UNIVERSITY OF NAIROBI
FACULTY OF HEALTH SCIENCES
DEPARTMENT OF DENTAL SCIENCES

EVALUATION OF FIT OF A SINGLE CROWN AND THREE - UNIT FIXED DENTAL PROSTHESES FABRICATED FROM CONVENTIONAL AND DIGITAL IMPRESSIONS IN NAIROBI, KENYA

MDS (Prosthodontics) Thesis

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V60/35289/2019

A thesis submitted in partial fulfilment of the requirements for the award of the Degree of Master of Dental Surgery in Prosthodontics at the Department of Dental Surgery, University of Nairobi

JULY 2023

DECLARATION AND SUPERVISORS' APPROVAL

This thesis is my original work. I also affirm that to the best of my knowledge; this has not been presented for a degree in any other university.

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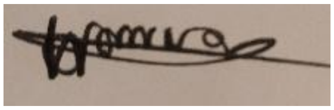

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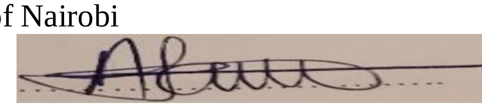

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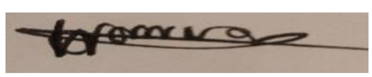
Signature:  ……………………………... Date: 26th July 2023………………...

DEDICATION

This Research project is dedicated to my Husband Eng. Frank David and my daughter Zuri Claire David who have been very patient and supportive as I undertook this project. It is also dedicated to the Late Dr. Catherine Gichangi one of my Supervisors who had immense contribution to this proposal but sadly passed on before its Completion.

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DEFINITION OF TERMS

Accuracy	Closeness of a measurement to the actual value, and to precision.
Marginal Fit	In fixed dental prostheses marginal fit is defined as the size of the gap between the margin of the restoration and finish line of the prepared tooth at a specific point of measurement.
Overall fit	This is the average fit of the restoration on all measured points.
Fit	Is determined by the marginal fit and overall fit values.
Conventional Impressions	Impressions where elastomeric materials and casts of stone replicas are used to copy the detailed surface shape of a prepared tooth and its relationship with the adjacent teeth and soft tissue.
Digital Impressions	Impressions generated by scanning the stone cast fabricated through directly scanning the prepared tooth using an intraoral scanner.
Dental Restorations	The process of repairing a damaged tooth (or teeth) by reinstituting it back to its normal appearance and function using single or multiple prosthesis.
Failure	Loss of prostheses in need of replacement.
Long Span Restorations	Long-span restorations entail the replacement of two or more teeth.
Span	Total number of units present on a fixed partial denture.
Success	Prostheses where restored teeth remain intact free from clinical signs of deterioration.

ABBREVIATIONS

ADA	American Dental Association
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
CEREC	Chairside Economical Restoration of Esthetic Ceramics
CS	Carestream 3600 digital scanner
DS	Dental Wings digital scanner
FPDS	Fixed Partial Dentures
LED	Light Emitting Diode
MIP	**M**aximum Intercuspation
M500	Medit i500 digital scanner
M700	Medit i700 digital scanner
PMMA	Polymethylmethacrylate
PVS	Polyvinylsiloxane
SC	Single Crowns
SIT	Segmental Impression Technique
SLM	Selective Laser Melting
SPSS	Statistical Package for Social Sciences
3D	Three dimensional

ABSTRACT

Background: There's hardly much evidence regarding the marginal fit of fixed partial denture restorations fabricated with digital impressions and computer-aided manufacturing and design technology as compared to conventional techniques.

Objective: To evaluate the fit of single crown and three-unit fixed dental prostheses fabricated from digital and conventional impressions.

Study design: A laboratory-based, analytical cross-sectional design.

Study setting: Prime Dental Studios, a private dental laboratory in Nairobi, Kenya.

Study population: Seventy-five zirconia restorations produced from a typodont model with tooth preparations for 25 single crowns and 25 three-unit fixed dental prostheses. Polyether impressions and four digital impressions – Dental Wings (DW), Carestream 3600 (CS), Medit i700 (M700) and Medit i500 (M500).

Materials and methods: On the maxillary typodont model, tooth preparation for a conventional all ceramic crowns was done on the left central incisor (single unit). Another preparation was made on the left first premolar and first molar for a three-unit fixed dental prosthesis to replace a missing second premolar. In the digital impression group, the crowns were fabricated by using simulated intraoral scans and CAD/CAM technologies without definitive casts. In the conventional group, impressions were taken using polyether mono-phase impression material in a special tray. The impressions were then used to fabricate stone casts that were scanned using an intra oral scanner. The stereolithography (STL) files were exported to a computer connected to the scanner as the conventional group. The STL files were used to produce zirconia FDP frameworks with CAD-CAM. These frameworks were placed on the standard model and evaluated

for marginal fit. Six measurement sites were evaluated five times for each prostheses unit, thus 90 observations for each of five impression techniques, resulting in a sample size of 450.

Data analysis: Quantitative data was entered into Microsoft excel sheet. Data was cleaned and analyzed using STATA, version 16 (Stata Corp LLC College Station, Texas 77845 USA). Descriptively, marginal fit determined by marginal gap measurements were summarized as means and their corresponding standard deviations, and medians and interquartile range. Independent student *t*-test, One Way Analysis of Variance (ANOVA), Kruskal Wallis test followed by Tukey's and Dunn's post hoc tests respectively, were performed for inferential statistical analysis and hypothesis testing. A p-value of <0.05 was considered significant.

Results: Conventional impressions produced single crown restorations with mean marginal gap measurements of 151.3±60.1µm and three-unit fixed restorations with mean marginal and overall gap measurements of 153.9±50.1µm. Nonetheless, there was no statistically significant difference in the marginal gap measurements of the single crown and three unit fixed dental prostheses (t=-0.22, p=0.825, 95% CI -26.5, 21.2). **DW** scanner produced single crown restorations with mean marginal gap measurements of 185.0±63.7µm and three-unit fixed restorations with mean marginal and overall gap measurements of 224.2±81.7µm. Significant differences were observed in the marginal gap measurements of the single crown and three unit fixed dental prostheses (t=-2.30, p=0.024, 95% CI -73, -5.3). **CS** scanner produced single crown restorations with mean marginal gap measurements of 177.1±81.3 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 146.4±44.9µm. Significant differences were observed in the marginal gap measurements of the single crown and three unit fixed dental prostheses (t=2.31, p=0.023, 95% CI 4.3, 57.1). **M700** scanner produced single crown restorations with mean marginal gap measurements of 158.0±48.7µm and three-unit fixed restorations with mean marginal and overall gap measurements of 184.3±86.2µm. However, there was no statistically significant difference in the marginal gap measurements of the single crown and three unit fixed dental prostheses (t=-1.55, p=0.124, 95% CI -60.1, 7.4). **M500** scanner produced single crown restorations with mean marginal gap measurements of 195.9±61.7µm and three-unit fixed restorations with mean marginal and overall gap measurements of 202.8±71.1µm. However, there was no statistically significant difference in the marginal gap measurements of the single crown and three unit fixed dental prostheses (t=-0.45, p=0.652, 95% CI -37.2, 23.4).

The overall fit of the three-unit prosthesis was significantly different among the five impression methods, both digital and conventional (F=13.52, χ^2=46.64, p<0.001) and among the four digital methods (F=12.32, p<0.001). Dunn's post hoc test showed that the difference in overall fit between the conventional and digital impression methods was statistically significant between polyether and three digital methods (DW – p<0.001, M700 – p=0.02 and M500<0.001) but not CS. Tukey's post hoc test showed that the difference in overall fit among the digital impression methods was statistically significant between Carestream and the other three digital methods (DW – p<0.001, M700 – p=0.024 and M500 – p<0.001) and Dental Wings and M700 (p=0.016). The marginal fit of the single crown prosthesis was significantly different among the five impression methods, both digital and conventional (F=2.54, p=0.042, χ^2=14.68, p=0.005) but not among the four digital methods (F=1.83, p=0.146). Dunn's post hoc

test showed that the difference in marginal fit between the conventional and digital impression methods was statistically significant between polyether and two digital methods (DW – $p<0.01$ and M500 – $p<0.001$) but not CS or M700.

Conclusion: Conventional impressions produced restorations within clinically acceptable marginal gap limits of approximately 150µm for both single crowns and three-unit fixed dental prostheses. Carestream produced restorations within clinically acceptable marginal and overall gap limits of approximately 150µm for three-unit fixed dental prostheses. Medit700 produced restorations within clinically acceptable marginal gap limits of approximately 150µm for single crown prostheses. Significant differences were observed between the conventional and digital impression techniques, which were dependent on the specific technique and possibly user experience.

CHAPTER ONE

1. INTRODUCTION

1.1 Digital Innovations in Dentistry

The evolutionary process of the science and technology of dentistry has been gradual and steady, steered primarily by technological innovations and new treatment protocols and methods that challenge conventional approaches [1]. Whereas these innovations were few and periodically far apart; the recent explosion in digital technology, software, scanning and manufacturing capabilities has resulted in an unparalleled revolution in all fields of dentistry. In the last few decades, a paradigm shift in how fixed prosthodontics is carried out has been witnessed [2].

For instance, in classical dental practice, dental impressions entail use of a full or half-arched metal, silicone or plastic impression tray. However, with the recent technological advancement, new techniques for digital impressions and manipulation of digital data for diagnosis, treatment and production of restorations have emerged [3]. Examples of these computerized digital technologies include digital cast scanners, intraoral digital impression-capture devices, cone beam computerized tomography, three dimensional (3-D) printers, laser sintering units and milling machines [4]. These digital technologies have and continue to affect the profession of dentistry in profound ways. Patients like these technologies, as it minimizes the discomfort associated with traditional impressions[3]. Moreover, these technologies minimize chair and office time, making the office significantly more efficient, reducing remakes, reducing seating time for restorations and lower laboratory billings. Generally, the transition to the new technologies has led to improvements in the quality of oral care, better patient experience and improved productivity and economics of the dental practice [5].

Predicting the future is difficult, but the recent trends and developments can serve as a guide to speculation. Technology in most global sectors is advancing exponentially, including numerous exciting dental technologies. The developments are expected to continue given the associated decreasing cost of processing power.

1.2 Digital Advances in Prosthodontics

Digital technology has profoundly impacted various operative principles within the dental profession. Impression capture, imaging and surgical techniques, model processing and production of indirect restorations employ modern digital processes. In Orthodontic and Prosthodontic practice, it can be predicted that in the not-too-distant future, the art of generating conventional impressions to produce gypsum models and dies may become non-essential, replaced by digital methods [4].

Generally, dental restoration involves the process of repairing a damaged tooth, with the aim of restoring it back to its normal appearance and function [6]. The restorative process typically requires high level accuracy and precision of the prepared tooth. A conventional impression based on elastomeric impression materials and casts of stone replicas are used to copy the detailed surface shape of the prepared tooth and its relationship with the adjacent teeth as well as soft tissue [1]. This conventional impression method has been widely investigated and is considered the baseline for the accurate and reliable information pertaining to patients' intraoral conditions [7, 8]. However, under this conventional approach the impression should be disinfected, shipped to a dental laboratory, poured in dental stone and trimmed before the technician can begin the manufacturing process of a restoration. As a result, the conventional impressions are associated with laborious procedures, which can cause inaccuracies in the final restoration [9].

Digital impressions are generated either by scanning the stone cast fabricated or through directly scanning the prepared tooth using an intraoral scanner [6]. The intraoral scanner is a 3D device capable of detecting dental impressions, through first acquisition of a large number of images and then the subsequent processing using dedicated software [10]. Under this technique, restorations may be directly fabricated through computer-aided design and computer-aided manufacturing using the digital impression, allowing the restoration of the damaged tooth in a short period. Additionally, the digital workflow may involve, transferring the scanned data electronically, fabricating the physical master cast model and making the restorations in a dental laboratory, which eliminates the need for the conventional impression and manual fabrication of master cast stone mode [11].

