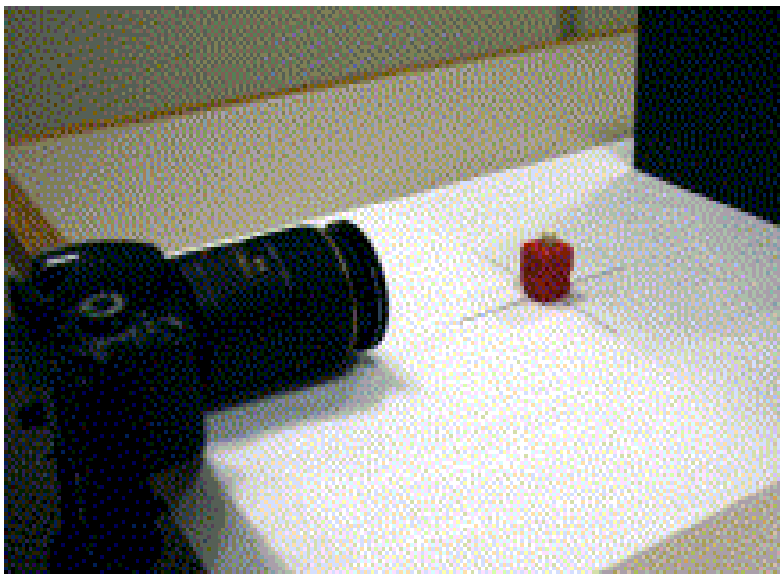

Figure 6: Example of how photography of the cast-metal crown copings and cast metal crown copings was done by Yoon *et al*. (2014)

[*Reproduced with permission from* Yoon *et al*. (2014) [56]]

In this study, the marginal fit of the fabricated cast-metal crown copings was evaluated using the computer on-screen calliper software by ImageJ (New York, USA). 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), set on a tripod, was used to photograph the fabricated cast-metal crown copings on a model die preparation. The images were transferred to a computer and analysed using the ImageJ National Institutes of Health (NIH) software. The images were magnified by a factor of x150%. 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 four pre-marked positions; mid-facial, mid-mesial, mid-palatal and mid-distal.

CHAPTER THREE:

PROBLEM STATEMENT, JUSTIFICATION OF THE STUDY, OBJECTIVES AND HYPOTHESES

3.1 PROBLEM STATEMENT

Clinicians providing fixed prosthodontic care need to ensure that quality service is given to patients who require prosthetic rehabilitation. The accuracy of marginal fit can be considered a marker of quality in prosthesis placement.

However, even the best efforts from a clinician in preparing the patient and the teeth to receive a crown or a fixed partial denture, may be compromised if any error occurs during the laboratory stages of fabrication. This is an area of concern for dentists in Kenya because it is not uncommon for crowns and fixed partial dentures to fail to sit even after the dentist took the best care in tooth preparation and impression taking. Experienced dental practitioners have found themselves restricting fabrication of their prostheses to specific laboratories within the city of Nairobi because of numerous poor casting outcomes they have had with some laboratories.

Technologists may compromise on some manipulation modalities and on use of some recommended materials in order to save on time and costs. Whereas one may be quick to postulate that venturing away from the manufacturers' recommendations would not produce the desired outcomes, it is prudent to evaluate some of these compromises made in the interest of cost-cutting, and compare the results with what is achieved by following the ideal protocols.

It is not possible to elucidate all the compromises that are made in the laboratory procedures for casting the metal copings for crowns and fixed partial dentures in our local set-up. It will be appreciated that many may not willingly volunteer such information. However, from the number of misfits of prostheses that dentists report in their clinical practices, it is important to investigate whether some of these laboratory practices that we do know of, have got any significance on the accuracy of the resultant castings.

There is a paucity of literature on dental investment materials. Moreover, there lacks research documenting comparative data on the various phosphate-bonded investment material commercial brands; their accuracy in usage, their manipulation modifications, and

the effect these modifications have on the accuracy of cast-metal copings for crowns and retainers for fixed partial dentures.

3.2 JUSTIFICATION OF STUDY

It is the desire of clinicians the world over to become good care providers to their clientele. Accurate and reliable work from the dental laboratory is a good adjunct to the clinician's endeavour in achieving efficiency in the provision of fixed prosthodontic treatment.

This study purposed to ascertain whether the choice of investment material or the manipulation strategy employed by some dental technologists in Nairobi, Kenya, has got any effect on the marginal fit of the cast-metal crown copings that they fabricate. It sought to provide information on the accuracy of the fit of cast-metal crown copings produced by the dental technologists using the various phosphate-bonded investment materials, employing various modifications to their manipulation procedures. It will also be informative for clinicians who are the recipients of the prostheses prepared for their patients, by various laboratory technologists.

It will also be informative for clinicians who are the recipients of the prostheses prepared by various laboratory technologists, for their patients. The information obtained will be useful in determining whether adverse dimensional changes of cast-metal crown copings, are as a result of venturing away from manufacturers' recommendations on investment material manipulation.

There are a number of stakeholders in the field of fixed prosthodontics. Foremost are the dental surgeons who are Kenya's primary dental health caregivers. As such, the findings of this study are of great interest to them. Dental technologists work hand in hand with the dental surgeons and their role is invaluable in ensuring the success of treatment. The recipients of this care – our patients, are also major stakeholders in fixed prosthodontics and it is evident that positive implementation of the findings of this study will impact greatly in the quality of care that they receive.

A lot of resources, particularly time and money will be saved if dental technologists utilized the best possible practices in the fabrication of cast-metal prostheses. The resultant

frustration of laboratory errors is shared by the doctor, the patient, and also by the dental technologist.

The study was structured as a laboratory based experimental study. The waxed-up die preparations and cast metal crown copings used in the study were prepared from a typodont tooth. No harm was inflicted on any patients.

3.3 STUDY OBJECTIVES

3.3.1 Main Objective

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.

3.3.2 Specific Objectives

1. To determine the marginal fit of cast-metal crown copings fabricated after investment with Bellavest T®, Wirofine®, Castorit®-super C and Rema® cc investment materials according to their various manufacturers' instructions on handling.
2. To determine the marginal fit of cast-metal crown copings fabricated after investment with a mixture of 50% Bellavest T® investment material and 50% Wirofine® investment material by weight.
3. To determine the marginal fit of 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.
4. To determine the marginal fit of 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.

3.4 HYPOTHESES

1. **H_0**: There is no significant difference in the accuracy of marginal fit of the cast-metal crown copings whether fabricated according to the manufacturers' instructions for investment or by utilizing various modifications in the handling of the investment materials.

   H_A: 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. **H_0**: There is no significant difference in the accuracy of marginal fit of the cast-metal crown copings fabricated according to the manufacturers' instructions for investment.

   H_A: There are significant differences in the accuracy of marginal fit of the cast-metal crown copings fabricated according to the manufacturers' instructions for investment.

3. **H_0**: There is no significant difference in the accuracy of marginal fit of the cast-metal crown copings fabricated whilst utilizing the modifications in the handling of the investment materials.

   H_A: There are significant differences in the accuracy of marginal fit of the cast-metal crown copings fabricated whilst utilizing the modifications in the handling of the investment materials.

3.5 VARIABLES

Table 1: Independent and dependent variables and their measurements

INDEPENDENT VARIABLES	**MEASUREMENTS**
Investment Materials	1. Bellavest T® phosphate-bonded investment material. 2. Castorit®-super C phosphate-bonded investment material. 3. Rema® cc phosphate-bonded investment material. 4. Wirofine® phosphate-bonded investment material. 5. Mixture of Bellavest T® and Wirofine® phosphate-bonded investment material. 6. Castorit®-super C investment material mixed with the liquid at a ratio of 1:1 – Distilled Water: Expansion Liquid. 7. Rema® cc investment material mixed with the liquid at a ratio of 2:3 – Distilled Water: Expansion Liquid.
DEPENDENT VARIABLES	**MEASUREMENTS**
Marginal fit of cast-metal crown copings	Measurements (in micrometres) of the gap between the margins of the cast-metal crown copings, and the marginal preparation on the cast-metal die at the following four points: • Mid-facial • Mid-palatal • Mid-mesial • Mid-distal

CHAPTER FOUR:

MATERIALS AND METHODS

4.1 Study Design

This was a descriptive cross-sectional study, designed as a laboratory-based experiment, with three control groups (coded: ***BV-mr, C-mr***, and ***R-mr***), and four experimental groups (coded: ***W-ma***, ***BV/W-mm***, ***C-mm*** and ***R-mm***).

4.2 Study Setting

The study was conducted in Nairobi, Kenya, in the year 2020, at the Kenyatta National Hospital Dental Prosthetics Laboratory, and at Prime Dental Studios, a privately-owned Dental Prosthetics Laboratory.

4.3 Sampling Procedure

A total of 70 cast-metal crown copings were fabricated and 840 measurements were taken from them. Four measurements (mid-facial, mid-palatal, mid-mesial and mid-distal) were taken from each cast-metal crown coping; each measurement being taken three times and an average of the three values calculated. Thus, a total of 280 measurements were considered as the sample size in this study. The sample size determination was derived from analysis of literature, and adaptation of sample sizes of studies of similar experimental designs [48-53].

4.4 Data Collection Tools

A digital single-lens reflex camera (D3300; Nikon) with a macro lens (Nikkor AF-S 105 mm f/2.8G IF-ED; Nikon USA), set on a tripod stand was used to photograph the cast-metal crown copings sat on the model die preparation.

An on-screen calliper software by ImageJ, from the National Institutes of Health (NIH) was used to take measurements on images captured. The captured images were transferred to a computer and uploaded onto the ImageJ software program. The mid-facial, mid-palatal, mid-mesial and mid-distal points of each cast-metal crown coping were captured on different photographs. Each photograph was magnified by a factor of x150% using the ImageJ software, focussing at the pre-determined reproducible reference point. The vertical measurement of the marginal gap was taken in micrometres, after having calibrated the software by inputting a known measurement (of the vertical height of the 50-gram metal

weight) to enable it generate the measurements of the marginal gaps (Figure 15 and Figure 17).

4.5 Data Collection Method

The method of collecting data used was a modification of the one employed by Lombardas *et al*. in their study from the year 2000 [25].

4.5.1: Sample Preparation

A total of 70 maxillary molar cast-metal crown copings were analysed. The 70 preparations were divided and coded as follows:

1. Ten cast metal crown copings fabricated after investment with Bellavest T® investment material according to the manufacturer's instructions (***BV-mr***).
2. Ten cast metal crown copings fabricated after investment with Castorit®-super C investment material according to the manufacturer's instructions (***C-mr***).
3. Ten cast metal crown copings fabricated after investment with Rema® cc investment material according to the manufacturer's instructions (***R-mr***).
4. Ten cast metal crown copings fabricated after investment with Wirofine® investment material according to the manufacturer's instructions for the manipulation of Wirofine® (***W-ma***).
5. Ten cast metal crown copings fabricated after investment with a mixture of 50% Bellavest T® investment material and 50% Wirofine® investment material powders by weight. The mixture of the two powders will be mixed in 100% expansion liquid (BegoSol®) (***BV/W-mm***).
6. 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 (***C-mm***).
7. 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 (***R-mm***).

In the code, the letters "***BV***", "***C***", "***R***" and "***W***" stand for Bellavest T®, Castorit®-super C, Rema® cc, and Wirofine®, respectively. The letters "***mr***" stand for "manufacturers' recommendation", whereas the letters "***ma***" and "***mm***" stand for "modified application" and "modified manipulation," respectively.

4.5.2 Cast-metal Die Preparation

A maxillary first molar typodont tooth (Frasaco CmbH, Tettnang, Germany) was prepared to have the following specifications:

- Five to ten percent total occlusal convergence.
- Approximately two-millimetre axial reduction on the buccal aspect.
- Shoulder finish line on the buccal aspect.
- Approximately 1.5-millimetre axial reduction on the palatal aspect.
- Chamfer finish line on the palatal aspect.
- Wings on the proximal margins in the intervening region between the chamfer and shoulder margins.

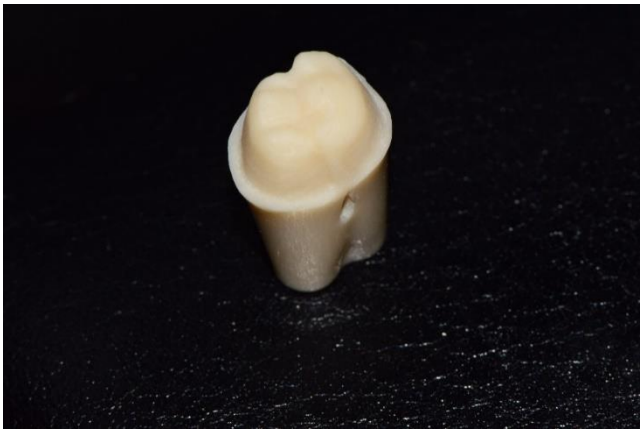

Figure 7: The prepared typodont tooth

The crown preparation was done with the intention of fabricating a porcelain-fused-to-metal crown, although the porcelain layer was not adapted to complete the final crown. The metal margin on the buccal shoulder margin was analysed. For the final prosthesis to be completed, the metal-coping would still have been modified by the addition of porcelain, to have it ready for cementation.

The occlusal reduction was approximately two millimetres on the functional cusp and 1.5 millimetres on the non-functional cusps.

The typodont tooth was marked just below the prepared margins at mid-facial, mid-palatal, mid-mesial and mid-distal points. The process of duplication of the typodont tooth in casting wax, followed by the investing and casting of the metal die, is illustrated in Figure 8 (below).

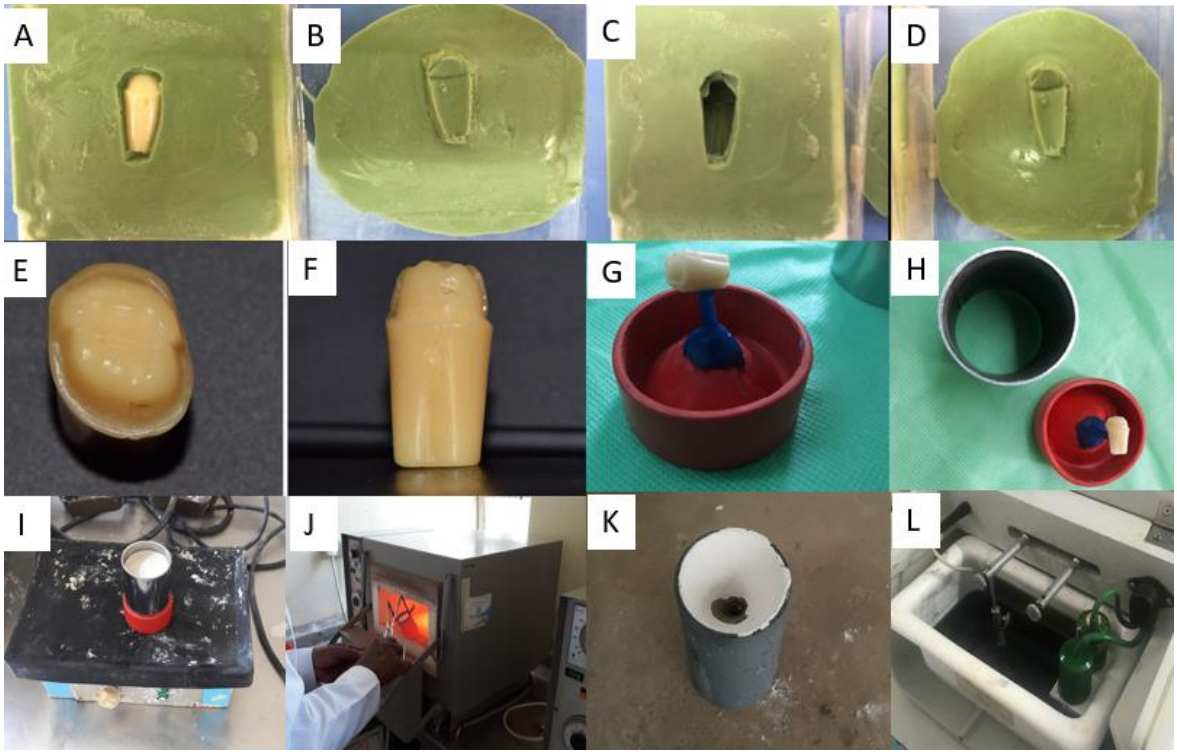

Figure 8: Duplication of the typodont tooth and investing and casting of the metal die. (A) and (B): The prepared molar typodont invested in Affinis® Perfect Impressions light body elastomeric impression material. (C) and (D): The negative elastomeric impression mould after removal of the acrylic typodont 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.