1.3 Comparison of Prosthodontics Treatment Outcomes Using Conventional and Digital techniques

The internal and marginal fit of restorations is key to the long-term function of fixed partial dentures in an oral environment. An ideal marginal fit helps maintain gingival health and hinders the dissolution of the luting cement which may render the exposed tooth surface prone to dental caries[1]. An excellent internal fit increases the resistance of restorations to horizontal and vertical forces opposite to the path of insertion, which may lead to dislodgement. The precise fit of an implant-supported fixed prosthesis is critical to its long-term clinical success because any discrepancy between the abutment and restoration allows bacteria to adhere, resulting in inflammation of the soft tissues around the implant and subsequent biological complications[10].

Studies have evaluated the fit of crowns and fixed partial dentures, but controversy still exists on the marginal fit of restorations manufactured by recently introduced digital technologies. For instance, Kim et al. reported that the marginal fit of selective laser melting (SLM), an example of digital technique appeared significantly inferior compared to the conventional lost-wax method. However, Pomp ET al.[12] found that the marginal fit of 4-unit cobalt-chromium frameworks was superior when fabricated with SLM versus the conventional technique. Furthermore, the effect of span length on the accuracy of restorations by conventional or digital techniques is unclear. Due to the relative novelty of this technique, a lot remains to be evaluated to determine its success potential. Globally, available data spans back to less than two decades. In our East Africa, there is hardly any information on the uptake and success of digital dental restoration fabrication. This presents an opportunity for investigation that may provide useful reference information.

From the aforementioned, it is clear that digital advances in dentistry are relatively new concepts and information on the same remains scarce. Specifically, certain aspects of the marginal fit of prostheses fabricated using conventional versus digital impressions have not been adequately answered. These include: the preferred intraoral scanner and the effect of the span length of the prosthesis on the accuracy of fit. Therefore, the purpose of this study was to evaluate the marginal and overall fit of single crown and three-unit fixed dental restorations fabricated using conventional and digital impression techniques in Nairobi, Kenya.

1.4 Summary and Thesis Structure

The importance of obtaining fixed dental restorations with precise marginal and overall fit cannot be over emphasized. Moreover, emerging information seems to indicate that another key factor may be the type of fabrication technique used, that is, conventional or digital. As it stands, little evidence is available to provide conclusive insights as to whether there is a significant difference between the two techniques with regards to the marginal and overall fit of the restorations. In Kenya, and indeed the East Africa, there is no information on the usage and outcome of the digital techniques.

Therefore, the aim of this study is to evaluate the marginal and overall fit of single crowns and three - unit fixed dental prostheses fabricated from conventional or digital impression techniques in Nairobi, Kenya.

This thesis is presented in sections as follows:

a) Review of literature to identify the research gap
b) Statement of the problem and justification of the study
c) Description of the materials and methods
d) Presentation of the results
e) Discussion, conclusion and recommendations

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

There are many clinical steps that will influence the accuracy of final restorations. Each step can create a variable that may increase the chances of the inaccuracy of the result. The procedures and materials involved in the conventional method and the digital methods of impression making are also factors that play a role in determining the accuracy of the final restoration.

The purpose of this chapter is to critically review the clinical and laboratory processes in prosthodontics and to provide detailed information regarding conventional and digital impression techniques. This will elicit the research gap, laying a foundation to justify the need for this study.

2.2 Clinical and Laboratory Processes in Prosthodontics Treatment

Throughout history of dentistry, dental practitioners have strived to create dental restorations that are both esthetically pleasing and function properly within reasonable limits. Multiple factors determine how therapeutic the restorations are and how long they last. One of the main factors affecting longevity of dental restoration is marginal adaptation or how well it fits the tooth [8]. When a prosthetic restoration does not fit properly, this can lead to plaque accumulation and consequently, micro leakage and subsequent endodontic pathology.

The marginal fit of a restoration is determined by various factors such as the type of fabrication technique used; the number of units in the substructure; the tooth's location and quality of preparation; the rigidity of the impression material, the type and thickness of the luting agent [1].

Prosthetic restorations can be made using conventional or digital techniques. Metal-ceramic crowns are still the most common full coverage crowns and FPDs. The lost-wax technique is also another classic conventional technique. However, these techniques have several disadvantages such as possible distortion of the wax patterns, imperfections in the cast metal, and employing complicated and time-consuming procedures. New CAD/CAM materials and processes such as milling have countered these disadvantages as the materials are strong and insensitive to thermal variations, quick to produce and dimensionally accurate. In the CAD/CAM milling system, CAD is used to design a pre-production digital frame, which is then manufactured (CAM) using this CAD data.[12]

2.3 Impression Accuracy

The term accuracy refers to trueness, describing the closeness of a measurement to the actual value, and to precision [13]. An accurate impression is fundamental to a successful outcome in prosthodontics. The accuracy of the impression affects the accuracy of the working cast, and an accurate working cast is essential to fabricate a clinically acceptable prosthesis. Impression and cast accuracy is influenced by the selection of impression materials, impression technique, operator skill, attention to detail, and production process of the working cast [6]. Different impression techniques have been adapted from traditional prosthodontics but were modified with time in order to capture excellent surface details of the abutment. The goal of taking impressions is to achieve accurate 3-dimensional reproduction of the abutment tooth surface in relation to other oral structures [14].

Impressions for crown and bridge (fixed partial dentures) present unique challenges to the restorative dentist and errors can be introduced in many ways. Common sources of error in fixed partial dentures include improperly seated impressions, dimensional changes of the impression material and miscast on models among others. Table 1 displays the potential sources of error associated with the use of conventional and digital impression techniques.

Table 2.1: Potential Sources of Error[18]

Conventional Impressions	**Digital Impressions**
Improperly seated impression tray	Unseated scanner
Deformation of impression material	Limitation in accuracy of digital intra-oral scanner
Dimensional change of impression material	Error introduced via the registration algorithm used to convert scan data to digital impression
Error due to manipulation of impression with closed tray technique	Error introduced during conversion of digital impression to digital model
Micro movement of impression coping during attachment of analogue. (For dental implants)	Error introduced during fabrication (milling process) of working cast

[19, 20] Studies evaluating impression accuracy are often contradictory. One contributing factor to this lack of consensus is the variety of methods or approaches used to evaluate impression and working cast accuracy.

Impression accuracy, as reflected by the distortion of the working cast compared to the master cast (simulated patient) can be measured as either absolute or relative terms. An absolute distortion measurement requires an external reference point to be used for each scan, while a relative distortion measurement uses the location of the restorations references and focuses on the inter-restoration relationship [19]. The accuracy of this spatial relationship between restorations is crucial to fabricate clinically acceptable prostheses and directly impacts the amount of strain present in the prosthesis-restoration-bone complex [20]. This parameter can be evaluated by measuring the relative distortion of working casts, reflected by the changes of inter-restoration distance and angulation when compared to the master cast.

In the past, two-dimensional evaluation comparing master and working casts could be performed using a microscope and profile projector or digital photography [14,21]; however, the majority of studies today attempt to evaluate working cast accuracy in three-dimensions. Three-dimensional measurements involve the measurement of the displacement of a point in all three axes, which can be compared individually per axis or used to calculate a 3-D vector. The distance between any two points is called the 3-D vector magnitude. 3-D vectors are a practical way to measure discrepancies in analogue relations, and can be measured to great accuracy using a variety of scanning approaches.

Computer-aided microscopes [20, 22], contact scanners [6], white light scanners [23, 24] or surface laser scanners [25, 26] have all been used with consistent results. The 3Shape laser scanner (D810 3D scanner, 3Shape, Denmark) is one such machine that is capable of scanning casts and impressions to accuracy of 8µm in all dimensions according to the manufacturer, and has been used to measure restorative impression accuracy in several recent studies [25].

Once the casts or impressions are scanned and digitized, specific software can be used to produce 3D coordinate systems, detailed measurements and image overlays. One option is to use professional quality control or inspection software adapted from industry, which has been designed to make such comparisons and measurements of the digitized data (e.g. 3Shape Convince, 3Shape, Denmark).

An alternate approach is to examine the fit of a framework fabricated on the master cast on each impression-generated working cast. This can be done using a clinical approach, like the one-screw test for passivity [27], or by taking more objective measurements via strain gauges or optical scanning [28]. A clinical approach such as the visual inspection of framework misfit or the one-screw test for passivity is only able to provide binary data (passive versus non passive) and does not quantify the degree of misfit should any be present. Strain gauge measurement of framework misfit provides more objective data, however it is difficult to extrapolate the clinical significance of strain measurements from an in vitro model to a biological setting.

Good marginal fit is one of the most important factors in improving the prognosis of the prosthetic restoration. Each of the impression manufacturing phases alters the dimensions and the fit of the final restoration. While there are studies that have sought to compare impression accuracy under conventional and digital techniques, much of the evidence has been inconclusive. It is against this backdrop that this study seeks to fill the gap by assessing differences in the marginal fit of short-span and long-span restorations fabricated from conventional and digital impressions.

2.4 Conventional Impressions

Restorative dentists have an array of impression materials and techniques from which they can choose when making impressions in fixed prosthodontics, and operative dentistry. With handling and choice of impression materials, accurate reconstructions can be made [29]. This section will cover a review of the trays, materials, and techniques used in conventional impressions.

2.4.1 Impression Materials

Despite the partial usage of some reversible hydrocolloids, synthetic elastomers are the materials commonly used in conventional impressions. They include polysulfide's, which were introduced in 1955, condensation silicones (Type I Silicones) introduced in 1958, polyether in 1966 and addition silicones (Type II Silicones) in 1976 [29].

The most common synthetic elastomers used in Conventional impressions include: condensation silicones, addition silicones polyvinylsiloxane (PVS), polysulfide rubber and polyether impression materials. Special attention is given to PVS materials as they are the most widely used in restorative dentistry today [29]. PVS materials meet the accuracy requirements of the American Dental Association (ADA) Specification #19 of having the best capability of fabricating precision castings to a fine detail of 25 micrometers and less. They additionally have the best elastic recovery at 99% (ability to readily flow to undercut areas, set and rebound to original shapes when removed from the mouth) [30]. This together with its exceptional dimensional stability (can be poured at the convenience of the dentist) makes it good for accurate second pours and makes PVS materials efficient as they can be poured at any time [29].

PVS materials have one disadvantage that on interaction with latex material, polymerization is inhibited or prevented from polymerizing [30]. This may occur if latex gloves are worn during the mixing of putty materials [31]. To prevent its occurrence, the use of vinyl and synthetic latex gloves, is advised since they do not inhibit polymerization [30].

Condensation Silicones and polysulfide rubber have a lower dimensional stability as they usually produce ethyl alcohol and water respectively, volatile by-products that cause the distortion of set impression when they evaporate from its surface. They should therefore not exceed more than half an hour before they are poured after removal. Polyether, on the other hand, absorbs atmospheric water vapor causing swelling as others shrink as a factor in the release of volatile compounds and polymerization which all result in distortion. It is therefore often recommended that polyether impression materials should be poured within an hour after removal [29].

Most of the modern PVS materials are thixotropic which means that they have good flow and flexibility [31]. Polyether is however a little bit more rigid making it hard when making thin preparations of teeth affected by periodontal disease, particularly when patients had existent crowns or bridges and wide gingival embrasures from the recession and bone loss. As a result, some of the common problems from this rigidity have included the fracture of gypsum dies and the tearing of the polyether when being removed. In such kinds of situations, it was therefore often advised that more flexible materials be used and that the undercuts be blocked with utility wax before the impressions are made[33].

Although PVS materials are also rigid, they meet the recommended threshold below problems with dies and fractures. These are therefore significant when making dual arch impressions [33]. PVS materials are also hydrophilic if surfactants are incorporated in the formulation but not as much as polyether. On cost, in comparison to other elastomers, PVS and polyether are the most expensive. However, this should be disregarded as costs have minimal consequence on impression making [29].

In this section the properties of various impression materials have been discussed. The discussion shows that accurate impressions depend on identifying the applications that do or do not fit each material's characteristics. Materials used without adequate knowledge of their characteristics can impair a successful outcome.

2.4.2 Impression Trays

The conventional impression demands the use of custom trays that are more efficient and comfortable for use by patients as compared to stock trays. The old polysulfide rubber materials and some reversible hydrocolloids (agar) required the use of bulky water-cooled trays [33].

Impression materials need to readily flow into the minute details of the cavity preparations to accurately capture grooves, cervical margins, and pinholes. Heavy body tray materials have to be used to force materials with lower viscosities to effectively flow into the gingival sulcus[39].

Custom trays have been particularly recommended when making full-arch impressions with multiple preparations as opposed to dual arch impressions using triple tray, which use minimal amounts of impression materials and limits the need for opposing arch impressions[32]. Custom trays are also more accurate than stock trays as well as more comfortable for use on patients. Custom trays are furthermore more cost effective as they use sufficiently less material making significant savings while reducing the number of remakes. Plastic stock trays, metal trays, full or partial trays have been associated with numerous deficiencies in impression making due to minimal control of bulky impression materials [39].

As seen in this discussion, when making a final impression, the goal is to make an accurate and exact replica of the soft and hard tissues as possible. The impression must be able to be used to create a master cast that will exhibit these same characteristics.

There is also general agreement among dental practitioners that impressions made using custom tray are necessary to achieve the desired goals of a final impression and master cast.

2.4.3 Management of Soft Tissues

For the purpose of making a high-quality impression, preparation margins have to be visually clear. Margins are however often sub gingival making capturing them a challenge. There are a number of retraction techniques that are available with the most common being the use of retraction cords, laser, chemical agents, and electro surgery [34].

Retraction is done before impressions are taken particularly in cases where gingiva is an impediment to the effective record of the complete tooth surface[35]. Gingival retraction is hence used to temporarily move the gingiva. The most prevalent method of retraction is the use of retraction cords, cords are available in different sizes, and they could be used as single or double cords. Retraction cords have to be removed from the sulci before the injection of impression materials around the tray.

When chemical retraction is used, careful attention has to be considered to prevent contamination of impressions material with sulfur containing gingival retraction chemicals as they will promote the inhibition of polymerization [36]. This mechanism of polymerization inhibition is thought to result from the reaction of chloroplatinic acid catalyst from PVS material with sulfur. Therefore, profuse washing of chemical is necessary before impression making [37].

In summary, periodontal factors are closely related to the quality of the marginal fit of a restoration, which in turn is closely related to impression taking. The quality of the impression, however, is directly influenced by clinical parameters such as location of the finish line, periodontal health, and sulcus bleeding during impression taking. In cases where the finish line is located sub gingival, tissue retraction is deemed mandatory prior to impression taking in order to clearly expose the prepared surfaces of the tooth.

2.4.4 Impression Techniques

The transfer of accurate impressions of the patients' soft and hard tissue for processing in dental laboratory is an important process [38]. There are some impressions techniques used in the making of fixed prosthesis. For instance, the single-step technique which is currently mostly used where impression materials of two different viscosities applied and allowed to set at the same time, the double step technique where impression is made in two stages using materials of different viscosities, the monophase technique whereby the impression materials used have single viscosity, and the single copper band technique [39]. Because impressions record both the soft tissue and teeth, it is also based on an understanding of the anatomy of soft tissues for the purpose of effective tissue preparation. This helps in the creation of decipherable and accurate impression [40].

Putty/Wash Impression Techniques

Putty/wash techniques are done either in two steps or one step. The first approach is the most acceptable and appropriate as the second has some potential drawbacks. The first and best approach requires the need for using putty materials for the fabrication of the custom trays with polymethylmethacrylate (PMMA) and light-cure materials. Putty impressions are often made in stock trays to make customized PVS trays. Often, a layer of base plate wax is used as a spacer over the diagnostic cast. Wax removal from non-functioning cusps on the other hand allows for the provision of occlusal stops [41].

Putty materials are advised to be used in control and in appropriate manners to create impressions with optimal accuracy[41]. Putty materials are often unable to reproduce fine details as they do not have the necessary required low viscosities to record fine details of up to the 25-µm level, they are instead only able to record required only to record detail of 75 µm. Another deficiency of putty materials is that they record critical areas of tooth preparation like cervical margins, which have a deleterious effect on the gypsum dye [42].

The second approach uses a relieved pre-operative putty impression made intra-orally. Plastic sheets have to be placed on teeth to prevent the enclosing of impression material into gingival embrasures. Impression materials are removed with a scalpel or a bar in the regions where the teeth are to be prepared as the impression is refined with PVS materials of lower viscosities or 'washed'[43]. The approach is often never quite successful as it has two drawbacks; first, limiting wash materials to the region of relieved impression is difficult as well as the fact that some wash materials often enter unrelieved impressions causing inaccurate occlusal patterns on the resultant cast. The 'washing' of the entire impression may hence be recommended which in essence poses the potential problem of the hydraulic distortion of the used putty material hence a deleterious effect on the precision of the impression [42].

A third approach is also referred to as ‘simultaneous’ or as the ‘squash’ technique. It involves the loading of a stock tray with putty material as the injectable material is squirted on prepared teeth. Putty trays are then pressed on the injected materials to set the putty material. This third approach is not preferred as it is difficult to control the thickness of the impression material. It is also impossible to control which material should record the margin details of the preparation hence not recommended [42].

Dual-Arch Impression Technique

The dual arch or double-bite impression techniques (using triple tray) are recommended for use when one or two posterior teeth have to be prepared for indirect restorations[44]. The dual-arch impression techniques capture the prepared teeth, the occlusal articulation in MIP (maximum intercuspation) and the opposing arch simultaneously [45]. By some studies, it has been demonstrated that this technique can provide accurate fabrication restorations through the use of confirmation maxilla-mandibular relation [44]. Its advantages include accurate recording of the MIP position and clinical simplicity. It can also be used with the closed-mouth technique to eliminate mandibular flexure associated with opening. Despite the fact that its laboratory procedures are a little bit complicated, technicians can handle once understood [46].

Segmental Impression Technique (SIT)

This is used for the preparation of simultaneous impressions of many teeth. The SIT can make successful impressions of multiple prepared teeth despite the inherent limits of moisture control maintenance and working time which make the process difficult in spite of the progress made on auto-mix systems and materials used [47]. It can be used with any impression material, but auto-mixed PVS materials are recommended.

The technique breaks down the arch to be impressed into smaller segments that are easily managed with the diagnostic casts in each segment fabricated with their own individual customized trays. A wax relief of 1 mm is provided as the trays are allowed to go past the 3 mm of the gingival margin of the teeth that have been prepared. This is significant because the gingival tissues have to prevent the over-seating of the trays and also because it has no occlusal stops [48]. The trays are made using PVS putty material and PMM acrylic resin, these can be individually made or as a single tray sectioned with a scalpel or disc. The individual trays should be able to simultaneously seat on the cast. Low viscosity materials are then loaded onto syringes and a segmental tray. This procedure is usually repeated for each of the different segments till all the segmental impressions are in place. SIT has proven effective particularly in cases where moisture control is tasking [46].

When looking into a conventional impression, one sees a negative image of the tooth preparations. It is difficult, if not sometimes impossible, to critically evaluate the quality of a preparation simply by looking at the negative of the preparation. When using conventional impression materials, one can only accurately evaluate the quality of the impression itself. It thus raises the question whether or not the margins adequately captured.

2.5 Digital Impressions

Computerization, laser technologies, optics, and miniaturization technological advances have enabled the capturing of dental impressions. Three-dimensional (3-D) digitizing scanners have been in use for more than 20 years for the acquisition of virtual impressions[1]. Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM), a special dental technique is responsible for the transfer of digital scans of the intraoral cavities to the milling unit. These systems can carve restorations from blocks of different materials without the need to obtain physical impression of target and opposing arch [37]. Currently, new esthetic and high-strength ceramic restorative materials like zirconia are developed in laboratories whereby master casts are poured from conventional impressions and then digitally scanned for the creation of stereo lithic models for the construction of restorations, replacing the conventional layering technique [42].

2.5.1 Scanning Systems

These systems allow for "one day or one appointment" dentistry. The patient receives the final restoration in one appointment. This category currently consists of the PlanScan (Planmeca Oy, Helsinki, Finland), the Chairside Economical Restoration of Esthetic Ceramics (CEREC) 3D BlueCam and OmniCam (Sirona, Bensheim, Germany), as well as the Carestream (CS) 3500 (Carestream Dental, Atlanta, Georgia, USA)[1]. A summary of some commercially available systems and their specifications are described herein.

The iTero (Align Technology, Redwood City, California, USA) digital impression scanner utilizes parallel confocal imaging technology to capture a color 3D digital impression of the tooth surfaces, contours, and surrounding gingival tissue [1]. The system captures up to 3.5 million data points per arch scan[47.] The scanner has the ability to capture preparations for crowns, bridges, inlays, and onlays. During scanning, a series of visual and verbal prompts are given that are customized for the patient being treated and guide the clinician through the scanning process[48]. For each preparation, a facial, lingual, mesio-proximal, and disto-proximal view is recorded in approximately 15–20 seconds, after which the adjacent teeth are scanned from the facial and lingual aspects[49].

The 3M True Definition Scanner (Midmark Incorporation, Dayton, Ohio, USA) is a digital scanning system only; however, similar to the iTero scanner, it is an open platform system offering the ability to connect to a certified design software and chair side milling machine[50]. Unlike the confocal imaging of the iTero system, the 3M system uses a blue Light Emitting Diode (LED) light and an active wave front sampling video imaging system to capture the data and create a virtual cast[51]. The clinical technique used with the 3M system requires proper isolation of the desired area to be captured as well as a light dusting of the teeth with a specific titanium oxide powder. This digital impression technique has been shown to be very accurate [52].

The CEREC Acquisition Center (AC) (Sirona, Bensheim, Germany) digital impression system with BlueCam, brought to the market in 2009, has some improved technologies over the older RedCam system. The improvements include an image-capturing system that automatically determines the focus on the subject and instantly saves the image, eliminating the need for the clinician to click a button or pedal to acquire the image as was the case with the RedCam. Included in the auto-capture with the BlueCam is an anti-shake function with a broad depth of field[1]. The BlueCam requires proper antireflective powdering to opaque the teeth [53]. Sirona's latest digital impression system is the CEREC AC with OmniCam unit released in 2012. In contrast to the BlueCam, where imaging is done by stitching of individual images together, creating a monochromatic yellow stone-like digital cast, the OmniCam captures without powdering via digital streaming a full-colour digital cast. The CEREC software is robust enough to design and mill single-unit inlays, onlays, veneers, crowns, and fixed partial dentures, both provisional, permanent and implant abutment[54].

The Planmeca PlanScan (E4D Technologies, Richardson, Texas, USA) system; is designed to be used similarly to Sirona's CEREC systems, as a digital impression system and chair-side design and milling system [55]. The PlanScan system uses blue laser light with real-time video-streaming technology to capture dental data, and it is powder-free translucencies, dental restorations, models, and conventional impressions. The digital casts can be used for designing inlays, onlays, crowns, bridges, and veneers. If needed, the scans can be sent to the laboratory for processing, designing, and manufacturing of the restorations[56].

The CS 3600 (Carestream Dental, Atlanta, Georgia, USA) intraoral scanner is one of the latest powder-free intraoral scanners that enables dental professionals to scan patients' teeth to create colour 3D images[1]. Similar to the CEREC BlueCam, it is a click-and-point system. Thus, it requires the user to keep the wand still during capturing[57]. The scanner can be used to design a single crown, bridge, inlay, onlay, and veneer through the CS Restore software and milled with the optional Carestream milling machine (CS 3000), or the data can be sent to a laboratory for design and milling. Moreover, the coloured 3D images are supposed to help draw margin lines easily and identify the differences between natural tooth structures and existing restorations[58].

Figure 2.1: CEREC digital scanner

(Image source, manufacturer’s website)

Figure 2.2: Carestream 3600 intra oral scanner

2.6 Outcomes of Short-span and Long-span Restorations from Conventional vs. Digital Impressions

Fixed partial dentures (FPDs) generally offer a higher degree of satisfaction for the patient as they greatly resemble natural teeth regarding the function and comfort of removable dentures[59]. Depending on the condition of the remaining dentition, a fixed replacement for the missing teeth may require long-span FPDs. Long-span restorations entail the replacement of two or more teeth [60]. In addition, for these restorations, more than one abutment must be prepared for support on either side.