The prepared molar typodont (Figure 7) 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. The molar typodont was removed from the elastomeric investment to get a complete negative replica of the prepared typodont.

Casting wax (Sybron/Kerr Romulus, Michigan) was poured into the negative elastomeric impression mould to obtain a positive wax die preparation. The wax die preparation was then sprued, invested and cast in cobalt-chromium alloy to form a cast-metal die preparation (Figure 9).

Figure 9: Cast-metal die preparation

4.5.3 Waxing Up and Spruing

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. Yenadent® CAD-CAM wax blocks (Istanbul, Turkey) were used (Figure 10).

Figure 10: Yenadent® CAD-CAM wax block with the milled wax patterns

The wax patterns were then sectioned out of the wax block and carefully trimmed (Figure 11).

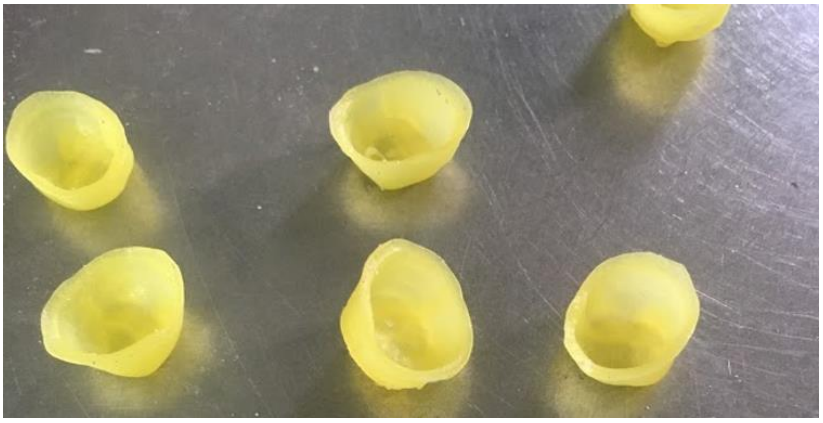

Figure 11: Wax patterns after sectioning and trimming

Each of the seven groups of ten wax patterns were milled, sectioned, 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® 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, as shown in Figure 12 (below).

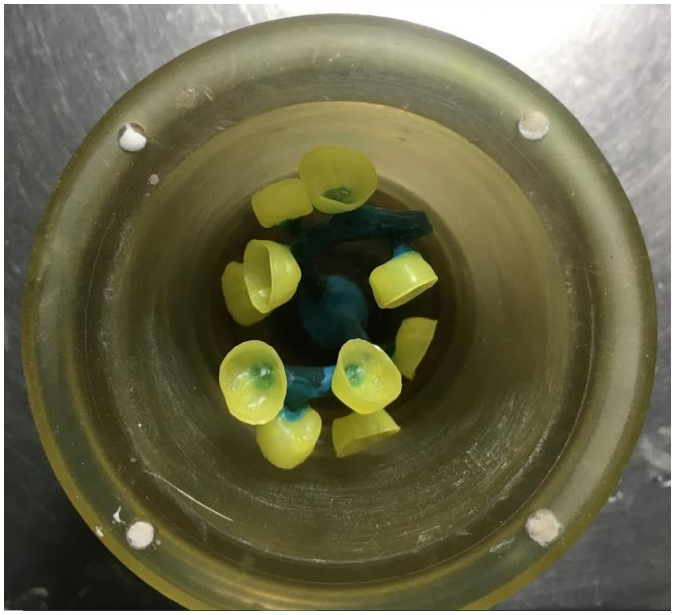

Figure 12: Sprued wax patterns

4.5.4 Casting Process

A total of 70 maxillary molar cast-metal crown copings were cast in batches of ten cast-metal crown copings per casting cycle.

The 70 castings were divided as follows:

1. Ten cast metal crown copings fabricated after investment with Bellavest T® investment material according to the manufacturer's instructions (***BV-mr***).
2. Ten cast metal crown copings fabricated after investment with Castorit®-super C investment material according to the manufacturer's instructions (***C-mr***).
3. Ten cast metal crown copings fabricated after investment with Rema® cc investment material according to the manufacturer's instructions (***R-mr***).
4. Ten cast metal crown copings fabricated after investment with Wirofine® investment material according to the manufacturer's instructions for the manipulation of Wirofine® (***W-ma***).
5. Ten cast metal crown copings fabricated after investment with a mixture of 50% Bellavest T® investment material and 50% Wirofine® investment material powders by weight. The mixture of the two powders will be mixed in 100% expansion liquid (BegoSol®) (***BV/W-mm***).
6. 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 (***C-mm***).
7. 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 (***R-mm***).

Each of the groups of ten wax patterns were invested according to the specific respective protocol.

The processes of investing, casting and divesting are illustrated in Figure 13 (below).

Figure 13: 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) Divesting the castings in the *C-mm* group using a hammer as is done by laboratory technologists in Nairobi, Kenya. (H) Divesting the copings using forceps as is recommended by the various manufacturers of the investment materials. (I) and (J): Removal of investment material from the fitting surface of the crowns. (K) and (L): Sand blasting using 50 µm alumina particles.

The manufacturers' instructions for handling of the investment materials (Appendices III, IV, V, and VI) were followed for the control groups. The experimental groups were cast after investing with the phosphate-bonded investment material mixtures that had the alterations entailed in each of the experimental groups, as outlined above. Other than the alteration in powder or liquid composition for the experimental groups, no other changes were made to the manufacturers' instructions in handling of the respective phosphate-bonded investment materials, before casting. In the divesting process for the experimental groups however, there was included the use of a hammer for gentle tapping of the casting formation to remove the bulk of the set investment material around the castings. This was followed by the use of forceps (as is recommended by the manufacturers), to section away the investment material [Figure 13 (G) and (H)].

The cast-metal crown copings were the 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 done on the castings when there were extensions that impeded the casting from fully sitting on the metal die (Figure 14 and Figure 18).

Figure 14: Divested, sand blasted crown copings showing one crown coping with an extension (shown by arrow) that was removed using a bur to allow for full seating onto the metal die.

The cast-metal crown copings were then sat on the metal die and a 50-gram metal weight was placed on the casting to apply a force of approximately five Newtons (Figure 15).

Figure 15: Seating of the cast-metal crown copings on the metal die preparation

4.5.5 Digital Photography of the Cast-metal Crown Copings

The jig for holding the metal die was fabricated by mounting the metal die using Portland cement onto a plastic Lego® (toy). The die was centred on the jig and the distance from the centre of the jig, up to the rim of the macro lens was set at 30 centimetres.

Images of the cast-metal crown copings 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 and used to photograph the fabricated cast-metal crown copings on the model die preparation.

The die was positioned against a black background for increased contrast.

Each cast-metal crown coping was photographed four times to capture the following four positions as initially documented for the original typodont tooth:

- Mid-facial
- Mid-palatal
- Mid-mesial
- Mid-distal

Figure 16: Photography set for the cast-metal crown copings

4.5.6 Image Analysis

The images were transferred to a computer and analysed using the ImageJ National Institutes of Health (NIH) software (Figure 17).

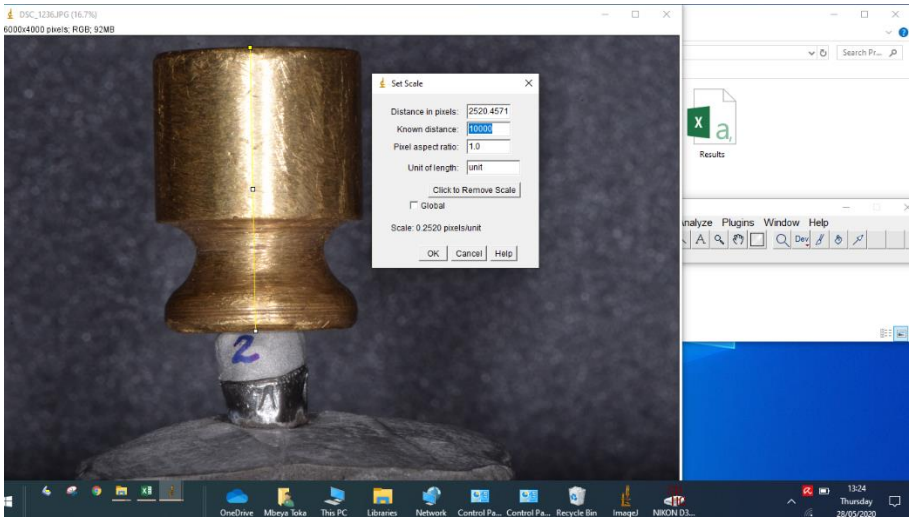

Figure 17: Image analysis using the ImageJ software

The images were magnified by a factor of x150%. The vertical distance between the margins of the cast-metal crown copings and the finish line of the cast-metal die preparation were 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. A total of 840 marginal gap measurements were taken from the 70 cast-metal crown copings. The observer was blinded from having knowledge of a previous measurement of a

specific site, 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 done.

4.5.7 Inter-rater Reliability

Table 2 (below) shows the comparison of measurements taken by the principal investigator and those taken by one of his supervisors, on 12 sites on three cast-metal crown copings in the ***R-mm*** group.

Table 2: Marginal gap measurements of 12 sites on three crowns in the R-mm group, by the principal investigator and the supervisor

Crown Number	Site of Measurement	Principal Investigator's Measurements (µm)	Supervisor's Measurement (µm)	Absolute Difference |Rater2 – Rater1|
61	Mid-facial	157.10	200.78	43.67
61	Mid-palatal	290.74	329.55	38.81
61	Mid-mesial	201.89	262.18	60.29
61	Mid-distal	46.13	89.47	43.34
62	Mid-facial	147.47	202.19	54.73
62	Mid-palatal	242.76	309.64	66.87
62	Mid-mesial	97.78	121.57	23.79
62	Mid-distal	36.17	39.59	3.42
63	Mid-facial	160.84	202.00	41.16
63	Mid-palatal	238.06	278.82	40.76
63	Mid-mesial	94.68	101.87	7.19
63	Mid-distal	42.79	79.92	37.13

The mean difference between the values was 38.43 (with standard deviation of 18.34), and the 95% limits of agreement were 28, 48.8. This implied that the marginal gap measurements of a particular site by Rater 1 could vary from that measured by Rater 2 from as little as 28

µm to as much as 48.8 µm. This is the case for 95% of individuals. The intra-class correlation coefficient was ***r=0.978, p<0.001***. This showed agreement between the two observers.

4.6 Data Analysis

The divested crown copings were first physically inspected. Impediments on the fitting surface preventing full seating of any cast-metal crown copings onto the metal die were noted on the specific crowns that presented with them (Figure 18). This information was documented before the impediments were sectioned out from the fitting surfaces of those specific crowns, using a bur.

From the 840 measurements taken, the sample size of 280 measurements was arrived at by averaging each of the three marginal gap measurements, taken at each respective individual site on the 70 cast-metal crown copings.

The data was then subjected to analysis using STATA software version 16.

The initial analysis of the data involved evaluation of the means and medians, as well as analysis of the marginal gap measurements of the different phases of the cast-metal crown copings (mid-facial, mid-palatal, mid-mesial and mid-distal).

Statistical tests were done to show the relationships between the manipulation and application of the various phosphate-bonded investment materials, and the comparisons of marginal fit of cast-metal crown copings in the different groups. The results were presented in tables and graphs. A p value of less than 0.05 was taken as statistically significant.

The statistical tests carried out initially were the Shapiro-Wilk W test (for normal distribution) and a preliminary ANOVA test. A Levene test (for homogeneity of variance) was done after the preliminary ANOVA test.

These initial tests were thereafter followed by the non-parametric, Kruskal-Wallis H test for subsequent analysis, and post-hoc (Dunn's) tests, where applicable. The non-parametric tests were selected because the preliminary tests done, showed that the data violated the assumptions of ANOVA.

The data analysis was concluded by testing of the hypotheses that had been initially stated.

4.7 Ethical Considerations

The research proposal was presented to The Kenyatta National Hospital–University of Nairobi Ethics and Research Committee for approval. The sought approval was granted (Appendix VII) and thereafter extended (Appendix VIII) due to the various challenges in carrying out the study that were experienced, as outlined in the subsequent section (4.8).

The study was purely in vitro; it had no human participants. The metal die was derived from a typodont tooth preparation. All the 70 fabricated cast-metal crown copings were not intended for cementation or fitting on any human subject. The findings of the study however, would be correlated to in vivo conditions, of similar cast crowns. The study was thus able to accrue findings that were beneficial to the practice of dentistry, without exposing any patient to risk.

4.8 Limitations of the Study

The following challenges and limitations were encountered during the course of this study:

1. Inability to do absolute blinding which reduced the power of the study.
   For all the measurements of marginal gaps to be interpreted, it was mandatory that each cast-metal crown coping be identified as per its placement in the pre-determined categories of the seven different groups of cast-metal crown copings.

   Some degree of blinding was however achieved, as the observer was blinded from having knowledge of the previous measurements of a point when the second and third measurements were recorded.

2. Inability to use materials of the same batch number in carrying out the study.
   It would have been ideal if all investment materials and their expansion liquids that were utilized in the study, had been manufactured at the same time. This would have eliminated the confounder that was brought about by use of different batches of materials. It is understandable that for optimum performance, manufacturers recommend the shelf life duration of products, within which optimum results would be easily obtainable when the product is used.

Comparisons between different products would also have been given greater credence, had they all spent the same amount of time on the shelf before use.

However, in this study, sourcing for some of the investment materials and the expansion liquid products, was extremely difficult. Local market stock-outs meant that the principal investigator had to wait for months before the new products could be imported into the country. This was particularly experienced in the sourcing of BegoSol®, the expansion liquid for Bellavest T® and Wirofine®. It also meant that for the study to be carried out within the proposed timeline (Appendix IX), the principal investigator had to use the materials available, notwithstanding their batch number.

3. There was a steep financial cost of carrying out the study (Appendix X). This contributed to lack of adherence to the proposed timeline for carrying out the study (Appendix IX).

   Unavailability of equipment and materials at the public facilities where the study was initially proposed to be carried out from further delayed its implementation. Successful completion of the study only became possible after the proprietor of Prime Dental Studios Laboratory offered the use of his premises free of charge.

   Similarly, for image analysis, financial constraints forced the principal investigator to abandon the use of the on-screen calliper software by Iconico Inc. (New York, USA), in favour of the ImageJ (New York, USA) software, which was available as a free download from The National Institutes of Health (NIH).

4. The seating of the 50-gram metal weight (Figure 15) over the cast metal crown copings was not reliably reproducible. The position of the metal weight depended on the trimmed occlusal surface of each individual cast-metal crown coping.

   Whereas is was postulated that any variations that may have arisen from this confounder were negligible, the study would have benefited from the use of an accurate and reproducible mechanism of seating and securing the cast-metal crown copings onto the metal die, such as a vice.

CHAPTER FIVE:

RESULTS

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.

There were seven different cast-metal crown coping groupings which were assigned the codes outlined below. In the code, the letters "***BV***", "***C***", "***R***" and "***W***" stand for Bellavest T®, Castorit®-super C, Rema® cc, and Wirofine®, respectively. The letters "***mr***" stand for "manufacturers' recommendation", whereas the letters "***ma***" and "***mm***" stand for "modified application" and "modified manipulation," respectively.

The following were the experimental groups:

1. ***W-ma***
2. ***BV/W-mm***
3. ***C-mm***
4. ***R-mm.***

The following were the control groups:

1. ***BV-mr***
2. ***C-mr***
3. ***R-mr***

5.1 Quality of Cast-metal Crown Copings

Each cast-metal crown coping was inspected on its fitting surface before the measurements were carried out. Adjustments were made on the fitting surfaces of crowns that had metal protrusions that impeded complete seating onto the metal die.

Four cast-metal crown copings in the ***W-ma*** group required adjustments on the fitting surface using a bur. Nine out of ten crowns in each of the ***BV/W-mm***, ***C-mm*** and ***R-mm*** groups required no adjustments. One cast-metal crown coping in each of these three experimental groups had to be adjusted on the fitting surface using a bur, before achieving complete seating on the metal die (Figure 18).

All thirty cast metal crown copings in the control groups (***BV-mr***, ***C-mr*** and ***R-mr***) had complete seating onto the metal die without any adjustments on the fitting surface using a bur.

Figure 18: 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.

5.2 Overall Marginal Gap Measurements

A summary of marginal gap measurements and standard deviations is presented in Table 3 (below). The table captures a sum total of 280 measurements that were arrived at by conducting measurements on the ten crowns in each group at the mid-facial, mid-palatal, mid-mesial and mid-distal sites.