Long-span FPDs have been found to have a high survival time than short-span FPDs. For instance, a study by Yi, Carlsson and Ericsson [58] in which fifty long-span FPDs were considered found the 100% of the FDPs to have an average survival time period of 3 years. In another study, De Backer et al. [59] observed 86 long-span FDPs and found that about 59% of the FPDs had a mean survival time of at least 20 years.

Long-span FPDs have, however, been associated with loss of retention, endodontic and periodontal problems as the main complications. For instance, in a study seeking to determine the long-term efficacy of long-span FPDs, De Backer et al. [61] examined a sample of 322 FPDs over a 20-year period. The scholars found that dental caries and loss of retention were the main reasons for failure and accounted for the majority of failures.

These are simple FPDs, which replace one or two adjacent teeth and are confined to three units. The teeth on either side are ideal abutments. These restorations are considered ideal because they have minimal torquing forces [60]. Ioannidis and Bindl[62] sought to assess the long-term clinical performance of posterior three-unit FPDs over a period of ten years. The study was based on a sample of 59 three-unit FPDs from 55 patients. The scholars found that the overall survival rate of the FPDs amounted to 85%.

It was also established that a majority of FPDs failed to survive due to technical complications while only few failed due to biological complications.

The ideal impression should be simple, reliable, accurate, and comfortable for the patient; and require minimal clinical time [63]. Traditional impressions can be technique sensitive and may cause patient discomfort, while digital impressions require clinicians to master a new treatment modality. As digital impression technology is relatively new in its application to restorative dentistry, published studies remain scarce. Only a few in vitro studies have directly compared traditional impression procedures and digital impression approaches.

Howell et al. [64] also found that the digital impression approach using encode abutments resulted in casts that were less accurate compared to casts generated from either conventional close-tray or open-tray impressions; the mean difference of restoration position relative to a reference point was 42-131µm using encode abutments and 22-74µm using conventional impressions. The authors asserted that further research is needed before clinical implications are made from such data.

Andressien et al. [26] recently conducted a clinical pilot study examining the applicability and accuracy of intra-oral digital impressions of multiple restorations in the edentulous mandible. The authors compared intra-oral digital impressions using the iTero scanner with the digitized master casts for 25 patients who were restored with a 2-restoration mandibular bar overdenture. Based on the measured inter-restoration distance error (mean = 226 um) and angle discrepancies (mean = 2.58 degrees), the authors concluded that the digital impressions were not accurate enough to fabricate a well-fitting supra-structure. A possible explanation that may account for this inaccuracy was a lack of stable reference points in the completely edentulous arch; therefore the results of the study cannot be extrapolated to a partially long situation.

Su and Sun [65] investigated differences in internal and marginal fit of three-unit ceramic fixed dental restorations fabricated from digital and conventional impressions. The results of the in vitro study showed that the mean marginal fit values of the digital group (64 ±16 μm) were significantly smaller than those of the conventional group (76 ±18 μm) ($p<.05$). The mean internal fit values of the digital group (111 ±34 μm) were significantly smaller than those of the conventional group (132 ±44μm, $p<.05$). As a result, the authors concluded that clinically, the marginal and internal fit of restorations fabricated from the digital impression system was better than those from the conventional impressions.

A study by Cheng et al. [66] sought to compare the time efficiency and fit of interim crowns fabricated by using either a digital or a conventional workflow. The results of the study showed that the digital workflow required significantly less total fabrication time (laboratory and clinical) than the conventional workflow ($p<. 001$). The less-experienced clinicians needed longer clinical time with the conventional workflow than the experienced ones ($p=0.023$). In contrast, the laboratory and total fabrication time were shorter for less-experienced clinicians using the digital workflow ($p=0.005$ and p=0.015). The interim single crowns (SCs) fabricated with the digital workflow had significantly better fit and occlusal contacts than those fabricated with the conventional workflow (p=0.005 and p<0.001). With the digital workflow, the interim SCs made by less-experienced clinicians were of the same quality as those made by experienced clinicians. When using the conventional workflow, the fit of the experienced clinicians was significantly better than that of the less-experienced clinicians. Consequently, the authors concluded that restorations fabricated using digital workflow required a shorter time and resulted in better fit, crown morphology and better occlusion than those with conventional workflow.

A study by Eliasson and Ortorp[25] compared the accuracy of restoration analogue positions in casts using digital impressions of coded healing abutments (Encode) versus conventional restoration-level impressions. The restoration analogue 13 centre-point positions in 3-dimensions (x, y, z) were compared on the master and working casts using a laser measuring machine concluded that both techniques resulted in slight inaccuracies of restoration position for the digital approach (35.0-47.3μm) and the conventional approach (13.9-18.5μm) depending on the axis measured. Although the difference was statistically significant (p=0.01) the authors could not conclude on the clinical significance and ultimately observed that both techniques produced sufficiently accurate working casts for most clinical situations.

It is apparent that the current literature has investigated the quality of restorations fabricated using conventional and digital techniques to a great extent. However, as it stands the empirical evidence is still inconclusive as to whether digital techniques produce short-span and long-span restorations with better marginal fit than conventional techniques. Accordingly, this study seeks to fill this gap by comparing the marginal fit of short-span and long-span restorations generated using conventional and digital techniques.

2.7 Conclusion

In summary, the capture of any accurate impression is the first step in the process of any prosthesis. Inaccuracies in impressions can lead to compounding errors in the subsequent steps of prosthesis fabrication. The resultant crowns can have defective margins that lead to periodontal diseases.

However, little global and East African evidence is available about the margin fit afforded by the latest digital methods compared to conventional techniques. Therefore, this study aims to evaluate the marginal and overall fit of single crowns and three-unit fixed dental prostheses fabricated from conventional or digital impression techniques in Nairobi, Kenya.

CHAPTER THREE

3. STATEMENT OF THE PROBLEM, STUDY JUSTIFICATION AND OBJECTIVES

3.1 Statement of the Problem

Although marginal opening alone does not directly correlate with microleakage, the accuracy of marginal fit is considered as an important criteria for the clinical quality and success of prosthetic restorations. The importance of precise marginal adaptation and the subsequent implications of marginal discrepancies, including microleakage, caries and periodontal inflammation, has been emphasized in many studies. In addition to marginal fit, internal fit and accuracy play a significant role in the longevity of a full-coverage restoration as well. All the required steps during the fabrication of a crown necessitate precision and exactness to produce an accurately fitting restoration.

Recent technological advances have dramatically altered impression and crown fabrication procedures; specifically, digital impressions and computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been introduced in dental clinical practice with claims to produce more accurately fitting restorations. The advantages of digital techniques are; the elimination of production steps that may cause misfit, less transport between clinic and dental laboratory, and less patient discomfort [12, 13]. However, which impression method, conventional or digital, produces the most accurate results based on marginal fit of the fabricated crowns is still controversial. Marginal gaps of between 1 and 161µm have been reported for ceramic crowns fabricated after conventional impressions, whereas marginal gaps range between 17 and

118µm have been detected for ceramic crowns fabricated after digital impressions [18-26]. Although different authors state that 75, 100, 160, and even 200 µm would also be within the acceptable range [25, 26, 27], recently, a marginal discrepancy of up to 50µm has been suggested as an acceptable limit [28].

Ceramic crowns fabricated after digital and conventional impressions have been reported to have acceptable adaptation, the values reported are measurements means found by the studies. However, there is always a range of marginal discrepancy values. A significant proportion of the restorations could have a substantially wider discrepancy and an unacceptable marginal fit. This proportion should be larger where higher means are reported. Therefore, identifying the impression method with the lowest mean values for marginal fit is still essential, and one way of doing this is by detecting whether the results of new digital methods are equivalent to those of the established conventional impression techniques. The results of the most current studies are inconsistent. Some studies indicate the superiority of the digital workflow [29]; others show that the conventional method provides a better marginal fit than fully digital fabrication [30]. Moreover, it is not possible to know whether this holds for fixed prostheses, as there is a tendency for higher values of marginal fit in frameworks with three-unit fixed dental configurations [32].

Evaluations of the quality of fit of FPDs have compared different types of materials and CAD/CAM manufacturing systems [15, 17, 18, 26, 28]. Although some accuracy studies have already been conducted [33, 34], there is insufficient data concerning the accuracy of digital impressions and their resulting marginal and internal fits. Accordingly, the study aims to evaluate the overall and marginal fit of short-span and long-span restorations made from conventional and digital impression techniques.

3.2 Justification of the Study

The crucial role of technology in dentistry is more apparent in recent years. This is reflected by a recent study on 385 UK-based dentists that found that 89% of the respondents recognized technology's substantial role in the future of dentistry. [67]

Patients today have high expectations regarding their dental treatments and are more concerned about how the dental restoration would look like, how it will function and for how long it was in service. It is important for dentists to pay more attention to the most common clinical errors that amount from fabrication of restorations using conventional and digital impression techniques. However, as it stands few studies have been devoted to investigating differences in clinical outcomes from the two impression outcomes in reference to single versus multiple unit restorations. There is thus need for more research on this subject to enable dentists to make reliable evidence-based decisions regarding the type of impression method to be used in order to optimize the prosthodontics treatment outcome.[68]

3.3 Study Objectives

3.3.1 Main Objective

To evaluate the marginal and overall fit of single crown and three-unit fixed dental prostheses fabricated from conventional or digital impressions in Nairobi, Kenya.

3.3.2 Specific Objectives

i. To determine the marginal fit of restorations (single crown and three-unit fixed dental prostheses) fabricated using conventional impressions on models.

ii. To determine the marginal fit of restorations (single crown and three-unit fixed dental prostheses) fabricated using digital impressions on models.

iii. To determine the overall fit of restorations (three-unit fixed dental prostheses) fabricated using conventional or digital impressions on models. (pontic is not being assessed)

iv. To analyze the difference between the two impression techniques (one conventional and four digital impression methods) when used to fabricate short (single crown) and three-unit fixed dental prostheses.

3.4 Study variables

The study variables are summarized in Table 3.1.

Table 3.1: Study variables

Variable Name	Type/Category	Measurable Outcome
Conventional Fabrication	Independent/Nominal	Specific impression material by name utilizing the lost wax technique. (1)
Digital Fabrication	Independent/Nominal	Specific type of scanner and digital processing technique by name – Carestream (2); Dental wings (3); Medit i700 (4); Medit i500 (5)
Marginal fit of Restorations	Dependent/ continuous	Marginal gap between crown and tooth (micrometres)
Overall fit of Restorations	Dependent/ continuous	The gap between the pontic and the saddle in the three-unit FDP (micrometres)

3.5 Hypothesis

1. H_0: There was no significant difference in the marginal fit of fixed dental prostheses (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions.

H_A: There was a significant difference in the marginal fit of fixed dental prostheses (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions.

2. H_0: There was no significant difference in the overall fit of three unit fixed dental prostheses fabricated from conventional and digital impressions.

H_A: There was a significant difference in the marginal fit of three unit fixed dental prostheses fabricated from conventional and digital impressions.

4.0 CHAPTER FOUR: MATERIALS AND METHODS

4.1 Study Design

The study adopted a laboratory based analytical cross-sectional study.

4.2 Study Setting

The study was set at Prime Dental Laboratory Studio, a private dental laboratory in Nairobi, Kenya.

4.3 Sample size and sample size calculation

The sample size was a total of **450 measurement points** done on a total of **75 zirconia restorations** reproduced on **three teeth preparations** for 25 crowns (single-tooth preparation) and 25 three-unit (two-teeth preparation) fixed dental prostheses. Five impression techniques were used – one conventional and four digital. Each impression was recorded five times to produce these 25 single crowns and 25 three-unit fixed dental prostheses. A single crown had 6 measurable points – mesial, distal and mid-mesial both on the facial and the buccal aspects. For the three-unit prosthesis, only the retainers were measured while the pontic was not. Therefore, the sample size of 450 measurement points was derived from six measurable points on each of the 25 single crowns (a total of 150) and six measurable points on two retainers on each of the 25 three-unit fixed dental prostheses (a total of 300 points). This is summarized it Table 4.1.