The mean marginal gap measurements for the seven cast-metal crown coping groups are illustrated in Figure 19 (below). The figure illustrates the overall mean marginal gap measurements for the seven different cast-metal crown groupings. It shows the mean marginal gap measurements of the experimental groups along with those of the control groups. The ***W-ma*** group had the largest (**236.8 µm ± 130.34**) mean marginal gap measurement while the ***BV-mr*** group had the lowest (**133.8 µm ± 85.88**) mean marginal gap. The ***C-mr***, the ***R-mr*** and the ***BV/W-mm*** groups had near equal mean marginal gap measurements of **152.5 µm (± 103.88)**, **149.6 µm (± 98.83)**, and **152.5 µm (± 85.67)** respectively.

Table 3: Mean marginal gap measurements and standard deviation for the cast-metal crown groups

GROUP	Mean Marginal Gap Measurement (μm) and Standard Deviations (SD)				
	Mid-facial	**Mid-palatal**	**Mid-mesial**	**Mid-distal**	**Overall Average**
W-ma	228.4 (82.6)	367.5 (67.6)	232.9 (116.7)	118.3 (118.1)	**236.8 (130.34)**
BV/W-mm	152.4 (33.5)	303.4 (56.2)	112.0 (40.7)	42.3 (14.0)	**152.5 (103.88)**
C-mm	161.3 (45.5)	267.7 (54.8)	158.6 (69.7)	113.9 (131.7)	**175.4 (97.85)**
R-mm	166.6 (65.8)	279.5 (57.7)	148.2 (91.1)	41.3 (11.6)	**158.9 (105.03)**
BV-mr	129.2 (35.1)	243.8 (90.8)	103.8 (37.4)	58.6 (18.8)	**133.8 (85.88)**
C-mr	118.2 (34.9)	263.4 (31.1)	136.1 (79.1)	92.5 (64.0)	**152.5 (85.67)**
R-mr	149.8 (44.3)	279.5 (67.9)	124.3 (62.6)	45.0 (14.8)	**149.6 (98.83)**

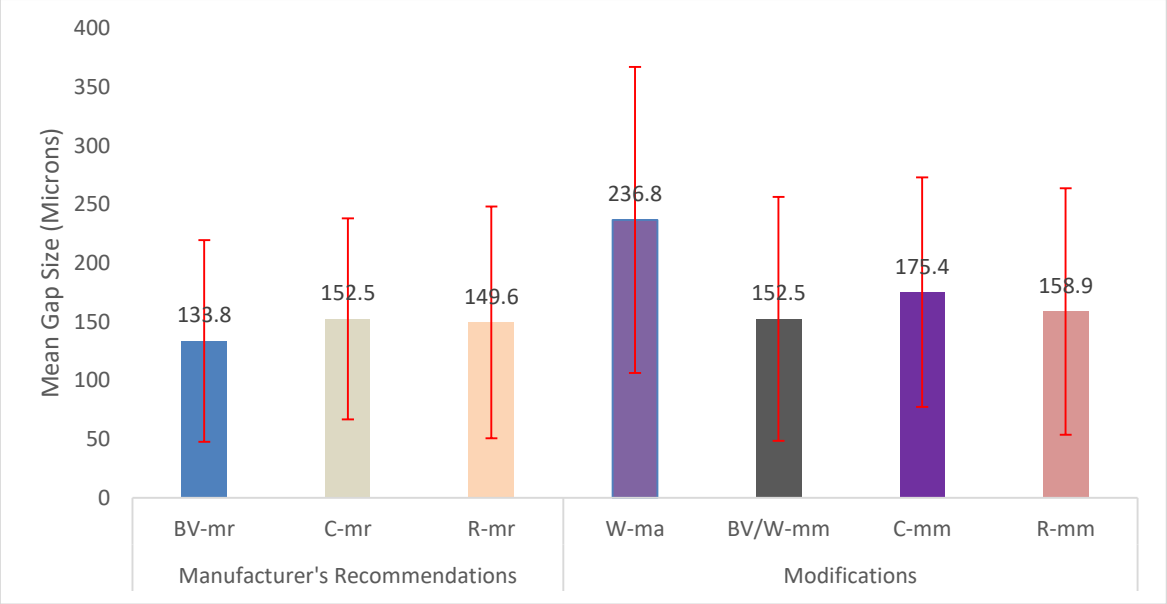

Figure 19: Overall mean marginal gap measurements for the different cast-metal crown coping groups

Figure 20 (below), shows the distribution of the measurements in every group, in box plots plotted against the marginal gap measurements. The median measurement is indicated by the line in the box plots. The information in Figure 20 is presented in greater detail in Table 4 (below), which shows the median marginal gap measurements, and first and third quartile values (in brackets) for the cast-metal crown coping groups.

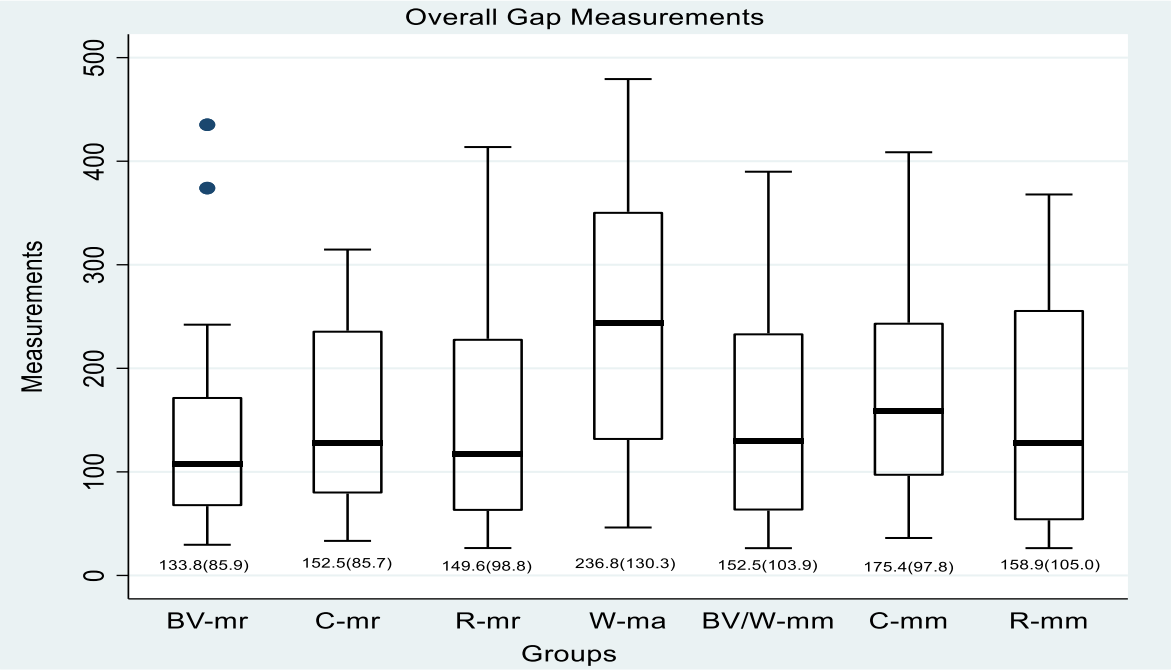

Figure 20: A comparison of the overall average gap measurements of the 70 cast-metal crown copings

Table 4: Median marginal gap measurements, and first and third quartile values for the cast-metal crown groups

GROUP	Median Marginal Gap Measurements (μm) and First and Third Quartile Values				
	Mid-facial	**Mid-palatal**	**Mid-mesial**	**Mid-distal**	**Overall Median**
W-ma	226.4 (147.6, 301.1)	386.2 (302.8, 421.8)	190.1 (168.7, 258.0)	66.0 (62.6, 90.1)	**244.2 (130.8, 351.1)**
BV/W-mm	139.3 (127.6, 171.1)	285.4 (255.8, 361.3)	104.8 (88.1, 135.1)	38.1 (29.8, 52.7)	**129.4 (62.7, 233.8)**
C-mm	153.8 (144.5, 160.8)	246.5 (241.6, 288.6)	144.9 (97.8, 232.6)	54.4 (42.8, 79.2)	**159.2 (96.2, 244.1)**
R-mm	143.9 (117.3, 208.8)	272.6 (254.2, 341.7)	118.0 (81.0, 226.9)	39.9 (32.9, 52.5)	**127.5 (53.3, 256.3)**
BV-mr	121.1 (100.7, 161.2)	224.0 (179.4, 242.1)	105.8 (64.3, 128.4)	57.7 (43.4, 69.6)	**107.6 (66.9, 172.3)**
C-mr	103.9 (97.4, 140.6)	253.7 (247.3, 276.6)	116.6 (70.9, 151.9)	61.1 (49.6, 171.9)	**128.3 (79.1, 236.3)**
R-mr	136.0 (117.1, 195.2)	253.4 (239.9, 304.8)	106.7 (81.0, 161.8)	44.9 (33.2, 52.8)	**117.2 (62.3, 228.5)**

5.3 Analysis of the Marginal Gap Measurements on the Four Different Faces of the Cast-metal Crown Copings

The mean marginal gap measurements of all the 70 cast-metal crown copings were compared on the mid-facial, mid-palatal, mid-mesial and mid distal faces of the cast-metal crown copings (Figure 21, below).

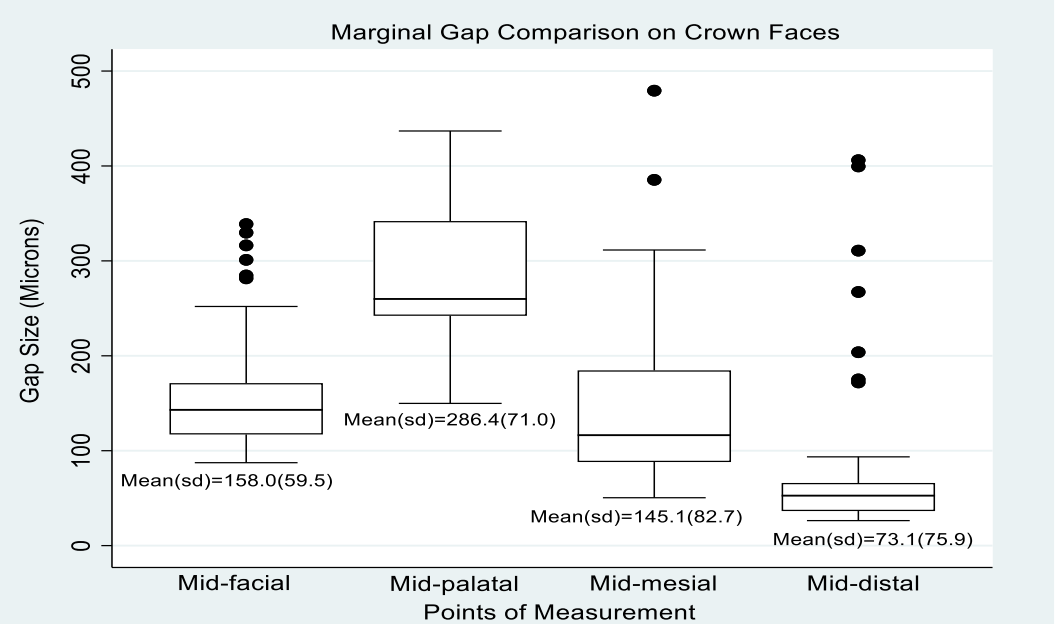

Figure 21: Box plot comparing the combined mid-facial, mid-palatal, mid-mesial and mid-distal marginal gap measurements on the 70 cast-metal crown copings

On average, the mid-facial aspect of the cast-metal crown copings had a mean marginal gap measurement of 158.0 µm (± 59.5). This, compared to mean marginal gap of 286.4 µm (± 71.0), 145.1 µm (± 82.7), 73.1 µm (± 75.9) for mid-palatal, mid-mesial and mid-distal points, respectively. The mid-facial aspect of the cast-metal crown copings had a median marginal gap measurement of 143.0 µm (IQR: 117.1, 171.2). The median marginal gap measurement for mid-palatal, mid-mesial and mid-distal points, were 259.9 µm (IQR: 242.1, 342.0), 116.4 µm (IQR: 88.1, 184.6), and 52.6 µm (IQR: 36.4, 66.0), respectively. There was a significant difference in these measurements (p=0.0001).

Figure 22: Figure 23, Figure 24 and Figure 25, show box-plots illustrating the marginal gap measurements of the cast-metal crown copings fabricated in the ***BV-mr***, ***C-mr***, ***R-mr*** and ***W-mr*** groups respectively, all manipulated according to their individual manufacturers' instructions. The box plots for the three other experimental groups (***BV/W-mm***, ***C-mm*** and ***R-mm***), showing the measures of central tendency, are illustrated in Figure 26, Figure 27 and Figure 28, respectively. All the groups show a similar pattern of marginal gap size for the different faces of the cast-metal crown copings measured. The mid-palatal measurement is largest in all the groups, while the mid-distal point generally has the lowest marginal gap measurement. The mid-facial and mid-mesial measurements fell in between the other two

measurements. This pattern was seen across all the seven groups of copings, as is illustrated in the box plots in Figures 22 to 28 (below).

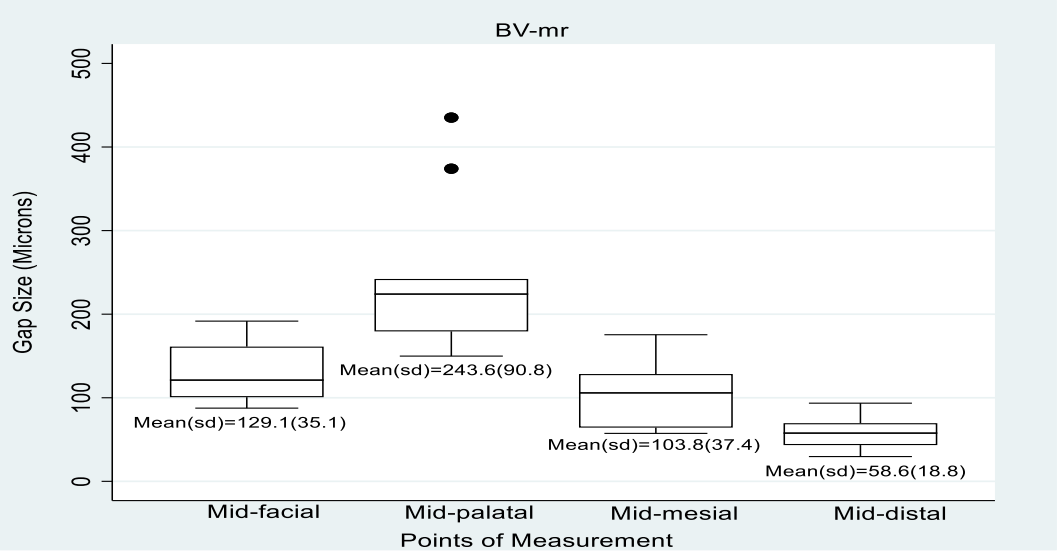

Figure 22: Box-plot showing distribution of marginal gap measurements in the BV-mr group

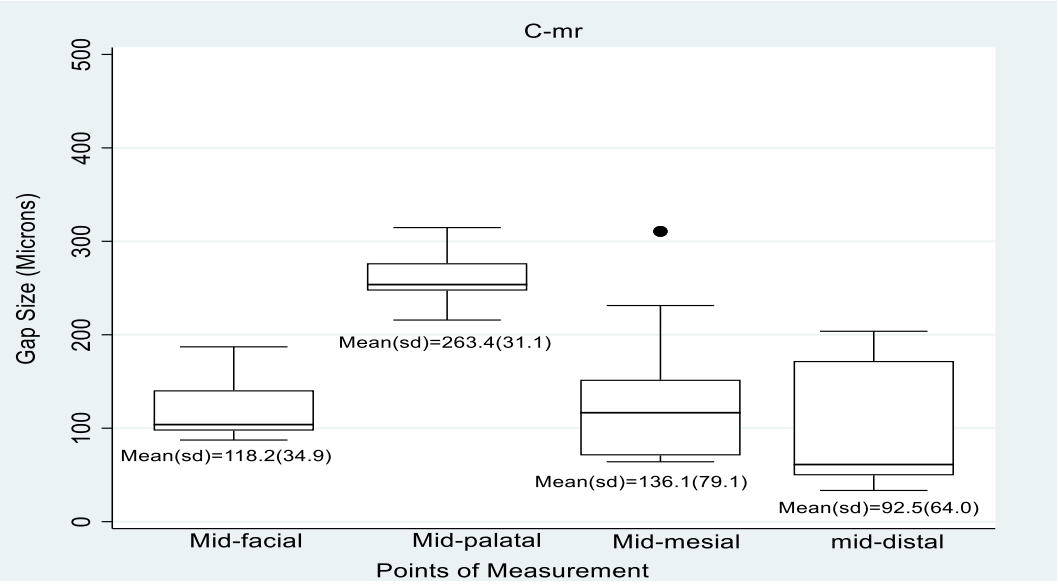

Figure 23: Box-plot showing distribution of marginal gap measurements in the C-mr group

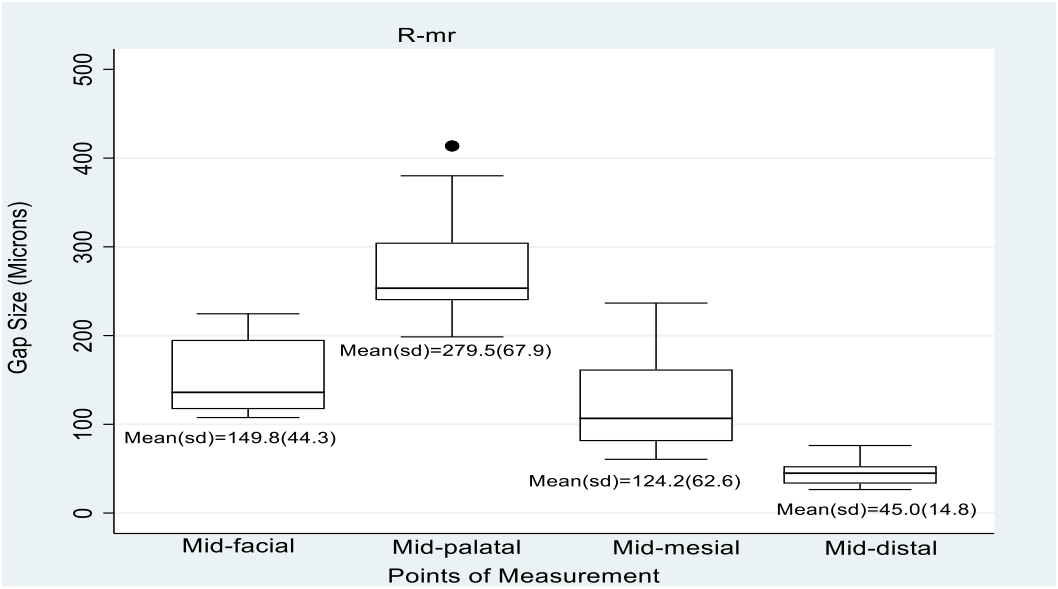

Figure 24: Box-plot showing distribution of marginal gap measurements in the R-mr group

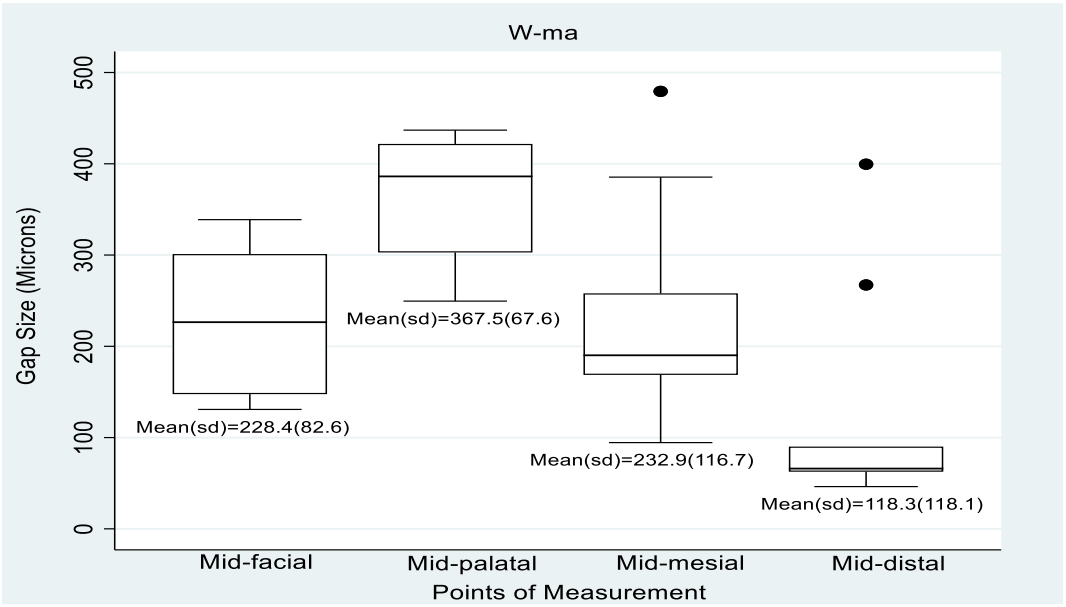

Figure 25: Box-plot showing distribution of marginal gap measurements in the W-mm group

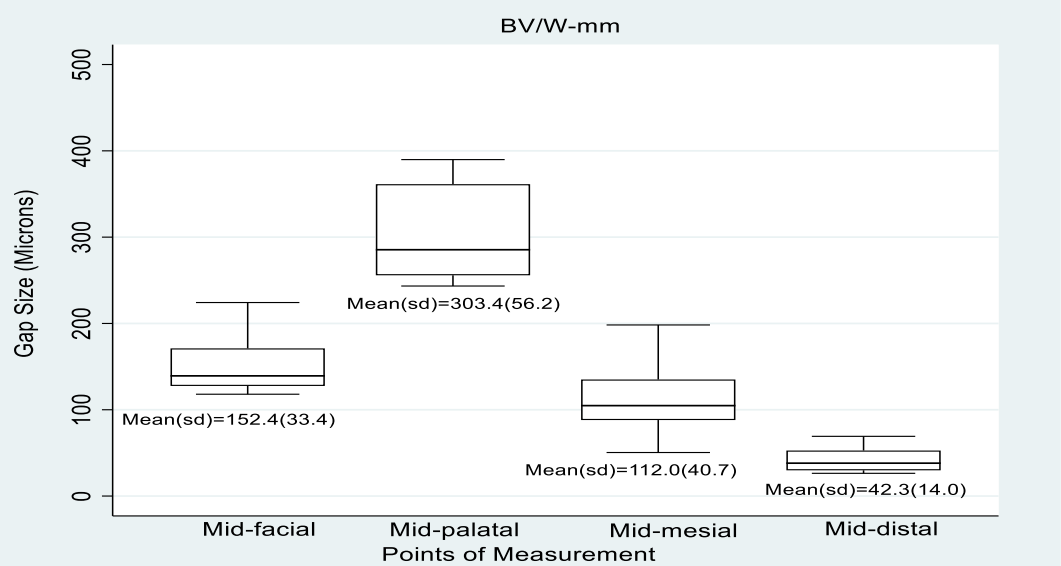

Figure 26: Box-plot showing distribution of marginal gap measurements in the BV/W-mm group

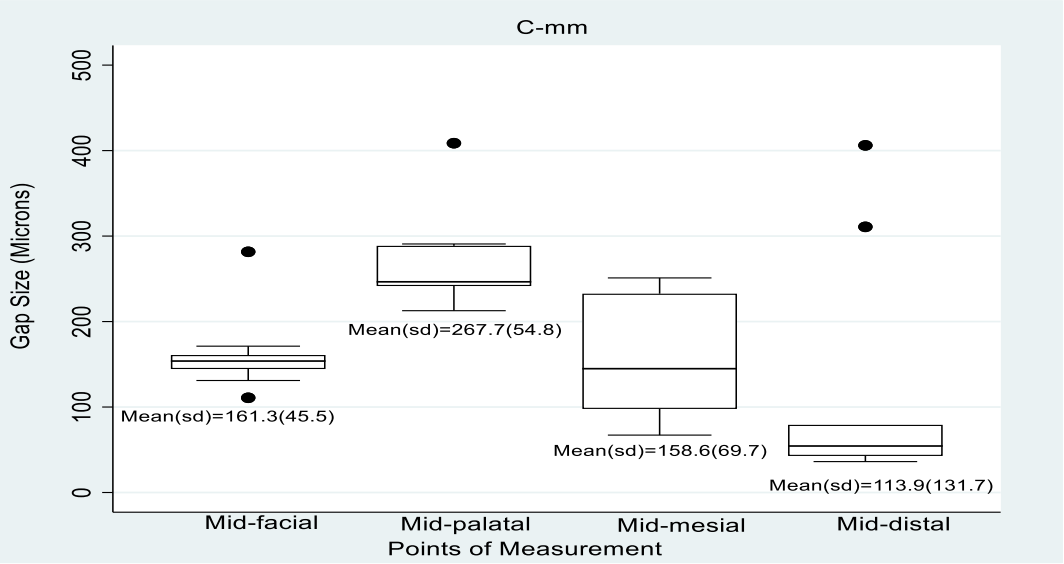

Figure 27: Box-plot showing distribution of marginal gap measurements in the C-mm group

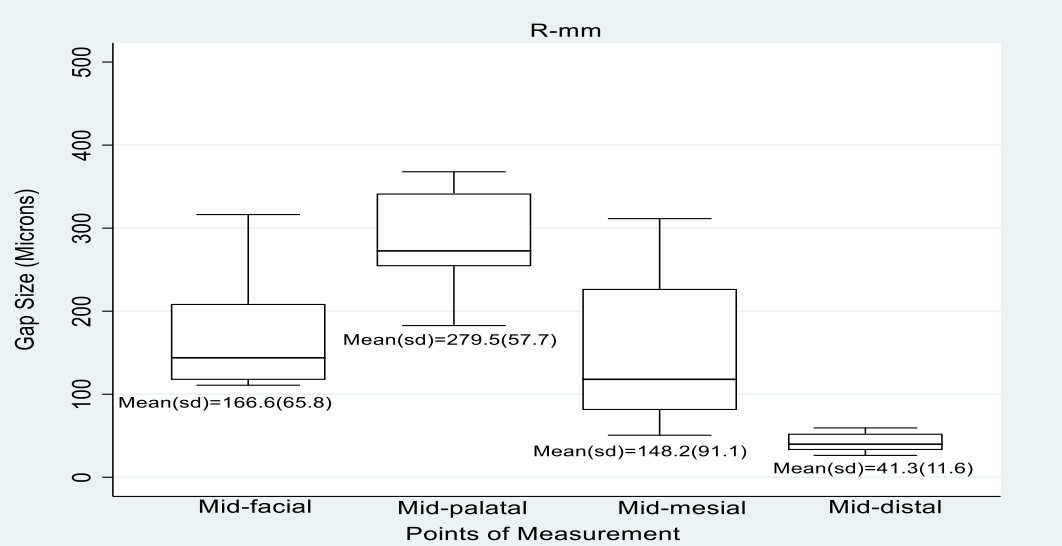

Figure 28: Box-plot showing distribution of marginal gap measurements in the R-mm group

5.5 Test for Normal Distribution and Homogeneity of Variance

5.5.1 Test for Normal Distribution

The Shapiro-Wilk W test was done (Table 5). It revealed that only the ***C-mm*** group showed some degree of normal distribution (Figure 29).

Table 5: Test for normal distribution (Shapiro-Wilk W Test)

Group	N	W	p-value
BV-mr	40	0.856	<0.001
C-mr	40	0.916	0.005
R-mr	40	0.919	0.007
W-ma	40	0.941	0.038
BV/W-mm	40	0.912	0.004
C-mm	40	0949	0.074
R-mm	40	0.919	0.007
Overall	280	0.931	<0.001

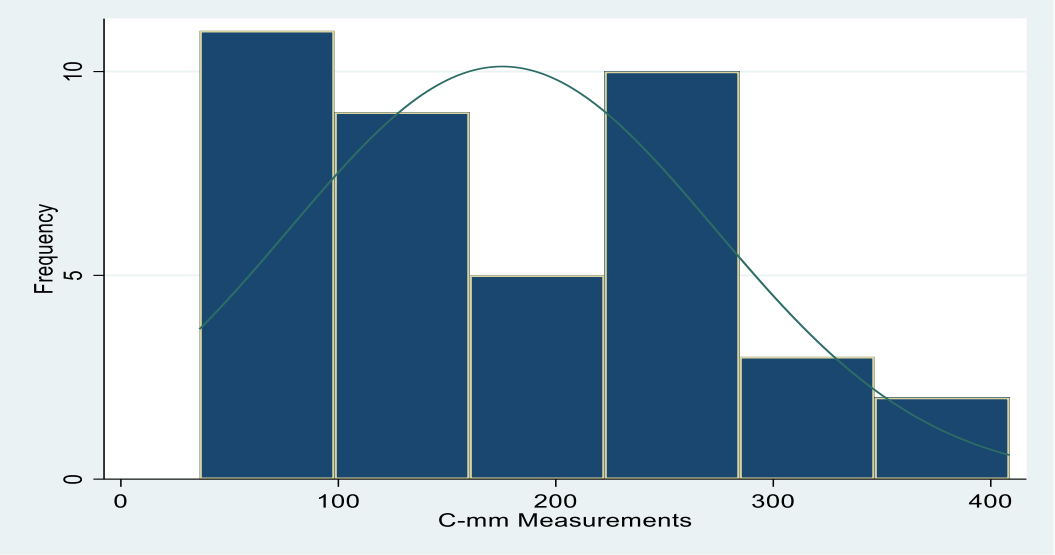

Figure 29: Histogram showing distribution of measurements for the *C-mm* group

5.5.2 Test for Homogeneity of Variance

The test for homogeneity of variance (Levene test) accompanying a preliminary ANOVA test that was done, is shown in Table 6 (below).

Since the data violated the assumptions of ANOVA, the non-parametric, Kruskal-Wallis H test was selected for subsequent analysis **(F(6, 273)= 3.058, p=0.006)**.

Table 6: 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

5.6 Comparison of the Marginal Gap Measurements on all the Cast-metal Crown Copings Groups

A Kruskal Wallis H test conducted on all the marginal gap measurements across the seven groups (Table 7) showed that the medians of the seven protocols were not equal statistically; **$\chi^2(6) = 18.681$, p=0.0047.**

Table 7: 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 8: 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 ***0.002**	-2.768 0.059	-3.228 ***0.013**			
BV/W-mm	-0.688 1.000	0.336 1.000	-0.124 1.000	3.104 ***0.020**		
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 ***0.047**	-0.262 1.000	0.926 1.000

A post-hoc (Dunn's) test was conducted on all the seven groups of measurements (Table 8). The difference in median was 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).

5.7 Comparison of the Marginal Gap Measurements on the Cast-metal Crown Copings Fabricated with Modifications to Manipulation Modalities of the Manufacturers' Instructions for the Respective Investment Materials

The cast-metal crown copings in the ***W-ma***, ***BV/W-mm***, ***C-mm***, and ***R-mm*** groups were fabricated after investment with five phosphate-bonded investment materials, manipulated with the various aforementioned modification modalities to the respective manufacturers' instructions on handling.

A Kruskal-Wallis H test was conducted to determine if marginal gap measurements was different for the four experimental groups (Table 9): ***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 10). It revealed that the statistically significant difference in median was between ***W-ma*** and ***BV/W-mm***, and between ***W-ma*** and ***R-mm***.

Table 9: 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 10: Post-hoc test (Dunn's test) on the experimental groups

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

5.8 Comparison of the Marginal Gap Measurements on the Cast-metal Crown Copings Fabricated According to Manufacturers' Instructions for the Respective Investment Materials

The ***BV-mr***, ***C-mr*** and ***R-mr*** groups comprised cast-metal crown copings fabricated after investment with three phosphate-bonded investment materials, manipulated according to the respective manufacturers' instructions. These were the designated control groups.

A Kruskal-Wallis H test was conducted to determine if marginal gap measurements was different for the three control groups (Table 11): ***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 11: 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

5.9 Hypothesis Testing

The hypotheses that were tested were presented in section 3.4 (above). The statistical analysis carried out led to the following conclusions:

1. Rejection of the first null hypothesis and the adoption of the alternate hypothesis; that 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. Adoption of the second null hypothesis; that there is no significant difference in the accuracy of marginal fit of the cast-metal crown copings fabricated according to the manufacturers' instructions for investment.
3. Rejection of the third null hypothesis and adoption of the alternate hypothesis; that there are significant differences in the accuracy of marginal fit of the cast-metal crown copings fabricated whilst utilizing the modifications in the handling of the investment materials.