The study sample size calculation was based on the formula for comparison of means as described by Kelsey et al., 1996 [(68)]

$$n \geq \left(\frac{r+1}{r}\right)\frac{\sigma^2 (Z_\beta + Z_{\alpha/2})^2}{(difference)^2}$$

Where:

n_1 = minimum sample size among group 1

$n_2 = r * n_1$ i.e. sample size among group 2

$n = n_1 + n_2$ i.e. total sample size

r = is the ratio of group 2 to group 1

σ = standard deviation in the population

$\mathbf{Z_\beta}$ =is the critical value for the desired power (Type II error β = 0.2, $\mathbf{Z_\beta}$ =0.84)

$\mathbf{Z_{\alpha/2}}$**=** is the critical value for standard normal distribution at α-level of significance (Type I error α= 0.05, $\mathbf{Z_{\alpha/2}}$=1.96)

Difference = expected effect size (i.e. the difference in means)

Table 4.1: Sample size calculation

Type of prosthesis	**Impression technique**	**Conventional (Polyether)**	**Digital 1 Care-stream**	**Digital 2 Dental wings**	**Digital 3 Medit i700**	**Digital 4 Medit i500**	**Total sample of points in a set of five specimens by prosthesis**
	Specimen	Number of measured points					
Single crown	*1*	6	6	6	6	6	30
	2	6	6	6	6	6	30
	3	6	6	6	6	6	30
	4	6	6	6	6	6	30
	5	6	6	6	6	6	30
Three-unit FDP	*1*	12	12	12	12	12	60
	2	12	12	12	12	12	60
	3	12	12	12	12	12	60
	4	12	12	12	12	12	60
	5	12	12	12	12	12	60
Total sample of points in a set of five specimens by technique		90	90	90	90	90	450

4.4 Data Collection Tools and Technique

The data collecting procedure entailed the following:

1. A set of typodont teeth (KaVo Dental, Biberach, Germany) as illustrated in Figure 4.1 was used as the model. It was randomly selected.
2. Tooth preparation for a conventional all-ceramic crown, which entails the preparation of a 2mm shoulder margin round the tooth was done by the study's principal investigator and was verified by one of the supervisors. On maxillary left central incisor, for a single crown. The preparations were done at the same sitting using a high speed hand piece and a diamond shoulder bur as per guidelines.
3. For the three-unit FDP, another preparation was made on the same model extending from the first premolar to the first permanent molar and to replace a missing second premolar. These preparations are illustrated in Figure 4.2 and were verified to meet acceptable specifications by one supervisor.
4. Impressions of the prepared models were then recorded as described in the following sections.

Figure 4.1: Typodont model

Figure 4.2: Typodont illustrating teeth preparations prior to recording impressions

4.4.1 Impression making and prostheses fabrication – Digital Technique

In the digital group, the crowns and three-unit FDPs were fabricated by using intraoral scans and CAD/CAM technologies without definitive casts.

Four different brands of intra-oral scanners illustrated in Figures 4.3 to 4.6 and available locally were used according to manufacturers' instructions. These scanners were availed to the study area which was Prime dental studio a Private Lab in Nairobi Kenya. Inclusion criteria for the scanners was those scanners available in the local market which were readily available for hire by the principal investigator during the period of the study. These were:

1. Dental wings digital scanner (Straumann Group, Montreal, Canada, 2007)
2. Medit digital scanner i500 (MEDIT corp. 8, Yangpyeong-ro 25-gil, Yeongdeungpo-gu, Seoul, Republic of Korea)
3. Medit digital scanner i700 (MEDIT corp. 8, Yangpyeong-ro 25-gil, Yeongdeungpo-gu, Seoul, Republic of Korea)
4. Care stream 3600 (Care stream Dental LLC 3625 Cumberland Blvd. Ste. 700, Atlanta, GA 3033)

All the scanners were availed in the lab. The principal investigator had a one week training on the usage of the scanners despite having used digital scanning before. All the scanners were calibrated according to manufacturer's instructions before each use. The images were then captured using each digital scanner to produce STL files. These STL files were then coded and uploaded to google drive accessible to the lab technician.

They were then used to fabricate zirconia frameworks. The following are samples of the captured images using each of the digital impression method.

Figure 4.3: **Sample measurements done using impressions from Medit i500 digital scanner**

Figure 4.4: **Sample measurements done using impressions from Medit i700 digital scanner**

Figure 4.5: Sample measurements done using impressions from Care stream 3600 digital scanner

Figure 4.6: Sample measurements done using impressions from Dental wings digital scanner

Impression making and prostheses fabrication – Conventional Technique

1. For the conventional group, impressions for both the three-unit fixed dental prostheses and single crowns were made using a special tray and polyether monophase material (Impregum Penta, 3M ESPE, Minnesota, USA).
2. The master special tray was fabricated from the standard model eight hours prior using heat polymerizing polymethylmethacrylate resin (Acropars® 200, Marlic Medical Industries Co, Iran). The master tray was spaced with two sheets of wax to achieve 2-3 mm spacer requirements then perforated (Figure 4.7).
3. Two impressions were taken using the two-step monophase technique recommended by the manufacturer, whereby one part of the material was placed on the tray while another part was syringed onto the prepared teeth. The impression was separated from the model and inspected and deemed free for porosities, bubbles and irregularities on the captured margins.
4. Each impression was used to fabricate five models (Figure 4.8), one set for the single crown and the other for the three-unit fixed dental prosthesis. Models were cast in high strength stone (Neelkanths, Healthcare Pvt. Ltd, Jodhpur, India). This was done by the same dental technician the fabricated models were inspected for porosities, bubbles and surface irregularities and were deemed accurate.
5. These models were then scanned using an extra oral scanner (laboratory scanner - Dental wings, Straumann group, Switzerland) and STL files exported to a computer connected to the scanner. The STL files were used to produce zirconia (*1 Lava™ Plus Zirconia Disc 98S x 18 mm 3 M US Minnesota)* FDP frameworks through CAD-CAM for the control group, as shown in Figure 4.9.

Figure 4.7 : Master special tray fabricated from heat polymerizing acrylic

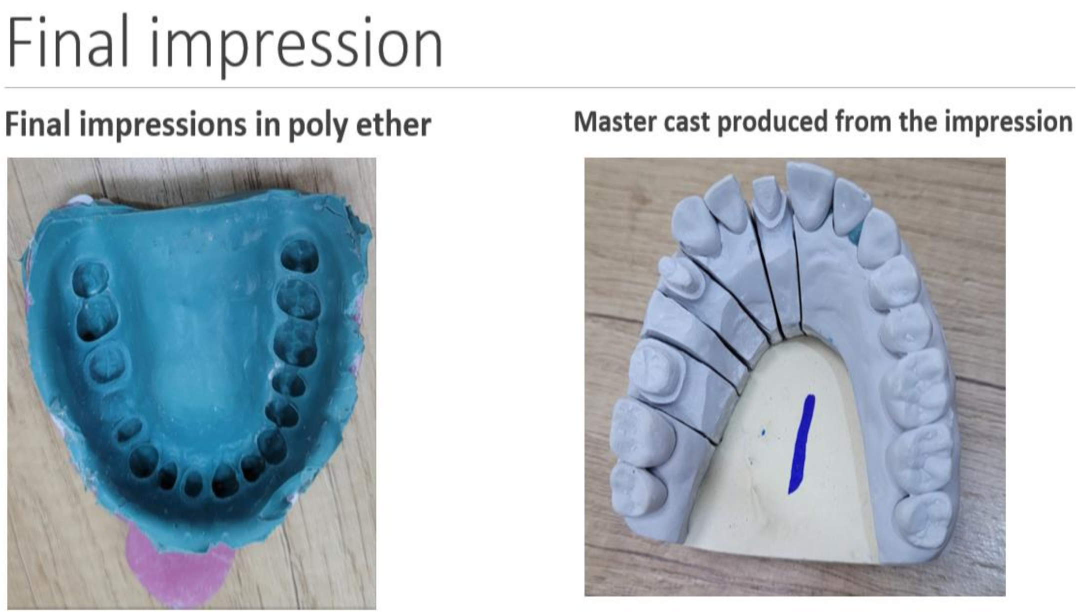

Figure 4.8: Polyether impression and the resultant high strength stone master cast

Figure 4.9: Samples of single crown and three-unit FPDs fabricated from digital and conventional impressions

Fabrication of the single crowns and the 3 unit FDPs was done by the dental technician. The STL files for both methods were this was done using zirconia milling machine (AIDITE Milling machine Switzerland) as per the manufacturer's specifications.

4.4.3 Quality assurance of restorations

Each prostheses was inspected on its fitting surface before the measurements were carried out. Adjustments were made on the fitting surfaces of crowns that had protrusions that impeded complete seating onto the standardized original typodont model.

4.4.4 Photography

1. The initial prepared typodont model was preserved carefully in an airtight container which was stored in a locked cabinet after the impressions were taken and was later used to verify that the fit of the restorations was acceptable as visualized

macroscopically. The verification was by ensuring that the prostheses fit was stable and when pressed vertically, the single crown copings and the frameworks were firm and not mobile.

2. The typodont model was then sectioned into two to allow for photography on the palatal aspect. A surveyor table was modified to be used as a jig to hold the master cast in place. Grooves were made on both ends of the sectioned model to fit on the surveyor table chosen, as shown in Figure 4.10.

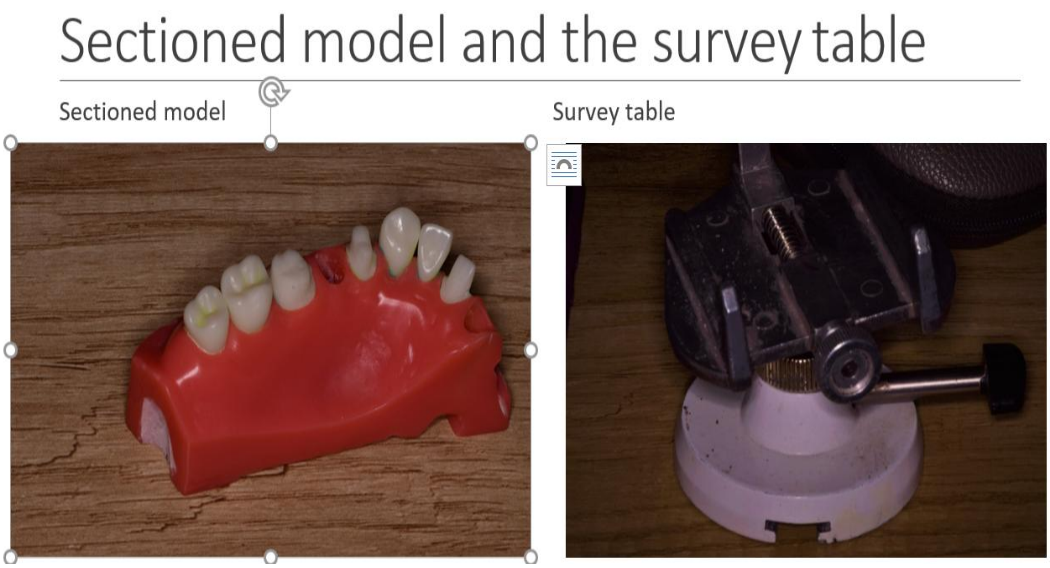

Figure 4.10: Sectioned model and the survey table for mounting

3. The master model was centered on the survey table and the distance from the center of the table to the rim of the macro lens set at 30 centimeters. Images of the fabricated crowns were captured using digital photographs (Figure 4.11).