CHAPTER SIX:

DISCUSSION

The marginal fit of a crown is a very important prognostic indicator for the success and longevity of the fixed prosthetic restoration [10]. The type of investment material used in a casting procedure should be able to accurately create a mould that would produce cast crown and retainer copings of the desired dimensions [13].

Various factors affect the accuracy of castings. The type of investment material; particularly its rheological properties and its ability to conform closely to the pattern that is being invested, is paramount. Of equal importance is the casting pressure and the viscosity of the molten fluid alloy being cast. These two latter factors are influenced by the casting technique and temperature. The casting technique involves the method employed to generate enough casting pressure to drive the molten alloy into the mould and fill it out completely without leaving voids. This is achieved in a number of ways, namely: hydrostatically, centrifugation, by use of pressurized air, or by use of vacuum [57]. The casting temperature can affect the following parameters that are critical in the creation of an accurate casting [58]:

a) Castability, that is the ability to fill the negative space of a mould, demonstrated by the molten alloy of the metals being cast [58], and,
b) The thermal contraction of the alloy, that is, the shrinkage that is experienced during the solidification of the molten alloy [58].

Various commercially available investment materials have got different ranges of expansion capabilities and so the resultant castings obtained after investing with the various phosphate-bonded investments may vary with different products [7].

In this study, the accuracy of various 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, in some instances as a measure meant for cost-cutting, whereas in other instances, due to the unavailability of some components of the investment material mixtures in the local market, from time to time. With reference to cost cutting measures, it is worth pointing out that the prices of phosphate bonded investment materials on the Kenyan market ranged from US $ 10 to US $ 25 per

kilogram of powder, and US $ 20 per litre of expansion liquid (for Castorit®-super C) up to US $ 30 per litre (for Rema® cc), and US $ 40 per litre (of BegoSol®). Furthermore, BegoSol® was only available in packaging of five litres which (as of September 2021), was retailing in Nairobi at US $ 197. Naturally, there may be a tendency to utilize the most cost-effective combination of the necessary powders and mixing fluids.

Materials that suffer major stock-outs in Kenya include the silica in water expansion liquid. The suppliers of these dental materials report occasional difficulty in the importation processes of the expansion liquid mainly due to the fact that it is classified as a hazardous chemical which many countries require special clearance before it can be ferried via air. The Government of Kenya requires (among others), documents such as these to be availed during the process of importation of goods; a Certificate of Conformity from the Pre-Export Verification of Conformity agent for regulated products, a valid commercial invoice from the exporting firm, a valid pro forma invoices from the exporting firm, a bill of landing (sea cargo)/airway bill (air cargo), a certificate of origin, a freight invoice for sea cargo and a permit/license for restricted goods [(59)].

Some of these documents are not readily availed by the concerned authorities in reasonable time. As a result, various products periodically experience stock-outs in Kenya. During the period of data collection for this study, the unavailability of Begosol® was particularly noteworthy, as it took an entire month before a shipment from Dubai, United Arab Emirates, was received by the sole local distributor of BEGO products in Nairobi, Kenya. Similar challenges have been experienced elsewhere around the world, in countries such as Ukraine, where efforts are underway to encourage use of locally manufactured dental materials as opposed to importation of the same. 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 [(60)]. It is prudent for any country to facilitate the provision of quality dental materials at competitive prices for its dental practitioners, as this translates to quality, readily available dental treatment for its citizenry.

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®-super C, mixed with 100% special liquid, for casting titanium at 70ºC, 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® Plus (Dentaurum J. P. Winkelstroeter KG, Pforzheim, Baden-Württemberg, Germany). However, the use of Rematitan® Plus was undesirable because it required heating up to 430ºC to achieve desired expansion, whereas similar expansion was achieved with Castorit®-super C at 70ºC [(61)].

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® Plus with an investment material that is referred to as "spinnel-based." This is an investment that contains MgO and Al_2O_3, and forms a reduced α-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. Pieralini *et al.* coated the wax patterns with this spinnel-based investment (Rematitan® Ultra, Dentaurum, Ispringen, Germany) before eventual investment with Rematitan® Plus, Rema® Exakt, and Castorit®-super C. They found that coating wax patterns with Rematitan® Ultra improved the castability of all the phosphate-bonded investments under investigation [(62)].

In India, Kanitkar *et al*. found that nickel-chromium cast after investment at a pressure of three bars for 30 minutes produced smoother casting surfaces compared to those invested at atmospheric pressure [(63)].

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.

6.1 Overall Mean Marginal Gap Measurements:

The overall marginal gap measurements for the castings ranged from **133.8 µm (± 85.88)** [for ***BV-mr***] to **236.8 µm (± 130.34)** [for ***W-ma***].

Fransson *et al.* showed that a marginal gap of up to **150 µm** was clinically acceptable [55]. Two groups of castings (***W-ma*** [**236.8 µm (± 130.34)**] and ***C-mm*** group [**175.4 µm (± 97.85)**]) recorded marginal gap measurements that were significantly higher than this, with the ***W-ma*** group, having the highest marginal gap measurements recorded in the study.

Wirofine® 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® for the investment of cast-metal crown copings and frameworks for fixed partial dentures. Therefore, the copings in the ***BV-mr*** 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® 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. This 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 [64].

6.2 Analysis of the Marginal Gap Measurements on the Four Faces of the Crown Copings

The comparison of the marginal gap measurements on the four faces of the crown copings revealed an interesting pattern. The bulk of the mid-palatal marginal gap measurements across all seven groups were predominantly higher [**286.4 µm (± 71.0)**] compared to any of the other faces of the cast-metal crown copings. Conversely, the bulk of the mid-distal marginal gap measurements were predominantly lower values [**73.1 µm (± 75.9)**] compared to any of the other faces of the cast-metal crown copings. The trend was noticed when all individual cast-metal crown copings in all seven groups were evaluated (Figures 21 to 28).

The consistent pattern of distribution of the measurements of the marginal gaps on the four faces of the cast-metal crown copings, across all seven groups may have stemmed from the wax pattern design, from which all cast-metal crown copings were fabricated.

Subsequent comparison of the marginal gaps for the groups fabricated as recommended by the manufacturer (***BV-mr***, ***C-mr***, and ***R-mr***) showed no statistically significant differences. However, where modifications to manipulation were introduced (***W-ma***, ***BV/W-mm***, ***C-mm***, and ***R-mm***), certain differences emerged. A Kruskal-Wallis H test conducted to determine whether the marginal gap measurements was different for the four experimental groups (Table 9), showed a statistically significant difference in measurements between the four groups. A post-hoc (Dunn's) test done on the experimental groups (Table 10) revealed that the statistically significant difference in median was 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® 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.

6.3 Variables Affecting Marginal Fit

The materials that are utilized in the lost wax technique include wax, investment materials, the metal alloy for casting, and the casting ring, which may or may not be used. All of these materials undergo expansion and/or shrinkage, and thus become part of the variables that may affect the marginal fit of a cast-metal crown or fixed partial denture retainer [(65)]. In this particular study, the same casting wax (Yenadent® CAD-CAM wax blocks; Istanbul, Turkey) and cobalt chromium alloy ingots, were used for all study groups. A casting ring was not employed. Therefore, any subsequent 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. All these factors are described further below, commencing with the generic factors associated with thermal expansion, followed by factors related to the wax pattern handling, before a more detailed discussion related to the hygroscopic expansion of investment material.

6.3.1 Thermal Expansion

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 [15].

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 [66]. 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 [25]. 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 [67, 68]. Since a metal casting ring was not used in this study, the expansion that was recorded in this study may be attributed to hygroscopic setting expansion of the investment material and wax pattern expansion.

6.3.2 Wax Pattern Handling and Burn-out Procedure

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 [15].

The dental wax that is invested and utilized in the lost wax technique is known as inlay wax [16]. 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 x 10^{-6}/°C [16].

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. Conversely, 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.

Conventionally, after a wax pattern has been invested, manufacturers recommend leaving the assembly to bench set for one hour, followed by a wax burn-out procedure that may either be one stage or two stage. An accelerated method of wax elimination has been described in literature. The procedure entails introduction of the mould into a furnace that has been pre-heated to the set maximum recommended temperature. This is done as soon as the mould has achieved adequate wet strength, typically 12 to 15 minutes after mixing [69-72].

In this study, the conventional wax burn-out procedure was used. Moulds were allowed to bench set overnight before the wax burn-out procedure and subsequent casting process. The wax patterns had been milled using a CAD-CAM machine using Yenadent® CAD-CAM wax blocks (Istanbul, Turkey). The milled wax patterns were sectioned, 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.

Elsewhere, Prasad *et al.* [73] found no significant differences in the marginal gap measurements of cast-metal crown copings fabricated after utilizing the conventional wax burn-out procedure as compared to those produced by the accelerated wax burn-out group. In their study, patterns were fabricated using molten modelling wax with a stainless-steel former over a lubricated dental stone die. They stored their wax patterns at room temperature for 24 hours before casting them.

It is therefore evident, that different researchers have different justifications for the protocol they employ in the handling of wax patterns. What is critical is the standardization in the handling of all wax patterns in the control and the experimental groups of the study.

6.3.3 Hygroscopic Setting Expansion

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 [7]. 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 [7].

The findings in this study showed that not using 100% pure expansion liquid, particularly while manipulating Castorit®-super C investment material resulted in castings that had significantly larger marginal gap measurements [**175.4 µm (± 97.85)**].

Dental technologists in Nairobi, Kenya reported using a ratio of 2:3 – Distilled Water: Expansion Liquid, in the manipulation of Rema® 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 µm (± 105.03)**].

6.4 Marginal Gap Measurement

The direct view technique of evaluation of marginal gaps is a popular method that has been employed by many researchers such as Pettenò *et al.* [48], Groten *et al.* [49], Olivera and Saito [50], Yoon *et al*. [56], and Prasad *et al*. [73]. Importantly, Olivera and Saito found out that optical microscopy and scanning electron microscopy correlate well [50]. This gives credence to the variation of direct view technique of marginal gap evaluation, which was utilized in this study. Our evaluation methodology was adapted from Yoon *et al*. whose 2014 study purposed to compare the total occlusal convergence of dental students' typodont crown preparations. Yoon *et al*. evaluated 165 typodont teeth prepared by dental students by placing individual typodont teeth in a custom-fit die base to ensure that the position of the die was stable and reproducible. They then proceeded to capture the images of the typodont teeth using a digital single-lens reflex camera (D3100; Nikon) with a macro lens (Nikkor AF-S 105 mm f/2.8G IF-ED; Nikon USA), set up on a tripod (Dolica) at a distance 30 cm from the base (as shown in Figure 6). The images were then uploaded onto a computer, magnified at least 30 times and evaluated with an on-screen protractor software by Iconico Inc. (New York, USA) [56].

In this study, the marginal fit of the fabricated cast metal crown copings was evaluated using the computer on-screen calliper software by ImageJ (New York, USA). ImageJ has been

referred to as a "*powerful*" image processing platform that has been invaluable in many scientific projects, particularly those in life sciences, since its inception in 1997 [74]. In a review of image analysis tools for the evaluation of microscopic views of immunohistochemically stained specimen in medical research, Prasad and Prabhu found that ImageJ performed better than optical microscopy in cell counting as it can automatically generate a staining index on microscopy images that is more reproducible and accurate compared to counting across the microscope [75]. We can thus speculate that similar accuracy in determining the marginal gap measurements may also have been attained in our study.

Another method that has been employed for the evaluation of margins is known as the impression replica technique. This method was employed by researchers such as Coli and Karlsson [52] and Wolfart *et al.* [53]. The method however involves the use of a silicon impression material and introduces the confounder of the elastomeric impression material into the marginal gap evaluation. Incorrect manipulation, handling or storage of the silicon would result in unreliable data.

Other researchers such as Kunii *et al.* [51] utilized the cross-sectional method of evaluating the marginal gap and the space between the cast crown coping and the prepared tooth surface. Admittedly, the cross-sectional method of evaluating the marginal gap measurements accompanied by the use of microscopy, as was done by Kunii *et al.* [51], would be a more accurate and reliable method. This method measures both the marginal and internal fit copings by measuring the thickness of the cemented layer under magnification [51]. This methodology however necessitates the availability of equipment for sectioning the castings and that the master abutment models be fabricated out of a material that can be sectioned using the diamond cutting machine without interfering with the marginal gap. Kunii *et al.* prepared their master abutments by numeric control (NC) machining using stainless steel (SUS304) [51]. Moreover, destruction of the samples during this evaluation would eliminate any possibility of repeat or longitudinal evaluations over time.

With the resources available to the principal investigator, the methodology utilized in this study was not only accurate and reproducible, but also cost effective. The results obtained were reliable as the marginal gap measurements recorded in this study are similar to the range of gap measurements recorded in similar studies. For example, Prasad *et al.* [73] evaluated the marginal fit of cast-metal crown copings fabricated whilst utilizing a metal casting ring and an accelerated wax burn-out procedure. They compared the marginal fit of

crowns cast using this method, and those cast conventionally using the ringless casting technique and conventional wax burn-out procedures. The marginal gap measurements recorded in their study were between 54.40 µm and 199.63 µm. They reported that these measurements were within the acceptable range, quoting from the 1982 paper by Dedmon, [76] on "Disparity in expert opinions on size of acceptable margin openings."

In this study the average marginal gap measurements recorded were between **133.8 µm (± 85.88)** for ***BV-mr*** and **236.8 µm (± 130.34)** for ***W-ma***. The acceptable marginal gap opening reported in this study was **150 µm,** citing the 1985 paper by Fransson *et al.* [55]. 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® [***W-ma***: **236.8 µm (± 130.34)**] and those fabricated using the modified manipulation of Castorit®-super C [***C-mm***: **175.4 µm (± 97.85)**].

CHAPTER SEVEN:

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

Within the limits of this study, it was concluded that:

1. There were 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 **($\chi^2(6) = 18.681, p=0.0047$)**.

2. There were significant differences in the accuracy of marginal fit of the cast-metal crown copings fabricated whilst utilizing the modifications in the handling of the investments materials (**$\chi^2(3)=11.817, p=0.008$**).

3. There were no significant difference in the accuracy of marginal fit of the cast-metal crown copings fabricated according to the manufacturers' instructions for investment **($\chi^2(2)=1.286, p=0.526$)**.

4. Modification of manufacturers' recommendations for the manipulation of Bellavest T®, and Rema® cc phosphate-bonded investment materials, as is done by laboratory technologists in Nairobi, Kenya, yielded crowns that had marginal gap measurements within clinically acceptable range **(<150 µm)**.

5. The respective modified application and manipulation, of Wirofine® and Castorit®-super C phosphate-bonded investment materials, yielded crowns that had marginal gaps measurements beyond the clinically acceptable range.

7.2 RECOMMENDATIONS

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 cast-metal crowns.

The findings of this study necessitate the proposition of the following recommendations:

1. The respective modified application and manipulation of Wirofine® and Castorit®-super C phosphate-bonded investment materials, should not be used to cast metal crowns.

2. A second study utilizing additional/alternative marginal gap measurement techniques should be carried out using the cast-metal crown copings from this study, to further bolster the findings of this study.

3. 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® Phosphate Bonded Dental Investment Material (Henan Shengbang Medical Technology Co., Ltd, Zhengzhou, Henan, China), Elite Vest Plus® (Zhermack, GmbH, Badia Polesine, Italy) and Yetivest® (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.

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APPENDIX I

SURVEY OF USE OF PHOSPHATE-BONDED INVESTMENT MATERIALS BY DENTAL TECHNOLOGISTS IN NAIROBI, KENYA

My name is Silas Mbeya Toka. I am a post-graduate student at the University of Nairobi, School of Dental Sciences. I wish to carry out a study to investigate the effect of different phosphate-bonded investment material brands and various modifications to their manipulation, on the marginal fit of cast-metal crown copings.

I wish to collect preliminary information that will be useful in evaluating which phosphate-bonded investment material brands are in common use in Nairobi, Kenya, and modalities employed by dental technologists in their manipulation.