4. A digital single-lens reflex camera (D5300; Nikon, USA) with a macro lens (Nikkor AF-S 110 mm f/2.8G IF-ED; Nikon, USA), was set on a tripod stand and used to photograph fabricated crowns on the master model. The model was positioned

against a blue background for increased contrast. This camera was calibrated at a local Nikon store Sarit center Nairobi Kenya by a licensed Nikon Dealer. The camera settings for the photography were: Aperture (F) 10, Shutter speed 1/25,ISO100-200 , magnification 1:10

5. Each restoration was photographed to capture the following six positions as initially documented for the original typodont tooth: Facial, mesial, distal, mid-facial and mid-palatal aspects, as shown in Figures 4.12 and 4.13. 3 photographs were captured per model.

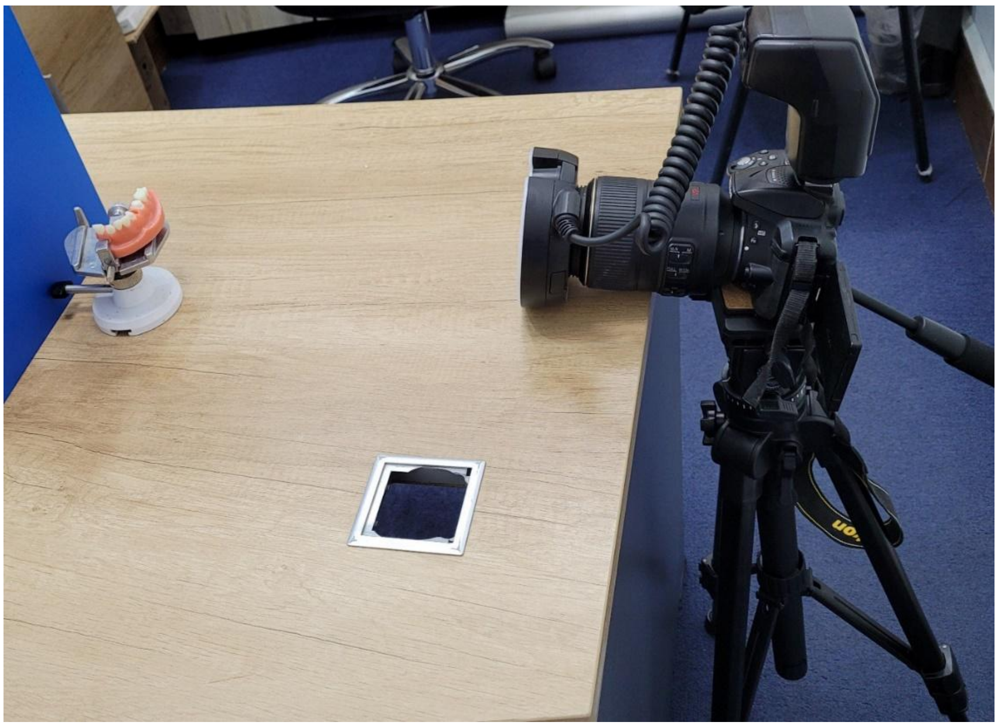

Figure 4.11: Photography set up

Figure 4.12: Palatal aspect of the typodont after seating the three-unit FDP framework

Figure 4.13: palatal aspect of the typodont after seating the single crown coping. Note the three markings mesial mid and distal

4.4.5 Image analysis

1. The captured photographic images were uploaded onto a computer and magnified by a factor of 150. Computer on-screen caliper software (ImageJ, National Institutes of Health and LOCI, University of Wisconsin, USA) was used to measure the vertical distance between the margin of the fitted bridge and the finish line.
2. Each individual measurement was done thrice in three different sittings. An endodontic ruler was placed against the models to calibrate and verify the measurements on the photos once uploaded on ImageJ software (Figure 4.14).
3. The observer was blinded from having knowledge of the previous measurement to eliminate bias while taking the second and third marginal gap measurements. This was achieved by having each of the three sets of measurements taken on different days and by not cross-checking the records of the previous measurements for the same point. The measurements were calibrated by one supervisor and confirmed by testing inter- rater reliability.

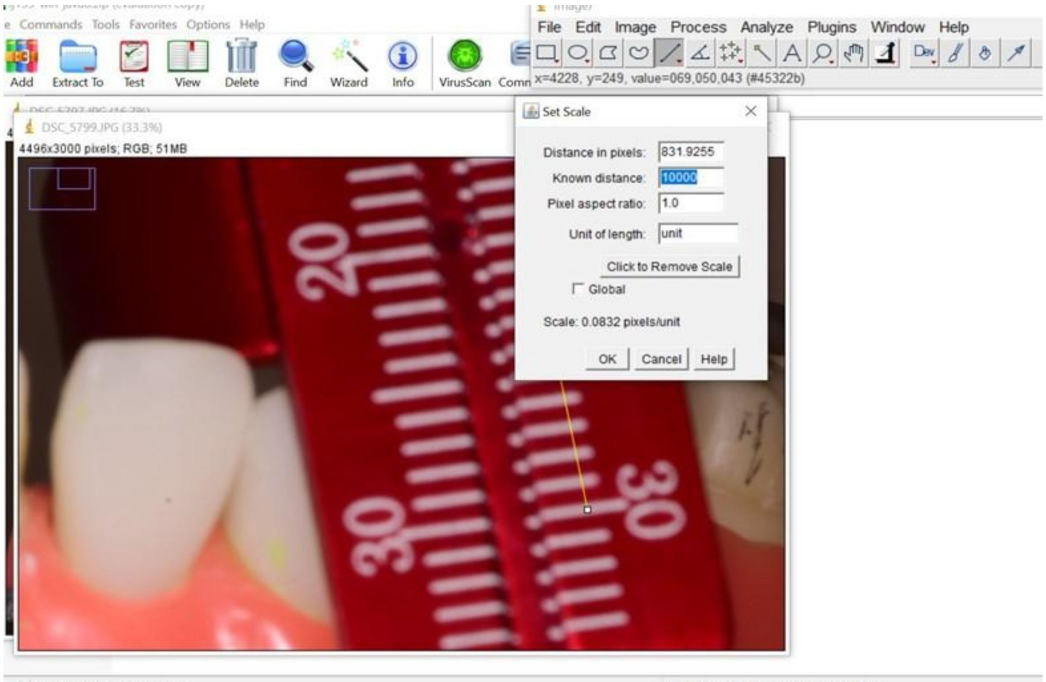

Figure 4.14 : Endodontic ruler used to verify measurements on ImageJ software

4.5 Data validity and reliability

A pilot study was done to determine the validity and reliability of the data. All the tools used were calibrated. Measurements were conducted at 6 points thrice for each abutment and a mean value obtained as the representative value. The PI was calibrated by one supervisor for every 5th model measurement and the Kappa score calculated to determine inter-examiner reliability. To ensure validity, the protocol was standardized including ensuring that only materials bearing similar batch numbers were used.

4.5.7 Inter-rater Reliability

Table 4.2 (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 4.2: Marginal gap measurements of 12 sites on three crowns in the R-mm group, by the principal investigator and the supervisor

Specimen Number	Site of Measurement	Principal Investigator's Measurements (µm)	Supervisor's Measurement (µm)	Absolute Difference |Rater2 – Rater1|
1	Mid-facial	155.10	198.78	43.67
5	Mid-palatal	280.74	319.55	38.81
10	Mid-mesial	191.89	252.18	60.29
15	Mid-distal	36.13	79.47	43.34
20	Mid-facial	157.47	212.19	54.73
25	Mid-palatal	222.76	209.64	8.87
30	Mid-mesial	87.78	111.57	23.79
35	Mid-distal	46.17	49.59	3.42
40	Mid-facial	160.84	202.00	41.16
45	Mid-palatal	238.06	278.82	40.76
50	Mid-mesial	94.68	101.87	7.19
55	Mid-distal	42.79	79.92	37.13

The mean difference between the values was 36.43 (with standard deviation of 17.34), 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=0.979, p<0.001***. This showed agreement between the two observers.

4.6 Data Analysis

Data was entered into Microsoft Excel spreadsheets and cleaned then analyzed using STATA, version 16 (StataCorp LLC College Station, Texas, 77845, USA). Descriptive statistics including mean, standard deviation and median was computed for the restoration parameters. The independent sample t-test for continuous data and for χ_2 for categorical data was used to for hypothesis testing to analyze differences in the marginal and overall fit of restorations made from conventional and digital techniques at $\alpha=0.05$. The data analysis plan is presented in Table 4.3.

Table 4.3: Data analysis plan

Variable name	Descriptive statistics	Inferential statistics
Objectives 1, 2,3: To describe the marginal and overall fit of single crown and three unit fixed dental prostheses		
Conventional technique	Means, median, standard deviations	Independent sample t-test, ANOVA and Kruskal-Wallis analysis within and between groups. Followed by Tukey's or Dunn's post hoc test
Digital technique		
Marginal and overall fit		
Objective 4: To determine whether there was a difference between the two treatment options in single crown and three unit fixed dental prostheses		
Marginal fit	Means, median, standard deviations	Independent sample t-test, ANOVA and Kruskal-Wallis analysis within and between groups. Followed by Tukey's or Dunn's post hoc test
Overall fit		

4.7 Ethical Considerations

The study proposal was submitted to the Kenyatta National Hospital – University of Nairobi Ethics and Research Committee for approval prior to data collection (Approval no P21/01/21).

4.8 Perceived Benefits of the Study

i. The study's findings will help guide clinicians to determine the most suitable impression technique for the practices.

ii. The findings will help portray with the best evidence available, the benefits of using digital systems, which will promote successful and improved clinical practice and patient satisfaction.

iii. The study will also be useful for future researchers intending to explore the subject of conventional and digital impressions.

4.9 Limitations

1. This study focused primarily on the marginal fit of short-span and long-span restorations. Therefore, the findings may not be generalizable to other clinical outcomes in reference to the use of conventional and digital fabrication techniques.
2. The in-vitro nature also makes inference to clinical relevance difficult.

CHAPTER FIVE

5. RESULTS

5.1 Introduction

The study aimed at evaluating differences in the marginal fit determined by marginal gap of restorations (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions. The sample size was 75 crowns with a total of 450 measurement points (5 impression methods done 5 times to produce 25 single crowns and 50 three units fixed dental prosthesis (5 three-unit three units FDP).

Despite different authors stating that 75, 100, 160, and even 200 µm marginal gap measurements would be within the acceptable range [27], a marginal discrepancy of up to 50µm has recently been suggested as an acceptable limit [28].

Within the context of this study, a marginal fit for crowns as determined by marginal gap measurements of 150 micrometers (µm) or less was deemed acceptable from a clinical standpoint.

5.2 Objective One: To determine the marginal fit of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional impressions on models.

Table 5.1: Marginal fit determined by marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional impressions (PE) on models

Crown Type	Aspect	Measurement Units (µm)						
		Distal		Mid		Mesial		Overall marginal gap
		Facial	Palatal	Facial	Palatal	Facial	Palatal	
Single n=30	Mean (SD)	199.8 (122.1)	124 (16.7)	184 (35.8)	152 (43.8)	120 (0)	127.8 (25.8)	151.3 (60.1)
	Median (IQR)	200 (100, 200)	120 (120, 140)	200 (200, 200)	120 (120, 200)	120 (120, 120)	139 (100, 150)	120 (120, 200)
Multiple n=60	Mean (SD)	120 (0)	164 (53.6)	110 (10.5)	159.5 (35.4)	165 (65.2)	205 (36.9)	153.9 (50.1)
	Median (IQR)	120 (120, 120)	140 (130, 170)	110 (100, 120)	139.5 (129, 200)	155 (110, 200)	200 (200, 200)	129.5 (120, 200)

Table 5.1 above shows the marginal fit determined by marginal gap measurements of restorations fabricated using conventional impressions. The table covers all the measurements units done per each crown type (single crown and three unit fixed dental prosthesis) summarized as means and median with their corresponding standard deviation and interquartile ranges respectively.