QUESTIONNAIRE

SERIAL NUMBER: (For Official Use Only) _____

1. **Age of Dental Technologist:** _____ (Years)

2. **Education Level (Tick where appropriate):**

   Diploma ☐

   Graduate ☐

   Post-graduate ☐

   Any other (Specify) _____

   _____

3. **Years of Experience:** _____ (Years)

4. **Nature of Employment (Tick where appropriate):**

   Public Laboratory ☐

   Private Laboratory ☐

5. **How often do you use the following phosphate-bonded investment material brands in investing wax-patterns for the purpose of fabricating cast-metal copings for crown and bridge work? (Tick where appropriate).**

	Very often	Often	Occasionally	Rarely	Never
i. **Bellavest T®** phosphate-bonded investment material	☐	☐	☐	☐	☐
ii. Wirofine® phosphate-bonded investment material	☐	☐	☐	☐	☐
iii. Castorit®-super C phosphate-bonded investment material	☐	☐	☐	☐	☐
iv. Rema® cc phosphate-bonded investment material	☐	☐	☐	☐	☐
v. Rema® Exakt phosphate-bonded investment material	☐	☐	☐	☐	☐

6. **What ratio of water to expansion liquid do you use for each of the following investment materials when investing wax-patterns for the purpose of fabricating cast-metal crown copings? (Indicate actual ratio or tick where appropriate).**

	Water: Expansion Liquid	100%Water	100%Expansion
i. Bellavest T® phosphate-bonded investment material	☐ : ☐	☐	☐
ii. Wirofine® phosphate-bonded investment material	☐ : ☐	☐	☐
iii. Castorit®-super C phosphate-bonded investment material	☐ : ☐	☐	☐
iv. Rema® cc phosphate-bonded investment material	☐ : ☐	☐	☐
v. Rema® Exakt phosphate-bonded investment material	☐ : ☐	☐	☐

11. **a. Do you ever mix the powders of any of the above investment materials when investing wax-patterns for the purpose of fabricating cast-metal crown copings? (Tick where appropriate):**

Yes ☐

No ☐

b. If *YES,* indicate which powders are mixed and the actual ratio of the mix:

POWDER MIX	**RATIO OF POWDERS**	**TICK BOX IF YOU DO NOT USE THIS MIX**
Bellavest T® : Wirofine®	☐ : ☐	☐
Bellavest T® : Castorit®-super C	☐ : ☐	☐
Bellavest T® : Rema® cc	☐ : ☐	☐
Bellavest T® : Rema® Exakt	☐ : ☐	☐
Wirofine® : Castorit®-super C	☐ : ☐	☐
Wirofine® : Rema® cc	☐ : ☐	☐
Wirofine® : Rema® Exakt	☐ : ☐	☐
Castorit®-super C : Rema® cc	☐ : ☐	☐
Castorit®-super C : Rema® Exakt	☐ : ☐	☐
Rema® cc : Rema® Exakt	☐ : ☐	☐

c. What are your reasons for mixing the powders? _____

APPENDIX II

DATA COLLECTION TOOL

1. **CAST METAL CROWN COPING FABRICATION METHOD:** Cast-metal crown copings fabricated after investment with Bellavest T® investment material according to the manufacturer's instructions.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

2. **CAST METAL CROWN COPING FABRICATION METHOD:** Cast-metal crown copings fabricated after investment with Wirofine® investment material according to the manufacturer's instructions.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

3. **CAST METAL CROWN COPING FABRICATION METHOD:** Cast-metal crown copings fabricated after investment with Castorit®-super C investment material according to the manufacturer's instructions.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

4. **CAST METAL CROWN COPING FABRICATION METHOD:** Cast-metal crown copings fabricated after investment with Rema® cc investment material according to the manufacturer's instructions.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

5. **CAST METAL CROWN COPING FABRICATION METHOD:** Cast-metal crown copings fabricated after investment with a mixture of 50% Bellavest T® investment material and 50% Wirofine® investment material by weight; mixture of the two powders being mixed in 100% expansion liquid (BegoSol®).

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, **MP**: Mid palatal, **MM**: Mid mesial: **MD**: Mid distal

6. **CAST METAL CROWN COPING FABRICATION METHOD:** 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.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

7. **CAST METAL CROWN COPING FABRICATION METHOD:** 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.

Serial Number of cast metal coping	Marginal gap measurements in divested cast metal crown coping			
	MF	**MP**	**MM**	**MD**

*__MF__: Mid facial, __MP__: Mid palatal, __MM__: Mid mesial: __MD__: Mid distal

APPENDIX III

Manufacturers' instructions for use of Bellavest® T Phosphate-bonded investment material

The manufacturers of Bellavest® T (BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany), describe their product as a "graphite-free, phosphate bonded precision investment material for crowns and bridges" [18]. They do not disclose the exact composition of the material and provide the following disclaimer in their web-page entitled: "Bellavest® T Graphite-free, phosphate-bonded precision investment material for crowns and bridges" [18]:

"Whether given verbally, in writing or by practical instructions, our recommendations for use are based upon our own experience and trials and can only be considered as standard values. Our products are subject to a constant further development. Therefore, alterations in construction and composition are reserved."

The following are the general instructions for the use of Bellavest® T [18].

Preparation

- Wax the sprued copings on the BEGO base socket mould former so that the distance to the mould edge and top surface is at least 5 mm (¼").
- Apply a thin coat of Aurofilm wetting agent and blow completely dry.
- Plastic copings (e. g. Pattern Resin or Palavit G) must be thinly coated with wax.
- Use BEGO fleecy inlay strips: 1 strip for metal mould rings in sizes 1+3, 2 strips on top of each other for sizes 6 +9 as well as for all non-precious alloys.
- Handling: The strips must be approximately ½ cm longer than the circumference of the mould ring.
- Moisten strips slightly.
- Press strips in mould ring such that they overlap and are flush with the top edge of the mould ring.
- Slip over the wax-up and press the lower edge of the mould ring into the base socket mould former.

Investment

- Liquid: BegoSol® (recommended) or BegoSol® HE, if higher expansion requested.

- BegoSol®: Storage and transport temperature of –10 °C to +35 °C / 14 °F to 95 °F.
- BegoSol® HE (sensitive to frost): Storage and transport temperature of +5 °C to +35 °C / 41 °F to 95 °F.
- Before mixing, rinse out the clean mixing bowl with water and wipe off.
- Mixing bowls that are not clean or are dry withdraw moisture from the investment material.
- First put in liquid and add powder.
- Mix thoroughly with a spatula for 15 seconds.
- After that mix for 60 seconds in a mixing unit under a vacuum.
- (Mixing without mixing unit: 2 minutes on the vibrator.)
- Time available for processing: approx. 5 minutes (20 °C / 70 °F).
- Higher room temperatures result in shorter working times.
- Fill crowns carefully with an instrument.
- Then fill mould ring while subjecting it to vibration and then take it off the vibrator.
- If heating is to be carried out without a ring, remove the ring used for investment as soon as possible after complete setting of the investment material (after approx. 15 minutes).
- Metal mould rings cannot be removed.

Mixing Ratio

The mixing ratio for the manipulation of Bellavest® T is 100 g Bellavest® T powder : 23 ml liquid [18].

Table 1 (below) illustrates the proportioning of powder to liquid for the various quantities of powder, as per the manufacturer's recommendations [18].

The setting time after investment is at least 30 minutes [18].

Table 12: Powder-Liquid ratios for Bellavest® T phosphate-bonded investment material

(Adapted from the webpage "Bellavest® T Graphite-free, phosphate-bonded precision investment material for crowns and bridges") [18]

	Bellavest® T Portion Bags	BegoSol® (BegoSol® HE)	Aqua dest.	Total Liquid	Concentration of Liquid
Precious metal and Precious metal-ceramic alloys	60g	7ml	7ml	14ml	50%
	90g	10.5ml	10.5ml	21ml	
	160g	18.5ml	18.5ml	37ml	
Precious metal secondary parts	60g	8.5ml	5.5ml	14ml	60 – 80%
	90g	12.5ml	8.5ml	21ml	
	160g	22ml	15ml	37ml	
Non-precious metal and non-precious metal-ceramic alloys	60g	12.5ml	1.5ml	14ml	90 – 100%
	90g	19ml	2ml	21ml	
	160g	33ml	4ml	37ml	

Wax burn-out procedure and casting after investment with Bellavest® T

The insertion temperature is at room temperature or 250 °C / 500 °F for furnaces with conventional control. The holding level temperature is at 250 °C / 500 °F. The final temperature for non-precious metal and non-precious metal-to-ceramic alloys is 900 – 950 °C / 1650 –1740 °F. The holding times for holding level is between 30 to 60 minutes and both that duration and the final temperature is dependent on the size and number of moulds [18].

After the casting process, the moulds are allowed to cool down until they are warm to the touch. Water should not be used to quench them. After the moulds have cooled down completely they are placed in water until they are thoroughly moistened. This is meant to avoid a dusty deflasking process [18].

APPENDIX IV

Manufacturers' instructions for use of Castorit®-super C phosphate-bonded investment material

Castorit®-super C is a product of Dentaurum GmbH & Co. KG (Ispringen, Germany). It is a phosphate bonded investment material for use during the investment and casting of fixed partial dentures, marketed as a "precision investment material for non-precious alloys" [19].

The instructions supplied by Dentaurum are in a pictorial format, shown in figures 3 to 15 (below) [19]:

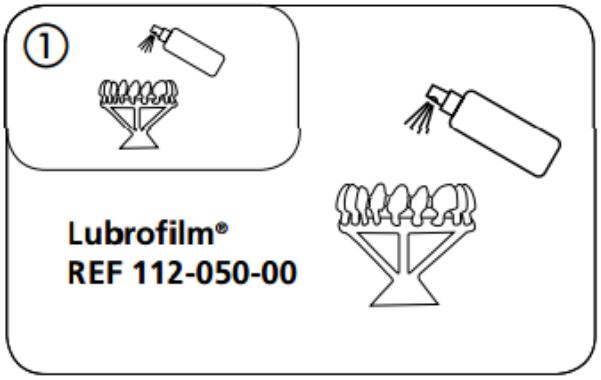


Figure 30: Surface treatment with Lubrofilm®

(Dentaurum, Ispringen, Germany)

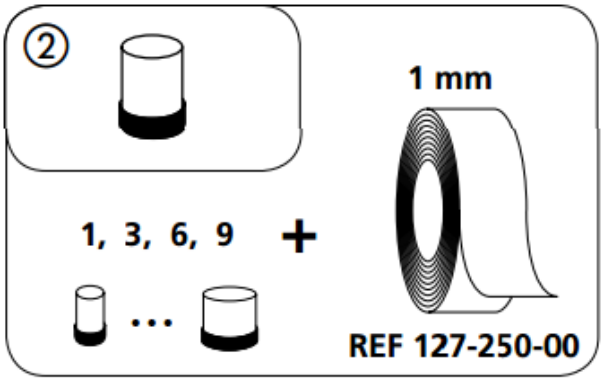


Figure 31: Casting ring formation using foil

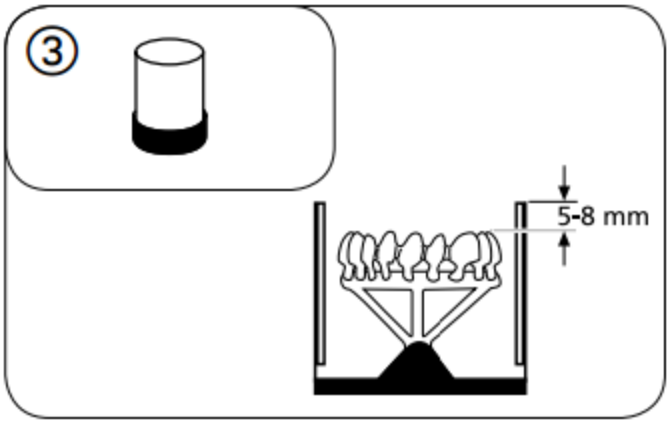


Figure 32: Placement of sprued patterns within the casting ring

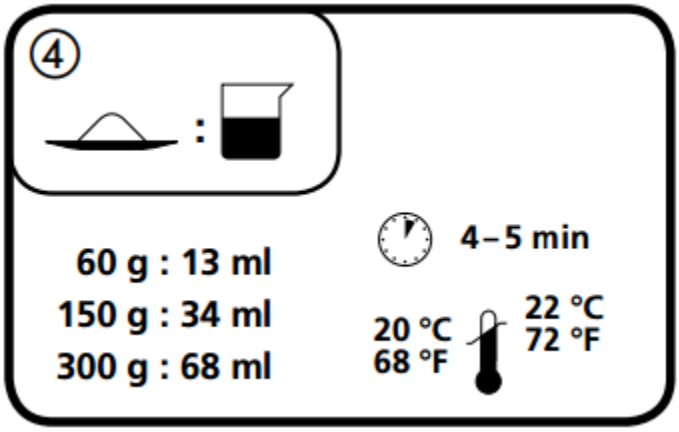


Figure 33: Powder to liquid ratios, mixing time and temperature for Castorit®-super C

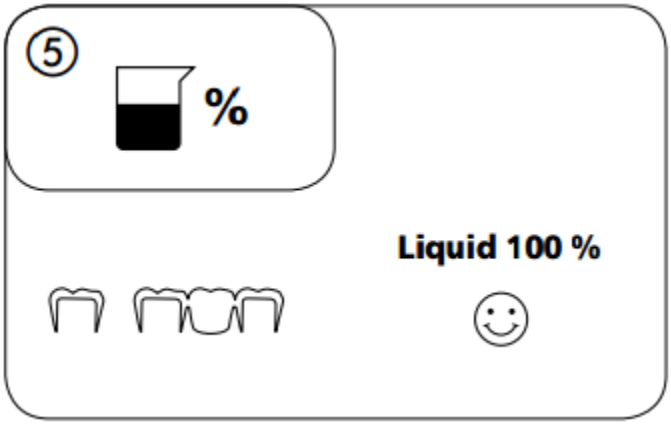


Figure 34: Concentration of expansion liquid for Castorit®-super C

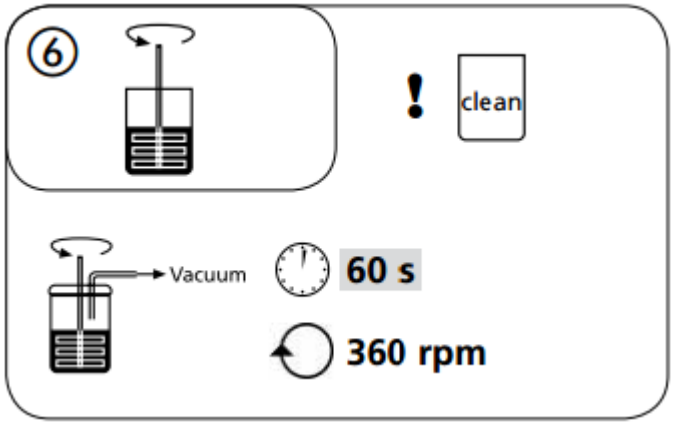


Figure 35: Mixing of the powder and liquid for Castorit®-super C

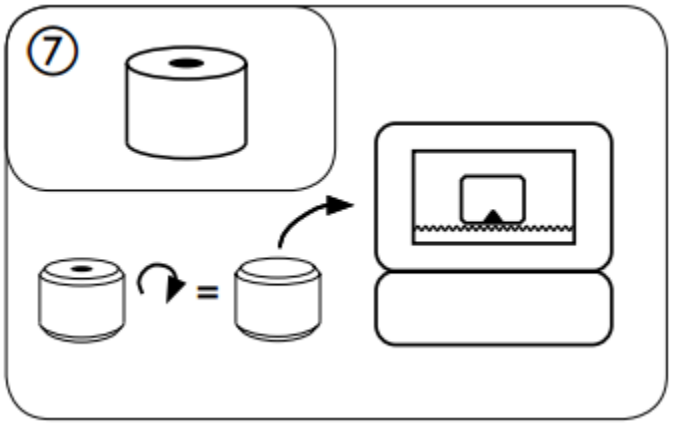


Figure 36: Mould placement into furnace

(Sprue channels facing downwards)

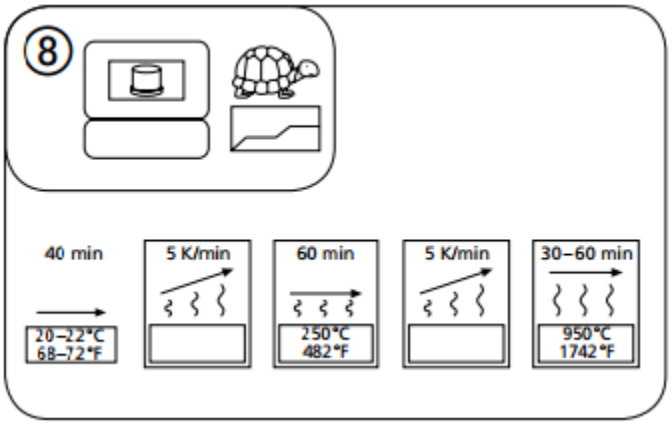


Figure 37: Wax burn-out procedure

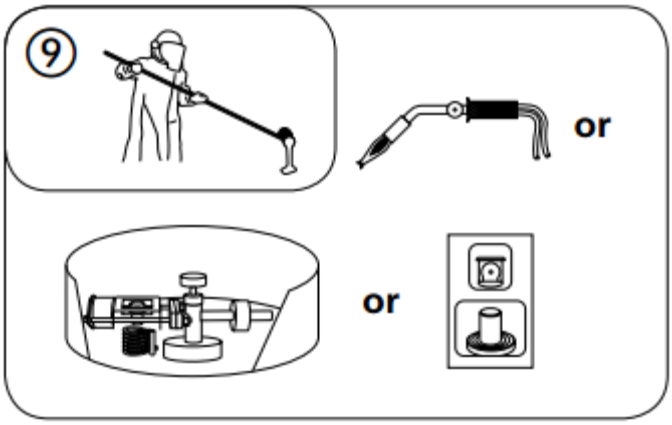


Figure 38: Casting process

(Either a centrifugal casting machine or an induction casting machine is used)

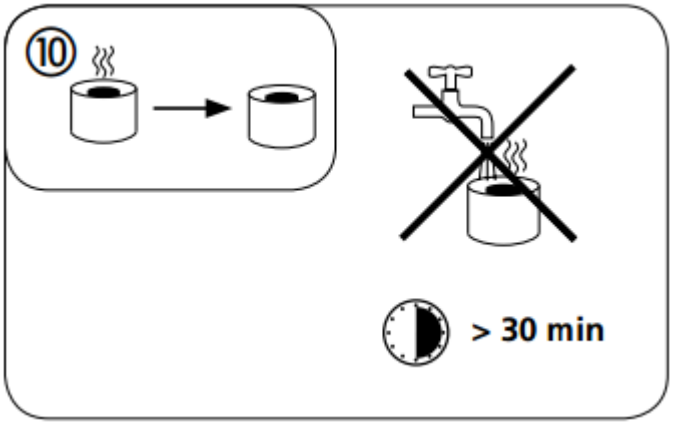


Figure 39: Bench cooling of mould

(Cooling time should exceed 30 minutes, and water should not be used to quench the mould)

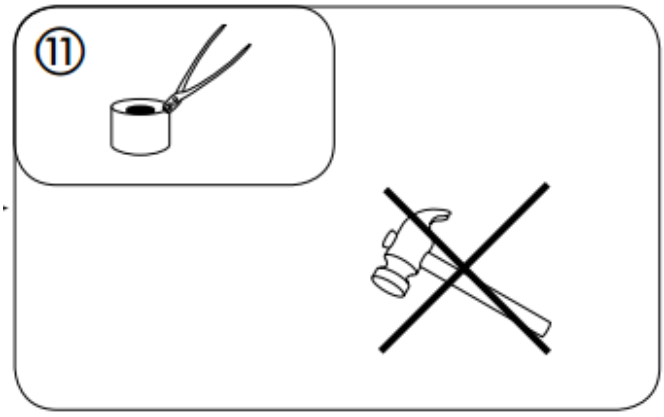


Figure 40: Procedure for divesting by use of forceps

(No undue force should be applied during this process)

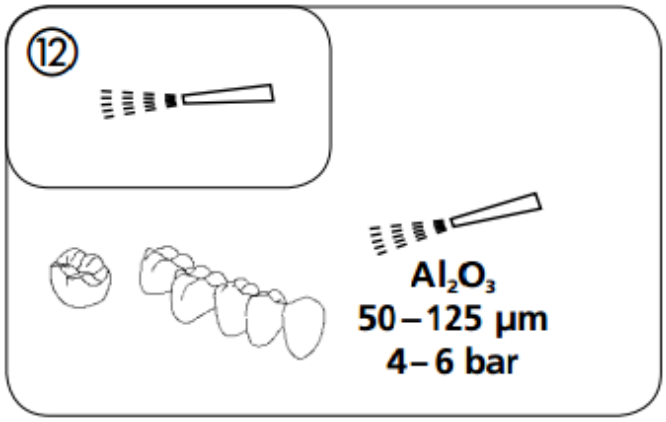


Figure 41: Sand-blasting procedure

(50 – 125 µm alumina particles at a pressure of 4 – 6 bar is used)

The manufacturers' instructions also contain the following safety information [19]:

"When using the speed heating method, ensure that the furnace door remains closed continuously for at least 15 min after the casting ring has been inserted (Danger of burning due to flames escaping).

"Investments contain quartz. Avoid inhalation of dust as this may cause lung diseases (silicosis /lung cancer). Wearing of face mask type FFP 2 – EN 149:2001 is recommended. Open pouch with scissors and avoid dust development when pouring into mixing bowl. Rinse empty pouch with water before disposal. Remove dust from working area only with a wet cloth. To avoid dust when divesting, place ring into water until it is completely soaked after ring has reached room temperature. When sandblasting use suction with fine dust filter."

Dentaurum, just like BEGO, also indicates that their products are subject to regular upgrading [18-19, 33].

APPENDIX V

Manufacturers' instructions for use of Rema® cc phosphate-bonded investment material

Rema® cc (Dentaurum GmbH & Co. KG, Ispringen, Germany) is marketed as a "phosphate bonded precision universal investment material for casting crowns and bridges, press ceramics and overpressing" [35].

The safety information and the disclaimers availed along with this product are identical to that supplied with Castorit®-super C (quoted above) [19, 35].

The instructions for the manipulation of Rema® cc are also supplied in a pictorial format as illustrated in figures 15 to 27 (below) [35].

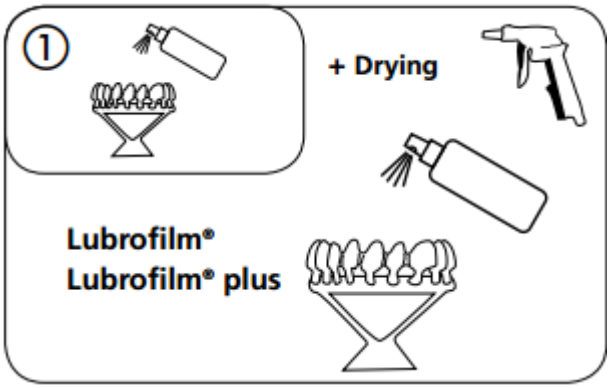


Figure 42: Surface treatment with Lubrofilm® or Lubrofilm®

(Dentaurum)

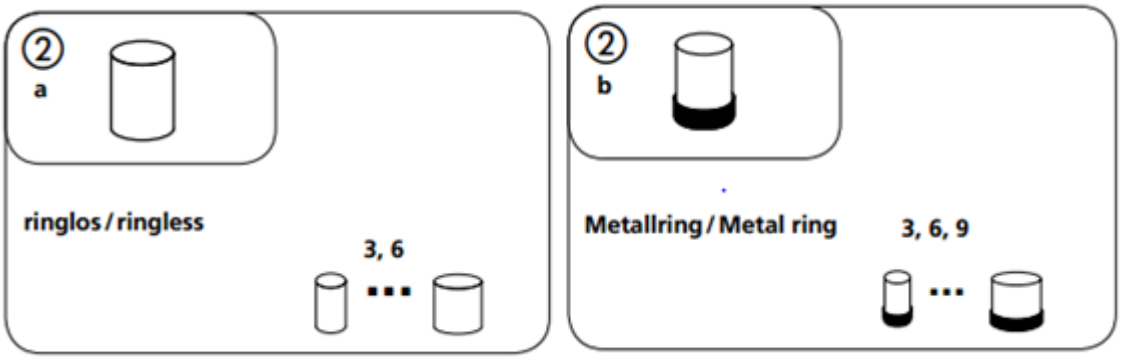


Figure 43: Ringless or metal ring investment

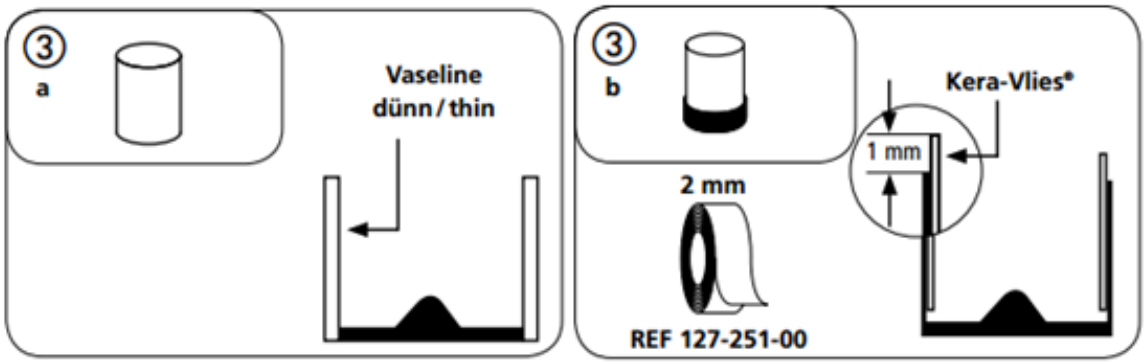


Figure 44: Vaseline application in ringless casting and asbestos free liner (Kera-Vlies®) for metal casting rings

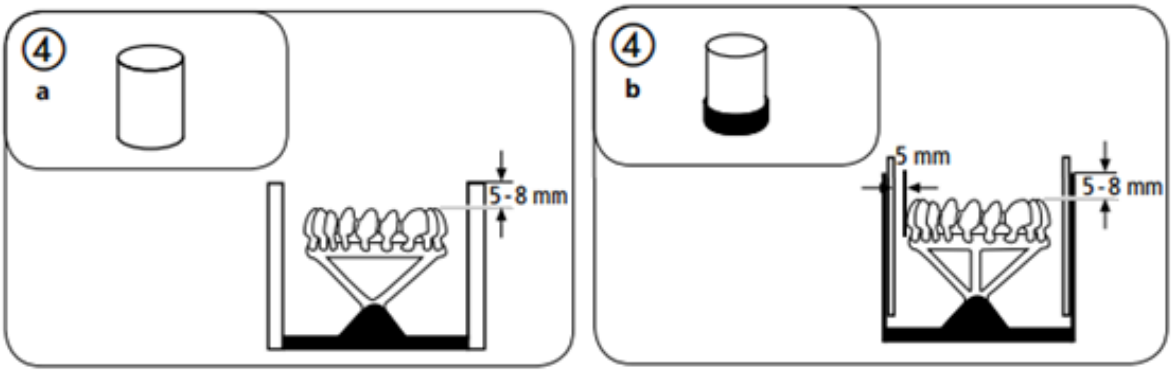


Figure 45: Placement of sprued wax patterns within the casting ring assembly

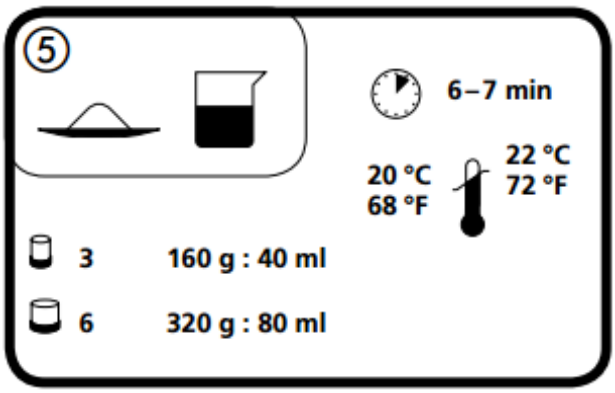
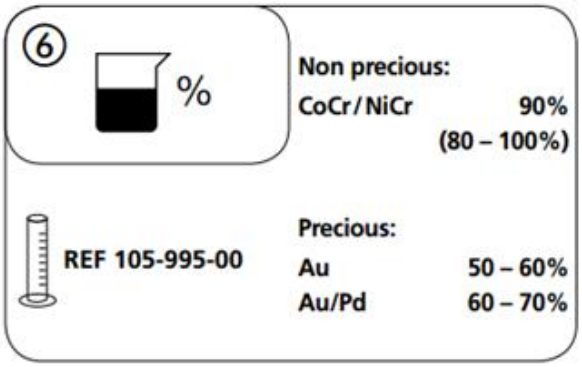


Figure 46: Powder to liquid ratios, mixing time and temperature for Rema® cc



Liquid	(160 g : 40 ml)
	Konzentrat : Aqua dest
40 %	16 ml : 24 ml
50 %	20 ml : 20 ml
60 %	24 ml : 16 ml
70 %	28 ml : 12 ml
80 %	32 ml : 8 ml
90 %	36 ml : 4 ml
100 %	40 ml : 0 ml

Figure 47: Concentration (Konzentrat) of expansion liquid for Rema® cc

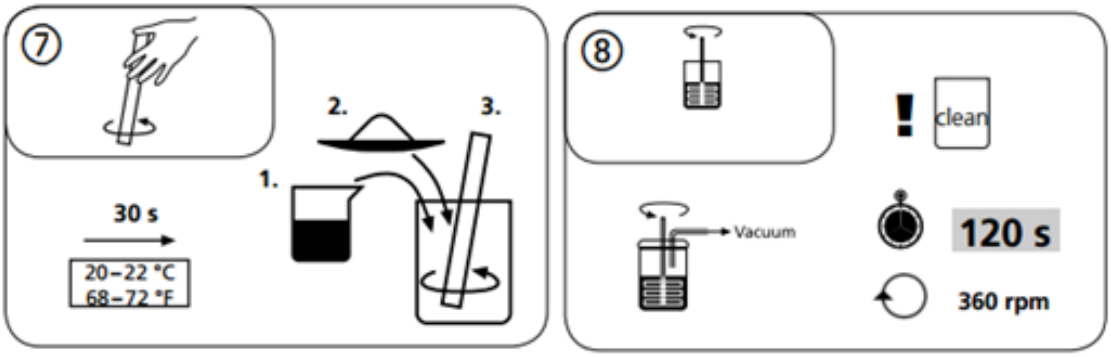


Figure 48: Mixing of the powder and liquid for Rema® cc

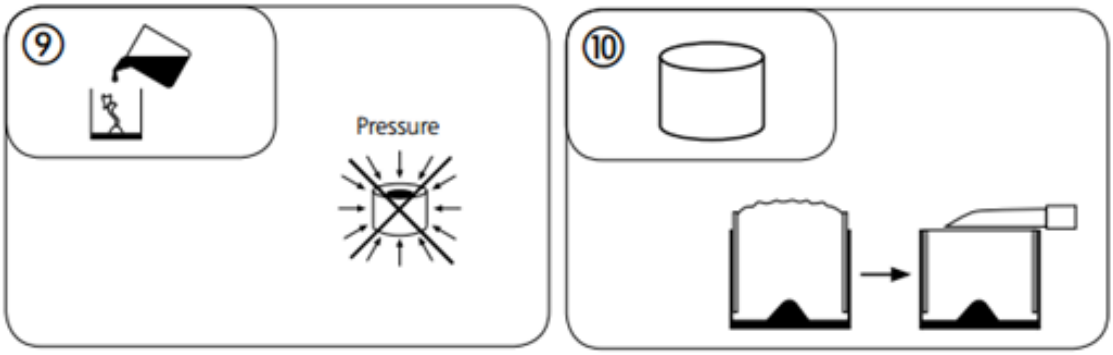


Figure 49: Investing process for Rema® cc

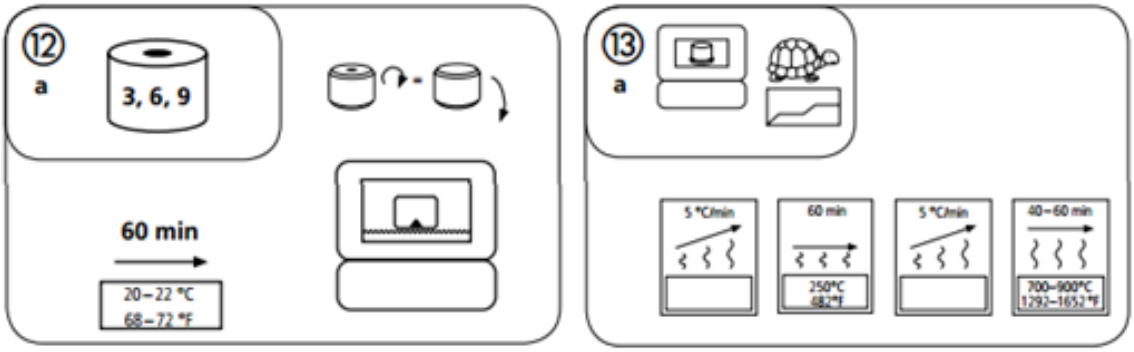


Figure 50: Conventional Wax burn-out procedure for Rema® cc

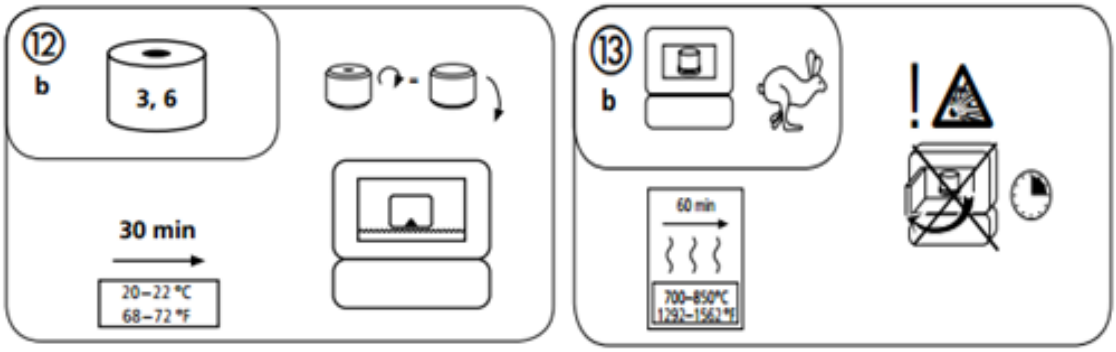


Figure 51: Speed wax burn-out procedure for Rema® cc

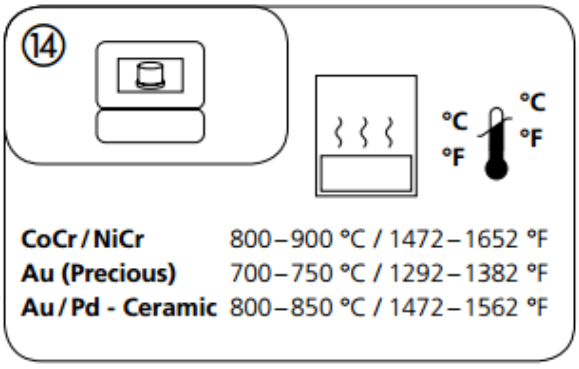


Figure 52: Final burn-out temperatures for the different casting metals and alloys