Table 5.2: Comparison of marginal fit determined by mean marginal gap measurements between facial and palatal aspects of single crown and three unit fixed dental prosthesis produced from conventional impressions (PE) (sd in parentheses)

Crown type	Measurement Aspect (µm)		*t*test value	p-value	95% CI
	Facial	Palatal			
Single (n=30)	167.9 (76.8)	134.6 (31.4)	1.56	0.131	-10.5, 77.2
Multiple (n=60)	131.7 (44.1)	176.2 (46.2)	-3.81	<0.001	-67.8, -21.2

As shown in Table 5.2, there was no significant difference in mean marginal gap measurements between facial (167.9 ±76.8) and palatal (134.6 ±31.4) aspects in the single crown prosthesis (t=1.56, p=0.131, 95% CI -10.5, 77.2). However, a statistically significant difference was observed between the facial and palatal aspect measurements in the three unit fixed dental restorations prosthesis (t=-3.81, p<0.001, 95% CI -67.8, -21.2)

Table 5.3: Comparison of marginal fit determined by mean marginal gap measurements between measurement units of single crown and produced from conventional impressions (PE) (sd in parentheses)

Crown type	Measurement Units (µm)			F statistic value	p-value
	Distal	Mid	Mesial		
Single (n=15)	161.9 (91.3)	168 (41.3)	123.9 (17.7)	1.65	0.210
Multiple (n=30)	142 (43.2)	134.7 (35.9)	185 (55.5)	7.09	0.002

As shown in Table 5.3, there was no significant difference in mean marginal gap measurements between distal (161.9 ±91.3), mid (168 ±41.3) and mesial (123.9 ±17.7) measurement units in the single crown prosthesis (F=1.65, p=0.210). However, there was a significant difference in the marginal gap between the three measurement units in the three unit fixed dental restorations (F=7.09, p=0.002). A Tukey post hoc test showed the difference to be between: Mesial and Distal (t=2.98, p=0.012), Mesial and mid (t=3.48, p=0.003).

Table 5.4: Comparison of marginal fit determined by mean marginal gap measurements between crown type (single crown and three unit fixed dental prosthesis) produced from conventional impressions (PE) (SD in parentheses)

Measurement (μm)		**Crown Type**		***t*test value**	**p-value**	**95% CI**
		Single	**Multiple**			
Aspect	Facial (n=45)	167.9 (76.8)	131.7 (44.1)	2.02	0.0499	0.01, 72.5
	Palatal (n=45)	134.6 (31.4)	176.2 (46.2)	-3.13	0.003	-68.3, -14.8
Reference Point	Distal (n=30)	161.9 (91.3)	142 (43.2)	0.82	0.421	-29.9, 69.8
	Mid (n=30)	168 (41.3)	134.7 (35.9)	2.27	0.031	3.3, 63.2
	Mesial (n=30)	123.9 (17.7)	185 (55.5)	-3.37	0.002	-98.2, -23.9
Overall (n=90)		151.3 (60.1)	153.9 (50.1)	-0.22	0.825	-26.5, 21.2

Table 5.4 shows the comparison of marginal fit determined by marginal gap measurements between the single crown and three-unit prosthesis produced from conventional impressions.

Student t-test was used to compare the mean measurements of conventional impression between the two crown types (short and long span). There were significant differences between short and three unit fixed dental restorations restoration while looking at facial aspect (t=2.02, p=0.0499, 95% CI: 0.01, 72.5) and also for palatal aspect (t=-3.13, p=0.003, 95% CI: -68.3, -14.8). Also, the measurements were significantly different (p<0.05) for mid (values) and mesial (values) measurement units between the two crown types (short and long span). However, the overall marginal fit as determined by the marginal gap measurements were not statistically different (t=-0.22, p=0.825, 95% CI: -26.5 – 21.2).

5.3 Objective Two: To determine the marginal fit of restorations (single crown and three unit fixed dental prosthesis restorations) fabricated using digital impressions on models.

Table 5.5: Marginal fit determined by marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using Dental wings (DW) digital scanner on models

Crown Type	Aspect	Measurement Unit (µm)						Overall marginal gap
		Distal		Mid		Mesial		
		Facial	Palatal	Facial	Palatal	Facial	Palatal	
Single n=30	Mean (SD)	154 (13.4)	180 (83.7)	176 (45.6)	180 (30.8)	224 (125.2)	196 (8.9)	185 (63.7)
	Median (IQR)	160 (160, 160)	200 (100, 200)	180 (140, 220)	180 (150, 200)	160 (120, 360)	200 (200, 200)	180 (150, 200)
Multiple n=60	Mean (SD)	173 (33.7)	260 (69.9)	199 (43.8)	254 (43)	267 (132)	192 (85.5)	224.2 (81.7)
	Median (IQR)	185 (150, 200)	250 (200, 300)	200 (150, 200)	250 (250, 300)	280 (150, 360)	175 (150, 200)	200 (165, 285)

As shown in Table 5.5, the overall mean and median measurements by Dental Wings were above the acceptable marginal fit of 150 micrometers in all the measurement aspects and units. Mesial facial measurement had consistently high values for single crown and three unit fixed dental prosthesis.

Table 5.6: Comparison of marginal fit determined by mean marginal gap measurements between facial and palatal aspects of single crown and three unit fixed dental prosthesis produced from Dental wings (DW) digital scanner (sd in parentheses)

Crown type	Measurement Aspect (µm)		*t*test value	p-value	95% CI
	Facial	Palatal			
Single (n=30)	184.7 (77.7)	185.3 (48.5)	-0.03	0.978	-49.1, 208.8
Multiple (n=60)	213 (89.3)	235.3 (73)	-1.06	0.293	-64.5, 19.8

As shown in Table 5.6, the marginal fit measurements were not significantly different (p>0.05) for single (t= -0.03, p=0.978, 95% CI: -49.1, 208.8) and multiple (t= -1.06, p=0.293, 95% CI: -64.5, 19.8) crown types between the two measurement aspects (facial and palatal).

Table 5.7: Comparison of marginal fit determined by mean marginal gap measurements between measurement units of single crown and three unit fixed dental prosthesis produced from Dental wings (DW) digital scanner (sd in parentheses)

Crown type	Measurement Units (µm)			F statistic value	p-value
	Distal	Mid	Mesial		
Single (n=30)	167 (58.1)	178 (36.6)	210 (85)	1.25	0.302
Multiple (n=60)	216.5 (69.6)	226.5 (50.8)	229.5 (114.9)	0.13	0.874

Table 5.7 shows that there was no significant different (p>0.05) in marginal fit measurements between the three measurement units (distal, mid and mesial) for single (F=1.25, p = 0.302) and multiple (F=0.13, p=0.874) crown types.

Table 5.8 : Comparison of marginal fit determined by mean marginal gap measurements between crown type (single crown and three unit fixed dental prosthesis) produced from Dental wings (DW) digital scanner (SD in parentheses)

Measurement (µm)		Crown Type		*t*test value	p-value	95% CI
		Single	Multiple			
Aspect	Facial (n=45)	184.7 (77.7)	213 (89.3)	-1.04	0.302	-83, 26.3
	Palatal (n=45)	185.3 (48.5)	235.3 (73.0)	-7.86	0.021	-92.1, -7.9
Reference Point	Distal (n=30)	167 (58.1)	216.5 (69.6)	-1.93	0.063	-101.9, 2.9
	Mid (n=30)	178 (36.7)	226.5 (50.8)	-2.68	0.012	-85.6, -11.4
	Mesial (n=30)	210 (84.9)	229.5 (114.9)	-0.47	0.639	-103.7, 64.7
Overall (n=90)		185 (63.7)	224.2 (81.7)	-2.30	0.024	-73, -5.3

As shown in Table 5.8, there were significant differences between short and three unit fixed dental restoration while looking at palatal aspect (t=-7.86, p=0.021, 95% CI: -92.1, -7.9) but for facial aspect the difference was not statistically different (t= -1.04, p=0.302, 95% CI: -83, 26.3). Also the measurements were significantly different ($p<0.05$) for mid (values) measurement units between the two crown (short and long span). In addition, the overall marginal fit as determined by the marginal gap measurements were statistically different (t= -2.30, p=0.024, 95% CI: -73, -5.3).

Table 5.9: Marginal fit determined by marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using Care stream 3600 (CS) digital scanner on models

Crown type	Aspect	Measurement Unit (µm)						Overall marginal gap
		Distal		Mid		Mesial		
		Facial	Palatal	Facial	Palatal	Facial	Palatal	
Single n=30	Mean (SD)	132 (16.4)	157.4 (41.4)	271.6 (101.3)	249.8 (70.4)	114 (21.9)	138 (50.2)	177.1 (81.3)
	Median (IQR)	120 (120, 150)	129 (129, 180)	229 (229, 250)	200 (200, 300)	100 (100, 120)	120 (100, 150)	150 (120, 220)
Multiple n=60	Mean (SD)	138 (34.3)	189 (36.7)	174.4 (34.4)	125.7 (30.9)	105 (15.8)	146.4 (54.5)	146.4 (44.9)
	Median (IQR)	120 (120, 150)	200 (200, 200)	200 (150, 200)	119.5 (100, 129)	100 (100, 100)	155 (100, 200)	129 (100, 200)

As shown in Table 5.9, the overall mean measurements by Care stream 3600 were within the acceptable marginal fit of 150 micrometers in only mesial and distal facial measurement units. Compared to Dental wings digital scanner, Care stream 3600 (CS) scanner had lower marginal fit measurement values.

Table 5.10: Comparison of marginal fit determined by mean marginal gap measurements between facial and palatal aspects of single crown and three unit fixed dental prosthesis produced from Care stream 3600 (CS) digital scanner (sd in parentheses)

Crown type	**Measurement Aspect (µm)**		***t*-test value**	**p-value**	**95% CI**
	Facial	**Palatal**			
Single (n=30)	172.5 (91.9)	181.7 (71.9)	-0.31	0.762	-70.9, 52.5
Multiple (n=60)	139.1 (40.4)	153.7 (48.5)	-1.26	0.212	-37.6, 8.5

As shown in Table 5.10, the marginal fit measurements were not significantly different (p>0.05) for single (t= -0.31, p=0.762, 95% CI: -70.9, 52.5) and multiple (t= -1.26, p=0.212, 95% CI: -37.6, 8.5) crown types between the two measurement aspects (facial and palatal).

Table 5.11: **Comparison of marginal fit determined by mean marginal gap measurements between measurement units of single crown and three unit fixed dental prosthesis produced from Care stream 3600 (CS) digital scanner (sd in parentheses)**

Crown type	**Measurement Units (µm)**			**F statistic value**	**p-value**
	Distal	**Mid**	**Mesial**		
Single (n=30)	144.7(32.6)	260.7(83.0)	126(38.6)	16.91	<0.001
Multiple (n=60)	163.5(43.3)	150.1(40.5)	125.7(44.4)	4.01	0.023

Table 5.11 shows that there was a significant difference in marginal fit measurements between the three measurement units (distal, mid and mesial) for single (F=16.91, p<0.001) and multiple (F=4.01, p=0.023) crown types. For single crown, the difference was between: Mid and Distal (t=4.62, p<0.001), Mesial and mid (t= -5.37, p<0.001).

While for multiple crown the difference was between: Mesial and Distal (t= -2.79, p=0.019).

Table 5.12: Comparison of marginal fit determined by mean marginal gap measurements between crown type (single crown and three unit fixed dental prosthesis) produced from Care stream 3600 (CS) digital scanner (SD in parentheses)

Measurement (µm)		**Crown Type**		***t-t*est value**	**p-value**	**95% CI**
		Single	**Multiple**			
Aspect	Facial (n=45)	172.5 (91.9)	139.1 (40.5)	1.69	0.096	-6.2, 73.0
	Palatal (n=45)	181.7 (71.9)	153.7 (48.5)	1.55	0.128	-8.4, 64.5
Reference Point	Distal (n=30)	144.7 (32.6)	163.5 (43.3)	-1.21	0.237	-50.7, 13.1
	Mid (n=30)	260.7 (83)	150.1 (40.4)	4.95	<0.001	64.9, 156.4
	Mesial (n=30)	126 (38.6)	125.7 (44.4)	0.02	0.985	-33.5, 34.1
Overall (n=90)		177.1 (81.3)	146.4 (44.9)	2.31	0.023	4.3, 57.1

Table 5.12 shows that there were no significant differences between short and three unit fixed dental restoration while looking at facial and palatal aspect (p>0.05). However, the measurements were significantly different (p<0.05) for mid (values) measurement units between the two crown (short and long span) (t=4.95, p=<0.001, 95% CI: 64.9, 156.4). Also, the overall marginal fit as determined by the marginal gap measurements were statistically different (t=2.31, p=0.023, 95% CI: 4.3, 57.1).