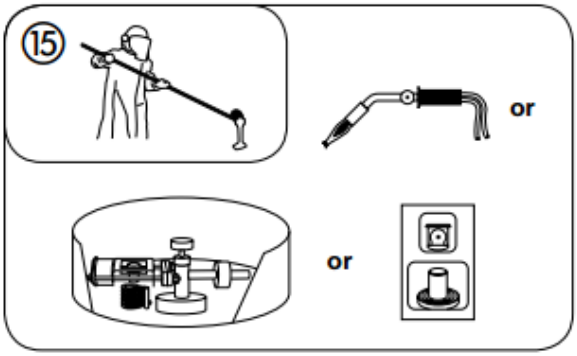


Figure 53: Casting process

(Either a centrifugal casting machine or an induction casting machine is used)

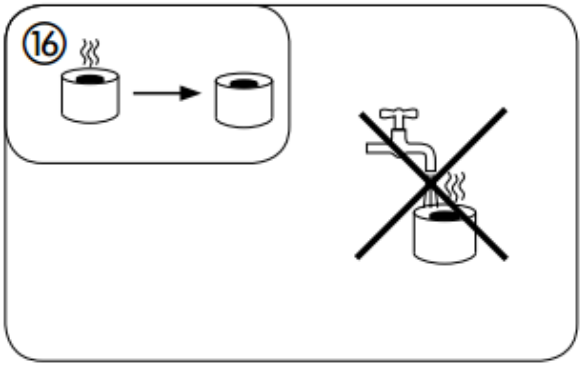


Figure 54: Bench cooling of mould

(Water should not be used to quench the mould)

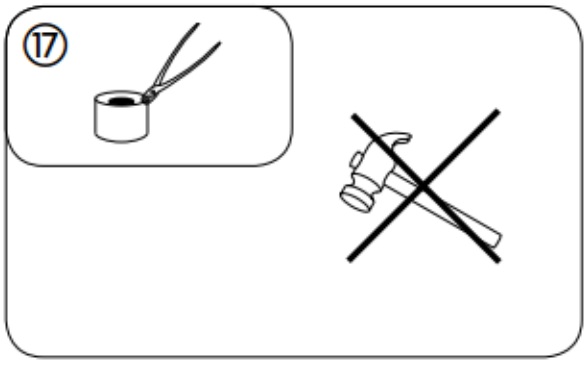


Figure 55: Procedure for divesting by use of forceps

(No undue force should be applied during the process)

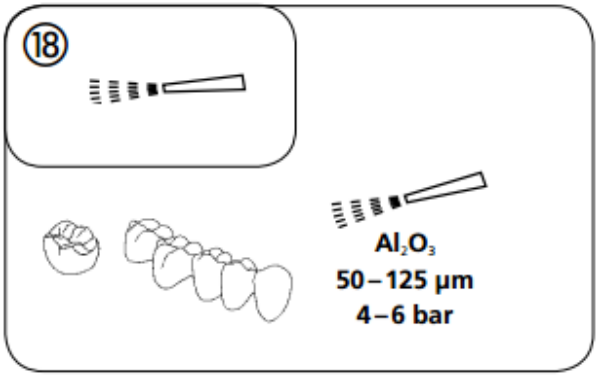


Figure 56: Sand-blasting procedure

(50 – 125 µm alumina particles at a pressure of 4 – 6 bar is used)

APPENDIX VI

Manufacturers' instructions for use of Wirofine® phosphate-bonded investment material

Wirofine® (BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, Bremen, Germany), is marketed as a "special investment material for partial dentures" [33].

The following are the instructions from the manufacturer's webpage entitled: "Wirofine® Special investment material for partial dentures" [33].

General Instructions

- Liquid: BegoSol® (storage and transport temperature: –10 °C to +35 °C / 14 °F to 95 °F).
- Before mixing, rinse out the clean mixing bowl with water and wipe off.
- Mixing bowls that are not clean or are dry withdraw moisture from the investment material.
- Processing width at 20 °C / 70 °F: approximately 2 minutes and 45 seconds.
- At higher room temperatures the working time will be reduced.
- The liquid is put first and then the powder is added.
- Mix thoroughly with a spatula by hand for 10 –15 seconds.
- Then proceed to mix for 60 seconds in a mixing unit under a vacuum, as far as possible. (Processing without mixer: mix for 2 minutes on the vibrator).

Duplication

- Duplication can be carried out in gel or in silicone moulds.
- When working with a pressure compaction unit, silicone moulds and the duplicate model must be made under the same conditions (2–4 bar).
- Duplicate in gel moulds only without pressure.
- Fill duplication mould on the vibrator and then remove it immediately from the vibrator.
- Removal: from gel moulds after 45 to 60 minutes, from silicone moulds after 30 – 60 minutes.

Table 13: Mixing of Wirofine® for duplication

(Adapted from the webpage "Wirofine® Special investment material for partial dentures") (33)

Mixing	Wirofine®	BegoSol®	Aqua dest.	Total liquid	Concentration of liquid
• For gel duplication (Castogel ®, Wirodouble®, WiroGel M) – without pressure					
Ratio	100 g			13 ml	
For 2 duplicate models	1 x 400 g	0 ml	52 ml	52 ml	0 % – 40 %*
		21 ml	31 ml		
• For silicone duplication (Wirosil®) – without pressure					
Ratio	100 g			15 ml	
For 2 duplicate models	1 x 400 g	0 ml	60 ml	60 ml	0 % – 40 %*
		24 ml	36 ml		
• For silicone duplication (Wirosil®) – with pressure (2 – 4 bar)					
Ratio	100 g			15 ml	
For 2 duplicate models	1 x 400 g	27 ml	33 ml	60 ml	45 %

* Duplication without pressure: 0 % to 40 % BegoSol®

Surface Treatment

Models duplicated in gel moulds are surface treated with Durol® or Durol E® whereas those duplicated using silicone moulds are surface treated using Durofluid® (33). The ecological dipping hardener Durol E® along with Durol® and Durofluid® are all products of BEGO Bremer Goldschlägerei Wilh. Herbst GmbH & Co. KG, (Bremen, Germany). Durol E® is free of solvents and is therefore biologically completely harmless. It has a hardening effect that is comparable to good conventional dipping hardeners. It has a fluid consistency, penetrates well and quickly, has a neutral odour, and can be easily removed with water (34).

Investment

- Before investing, prepare the wax-up with Wiropaint plus fine investment material or Aurofilm wetting agent while following the processing instructions for the products.
- Fill the mould ring on the vibrator.
- Then remove immediately from the vibrator.

- Setting time: at least 30 minutes.

Table 14: Mixing of Wirofine® for investment

(Adapted from the webpage "Wirofine® Special investment material for partial dentures") (33)

Mixing	Wirofine®	BegoSol®	Aqua dest.	Total liquid	Concentration of liquid
Ratio	100 g			15 ml	
For 1 mould	1 x 400 g	0 ml	60 ml	60 ml	0 %
		18 ml	42 ml		30 %*

* 30 % BegoSol® prevents cracks in the mould, which may occur due to rapid heating. As a rule, distilled water is used for mixing.

Wax burn-out procedure and casting after investment with Wirofine®

The moulds are inserted into the furnace at room temperature. The temperature of the furnace is then increased gradually at either 5 °C/min or 7 °C/min (depending on the size and number of moulds), up to a final temperature of between 950 –1050 °C (33).

The moulds are allowed to cool down after the casting process until they are warm to the touch. As in the handling of Bellavest® T moulds, Wirofine® moulds should also not be quenched in water. Investment materials contain quartz and so their dust should not be inhaled. There is danger of lung pathologies such as silicosis and lung cancer. To avoid dust during deflasking, the moulds are soaked in water after they have cooled down completely after casting until they are thoroughly moistened (33).

The instructions for use of Wirofine® are for the fabrication of a removable partial denture, hence the inclusion of the segment on duplication. Models for fixed partial dentures are not poured in investment material. They are also not duplicated in investment material and so, in this study, the "manufacturers'" instructions on the use of Wirofine® will be adhered to only as far as the procedures of investment are concerned.

The webpage for Wirofine® also has a disclaimer on the manufacturers' decision to withhold information about the exact contents of the material, and their freedom to subject the product to "constant further development" (33).

APPENDIX VII

Ethical Approval

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P O BOX 20723 Code 00202
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Telegrams: MEDSUP, Nairobi

Ref: KNH-ERC/A/126

12th April 2017

Dr. Silas Toka
V60/81100/2015
Dept.of Conservative and Prosthetic Dentistry
School of Dental Sciences
College of Health Sciences
University of Nairobi

Dear Dr.Toka

REVISED RESEARCH PROPOSAL- EFFECT OF PHOSPHATE-BONDED INVESTMENT MATERIALS AND THEIR MANIPULATION ON THE MARGINAL FIT OF CAST-METAL CROWN COPINGS (P122/03/2017)

This is to inform you that the KNH- UoN Ethics & Research Committee (KNH- UoN ERC) has reviewed and **approved** your above revised proposal. The approval period is from 12th April 2017 – 11th April 2018.

This approval is subject to compliance with the following requirements:

a) Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
b) All changes (amendments, deviations, violations etc) are submitted for review and approval by KNH-UoN ERC before implementation.
c) Death and life threatening problems and serious adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH-UoN ERC within 72 hours of notification.
d) Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH- UoN ERC within 72 hours.
e) Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (*Attach a comprehensive progress report to support the renewal*).
f) Clearance for export of biological specimens must be obtained from KNH- UoN ERC for each batch of shipment.
g) Submission of an *executive summary* report within 90 days upon completion of the study. This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/ or plagiarism.

For more details consult the KNH- UoN ERC website **http://www.erc.uonbi.ac.ke**

"Protect to Discover"

Yours sincerely,

PROF M. L. CHINDIA
SECRETARY, KNH-UoN ERC

c.c. The Principal, College of Health Sciences, UoN
The Director, CS, KNH
The Assistant Director, Health Information, KNH
The Chair, KNH-UoN ERC
Co-Principal Investigators: Prof Neil Poulter, Prof. Daniel T. Lackland
Co-investigators: Prof. Alta Schutte, Prof. Maciej Tomaszewski
Local co-investigator: Dr. Bernard Gitura

"Protect to Discover"

APPENDIX VIII

Ethical Approval Extension

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KENYATTA NATIONAL HOSPITAL
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Telegrams: MEDSUP, Nairobi

Ref. No.KNH/ERC/R/98

18th May 2018

Dr.Silas Mbeya Toka
Principal Investigator
Dept.of Conservative and Prosthetic Dentistry
School of Dental Sciences
College of Health Sciences
University of Nairobi

Dear Dr. Toka

Re: Approval of Annual Renewal - Effect of Phosphate-bonded investment materials and their manipulation on the marginal fit of cast-metal crown copings (P122/03/2017)

Refer to your communication dated 12th April 2018.

This is to acknowledge receipt of your study progress report and hereby grant you annual extension approval for ethics research protocol **P122/03/2017.**

The approval dates are 12th April 2018 – 11th April 2019.

This approval is subject to compliance with the following requirements:

a) Only approved documents (informed consents, study instruments, advertising materials etc) will be used.
b) All changes (amendments, deviations, violations etc) are submitted for review and approval by KNH/UoN ERC before implementation.
c) Death and life threatening problems and severe adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the KNH/UoN- ERC within 72 hours of notification.
d) Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH/UoN ERC within 72 hours.
e) Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. (*Attach a comprehensive progress report to support the renewal*).
f) Clearance for export of biological specimens must be obtained from KNH/UoN-Ethics & Research Committee for each batch of shipment.

g) Submission of an *executive summary* report within 90 days upon completion of the study
This information will form part of the data base that will be consulted in future when processing related research studies so as to minimize chances of study duplication and/or plagiarism.

For more details consult the KNH- UoN ERC website **http://www.erc.uonbi.ac.ke**

Yours sincerely,

PROF. M.L. CHINDIA
SECRETARY, KNH-UON ERC

c.c. The Principal, College of Health Sciences, UoN
The Deputy Director CS, KNH
The Chairperson, KNH-UoN ERC
The Dean, School of Dental Sciences, UoN
Supervisors: Dr.Simila Hazel Orengo, Dr. Nyaga James Muriithi, Dr.Mutave Regina James

APPENDIX IX

WORKPLAN

Schedule of Activities

ACTIVITY	**TIMELINE**
Proposal writing:	1st September, 2015 to 20th April, 2016
Submission of proposal for departmental approval	21st April, 2016
Re-submission of proposal for departmental approval	30th June, 2016
Submission of proposal for faculty approval:	28th July, 2016
Submission of proposal for ethical approval:	1st March, 2017
Data Collection:	1st May, 2017 to 30th June, 2017
Data analysis and report writing:	1st July, 2017 to 31st August 2017
Submission for supervisors' approval:	1st September, 2017
Submission to external examiner:	1st February, 2018
Thesis defence	May, 2018

APPENDIX X

BUDGET

Proposal Writing

ITEM	**NUMBER**	**UNIT COST (US $)**	**TOTAL (US $)**
Internet search for literature	7.5GB	20	20
Purchase of EndNote X3 (Reference Manager Program)	N/A	50	50
Printing and binding (proposal)	15 copies	4	60
Institutional Review Board Fees	N/A	50	50
Subtotal			180

Data Collection

ITEM	NUMBER	UNIT COST **(US $)**	TOTAL **(US $)**
D3300; Nikon Camera	1	383	383
Macro lens (Nikkor AF-S 105 mm f/2.8G IF-ED; Nikon USA)	1	996	996
Dolica tripod stand	1	610	610
Bellavest T® phosphate bonded investment material (160g pack)	4	3	12
Wirofine® phosphate bonded investment material (400g pack)	2	4	8

Castorit®-super C phosphate bonded investment material (150g pack)	4	2	8
Rema® cc phosphate bonded investment material (160g)	4	4	16
Fabrication of 70 cast-metal crown copings	70	10	700
Set of metal weights	1	10	10
Subtotal			2743

Data entry, analysis and report writing

ITEM	NUMBER	UNIT COST **(US $)**	TOTAL **(US $)**
On-screen calliper software (Iconico Inc.)		30	30
Statistician		300	300
Printing and binding of report	15 copies	20	300
Subtotal			630

Budget Summary

TOTAL	US $ 3,553
CONTINGENCIES (10% of the total)	US $ 356
GRAND TOTAL	**US $ 3,909**
SOURCE OF FUNDS	Self