Table 5.13: Marginal fit determined by marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using Medit i700 (M700) digital scanner on models

Crown type	**Aspect**	**Measurement Unit (μm)**						**Overall** marginal gap
		Distal		**Mid**		**Mesial**		
		Facial	**Palatal**	**Facial**	**Palatal**	**Facial**	**Palatal**	
Single n=30	Mean (SD)	132 (11)	126 (13.4)	140 (0)	141.8 (24.8)	200 (0)	208 (90.1)	158 (48.7)
	Median (IQR)	130 (130, 130)	120 (120, 120)	140 (140, 140)	140 (120, 149)	200 (200, 200)	200 (120, 300)	140 (120, 200)
Multiple n=60	Mean (SD)	177 (21.1)	230 (153.8)	215 (85.1)	192.2 (87.8)	152 (44.9)	139.8 (28.2)	184.3 (86.2)
	Median (IQR)	170 (160, 200)	160 (120, 300)	200 (200, 200)	150 (150, 200)	150 (150, 150)	135 (120, 160)	160 (150, 200)

As shown in Table 5.13, the mean measurements by Medit i700 for single crown were within the acceptable marginal fit of 150 micrometers in all the measurement aspects and units except for mesial measurement unit and the opposite for the three unit fixed dental prosthesis.

Table 5.14: Comparison of marginal fit determined by mean marginal gap measurements between facial and palatal aspects of single crown and three unit fixed dental prosthesis produced from Medit i700 (M700) digital scanner (sd in parentheses)

Crown type	**Measurement Aspect (μm)**		***t*test value**	**p-value**	**95% CI**
	Facial	**Palatal**			
Single (n=30)	157.3 (31.9)	158.6 (62.4)	-0.07	0.944	-38.4, 35.8
Multiple (n=60)	181.3 (60.9)	187.3 (106.7)	-0.27	0.790	-50.9, 38.9

Table 5.14 shows that the marginal fit measurements were not significantly different (p>0.05) for both single (t= -0.07, p=0.944, 95% CI: -38.4, 35.8) and multiple (t= -0.27, p=0.790, 95% CI: -50.9, 38.9) crown types between the two measurement aspects (facial and palatal).

Table 5.15: Comparison of marginal fit determined by marginal gap measurements between measurement units of single crown three unit fixed dental prosthesis produced from Medit i700 digital scanner (M700) (sd in parentheses)

Crown type	Measurement Units (µm)			F statistic value	p-value
	Distal	Mid	Mesial		
Single (n=30)	129 (12)	140.9 (16.6)	204 (60.2)	12.05	<0.001
Multiple (n=60)	203.5 (110.3)	203.6 (85)	145.9 (37)	3.20	0.048

Table 5.15 shows significant differences in marginal fit measurements between the three measurement units (distal, mid and mesial) for both single (F=12.05, p<0.001) and multiple (F=3.20, p=0.048) crown types. A Tukey post hoc test showed the difference to be between: Mesial and Distal (t= 4.57, p<0.001), Mesial and mid (t=3.84, p=0.002).

Table 5.16: Comparison of marginal fit determined by mean marginal gap measurements between crown type (single crown and three unit fixed dental prosthesis) produced from Medit i700 (M700) digital scanner (SD in parentheses)

Measurement (μm)		Crown Type		*t*test value	p-value	95% CI
		Single	Multiple			
Aspect	Facial (n=45)	157.3 (31.9)	181.3 (60.9)	-1.43	0.161	-57.1, 9.9
	Palatal (n=45)	158.6 (62.4)	187.3 (106.7)	-0.96	0.342	-89.1, 31.6
Reference Point	Distal (n=30)	129 (11.9)	203.5 (110.3)	-2.11	0.043	-146.8, -2.2
	Mid (n=30)	140.9 (16.6)	203.6 (84.9)	-2.29	0.029	-118.7, -6.7
	Mesial (n=30)	204 (60.2)	145.9 (37)	3.28	0.003	21.8, 94.4
Overall (n=90)		157.9 (48.7)	184.3 (86.2)	-1.55	0.124	-60.1, 7.4

Table 5.16 shows that there were no significant differences between short and three unit fixed dental restoration while looking at facial and palatal aspect (p>0.05). However the measurements were significantly different (p<0.05) for distal (values) (t=-2.11, p=0.043, 95% CI: -146.8, -2.2), mid (values) (t=-2.29, p=0.029, 95% CI: -118.7, -6.7) and mesial (values) (t=3.28, p=0.003, 95% CI: 21.8, 94.4) measurement units between the two crown (short and long span). However, the overall marginal fit as determined by the marginal gap measurements were not statistically different (t=-1.55, p=0.124, 95% CI: -60.1, 7.4).

Table 5.17: Marginal fit determined by marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using Medit i500 (M500) digital scanner on models

Crown type	Aspect	Measurement Unit (μm)			Overall marginal
		Distal	Mid	Mesial	

		Facial	Palatal	Facial	Palatal	Facial	Palatal	gap
Single n=30	Mean (SD)	215.8 (81.1)	214 (79.9)	208 (90.1)	176 (51.8)	161.8 (28.0)	200 (0)	195.9 (61.7)
	Median (IQR)	200 (150, 300)	180 (150, 300)	200 (120, 300)	200 (120, 220)	150 (150, 180)	200 (200, 200)	200 (150, 220)
Multiple n=60	Mean (SD)	176 (39.8)	281 (32.1)	300 (0)	168 (36.1)	123 (9.5)	169 (37.2)	202.8 (71.1)
	Median (IQR)	200 (120, 200)	290 (290, 300)	300 (300, 300)	190 (120, 200)	120 (120, 120)	190 (120, 200)	200 (120, 290)

As shown in Table 5.17, only mesial facial median measurements by Made it i500 were within the acceptable marginal fit of 150 micrometers both single crown and three unit fixed dental prosthesis.

Table 5.18: Comparison of marginal fit determined by mean marginal gap measurements between facial and palatal aspects of single crown three unit fixed dental prosthesis produced from Merit i500 (M500) digital scanner (sd in parentheses)

Crown Type	Measurement Aspect (µm)		*t*test value	p-value	95% CI
	Facial	Palatal			
Single (n=30)	195.2 (70.9)	196.7 (53.4)	-0.06	0.949	-48.4, 45.5
Multiple (n=60)	199.7 (78.8)	206 (63.8)	-0.34	0.733	-43.4, 30.7

As shown in Table 5.18, the marginal fit measurements were not significantly different ($p>0.05$) for both single ($t= -0.06$, $p=0.949$, 95% CI: -48.4, 45.5) and multiple ($t= -0.34$, $p=0.733$, 95% CI: -43.4, 30.7) crown types between the two measurement aspects (facial and palatal).

Table 5.19: Comparison of marginal fit determined by mean marginal gap measurements between measurement units of single crown and three unit fixed dental prosthesis produced from Medit i500 (M500) digital scanner (sd in parentheses)

Crown type	Measurement Units (µm)			F statistic value	p-value
	Distal	Mid	Mesial		
Single (n=30)	214.9 (75.9)	192 (71.3)	180.9 (27.5)	0.78	0.469
Multiple (n=60)	228.5 (64.3)	234 (72.1)	146 (35.4)	13.75	<0.001

As shown in table 5.19, there was no significant difference in marginal fit measurements between the three measurement units (distal, mid and mesial) for single crown type (F=0.78, p=0.469) thought the difference was significant for multiple (F=13.75, p<0.001) crown types. A Tukey post hoc test showed the difference to between: Mesial and Distal (t= -4.39, p<0.001), Mesial and mid (t= -4.68, p<0.001).

Table 5.20: Comparison of marginal fit determined by mean marginal gap measurements between crown type (single crown and three unit fixed dental prosthesis) produced from Medit i500 (M500) digital scanner (sd in parentheses)

Measurement (µm)		Crown Type		*t*test value	p-value	95% CI
		Single	Multiple			
Aspect make one	Facial (n=45)	195.2 (70.9)	199.7 (78.8)	-0.18	0.854	-53.1, 44.1

	Palatal (n=45)	196.7 (53.4)	206 (63.8)	-0.49	0.629	-47.9, 29.3
Reference Point	Distal (n=30)	214.9 (75.9)	228.5 (64.3)	-0.51	0.611	-67.7, 40.5
	Mid (n=30)	192 (71.3)	234 (72.1)	-1.51	0.142	-99, 15
	Mesial (n=30)	180.9 (27.5)	146 (35.4)	2.72	0.011	8.6, 61.2
Overall (n=90)		195.9 (61.7)	202.8 (71.1)	-0.45	0.652	-37.2, 23.4

As shown in Table 5.20, there were no significant differences between short and three unit fixed dental restoration while looking at facial and palatal aspect ($p>0.05$). However the measurements were significantly different ($p<0.05$) for mesial (values) ($t=2.72$, $p=0.011$, 95% CI: 8.6, 61.2), between the two crown (short and long span). Though, the overall marginal fit as determined by the marginal gap measurements were not statistically different ($t= -0.45$, $p=0.652$, 95% CI -37.2, 23.4).

Table 5.21: Summary of marginal fit determined by mean marginal gap measurements of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional impression and four digital scanners on models (SD in parenthesis)

Impression method	Crown type	Measurement Units (µm)			Overall marginal
		Distal	Mid	Mesial	

		Facial	Palatal	Facial	Palatal	Facial	Palatal	gap (µm)
Conventional impression (PE)	Single n=30	199.8 (122.1)	124 (16.7)	184 (35.8)	152 (43.8)	120 (0)	127.8 (25.8)	151.3 (60.1)
	Multiple n=60	120 (0)	164 (53.6)	110 (10.5)	159.5 (35.4)	165 (65.2)	205 (36.9)	153.9 (50.1)
Dental Wings scanner (DW)	Single n=30	154 (13.4)	180 (83.7)	176 (45.6)	180 (30.8)	224 (125.2)	196 (8.9)	185 (63.7)
	Multiple n=60	173 (33.7)	260 (69.9)	199 (43.8)	254 (43)	267 (132)	192 (85.5)	224.2 (81.7)
Carestream scanner (CS)	Single n=30	132 (16.4)	157.4 (41.4)	271.6 (101.3)	249.8 (70.4)	114 (21.9)	138 (50.2)	177.1 (81.3)
	Multiple n=60	138 (34.3)	189 (36.7)	174.4 (34.4)	125.7 (30.9)	105 (15.8)	146.4 (54.5)	146.4 (44.9)
Medit i700 scanner (M700)	Single n=30	132 (11)	126 (13.4)	140 (0)	141.8 (24.8)	200 (0)	208 (90.1)	158 (48.7)
	Multiple n=60	177 (21.1)	230 (153.8)	215 (85.1)	192.2 (87.8)	152 (44.9)	139.8 (28.2)	184.3 (86.2)
Medit i500 scanner (M500)	Single n=30	215.8 (81.1)	214 (79.9)	208 (90.1)	176 (51.8)	161.8 (28.0)	200 (0)	195.9 (61.7)
	Multiple n=60	176 (39.8)	281 (32.1)	300 (0)	168 (36.1)	123 (9.5)	169 (37.2)	202.8 (71.1)

Table 5.21 is a summary table of the results of objectives one and two. The results of the marginal fit determined by mean marginal gap measurements of single crown restorations show that the marginal gap ranged between 151.3±60.1µm for conventional impressions and 195.9±61.7µm for Medit i500 digital scanner. For three-unit fixed dental prostheses, the results of the marginal fit determined by mean marginal gap measurements show that the marginal gap ranged between 146.4±44.9µm for Carestream digital scanner and 224.2±81.7µm for Dental Wings digital scanner.

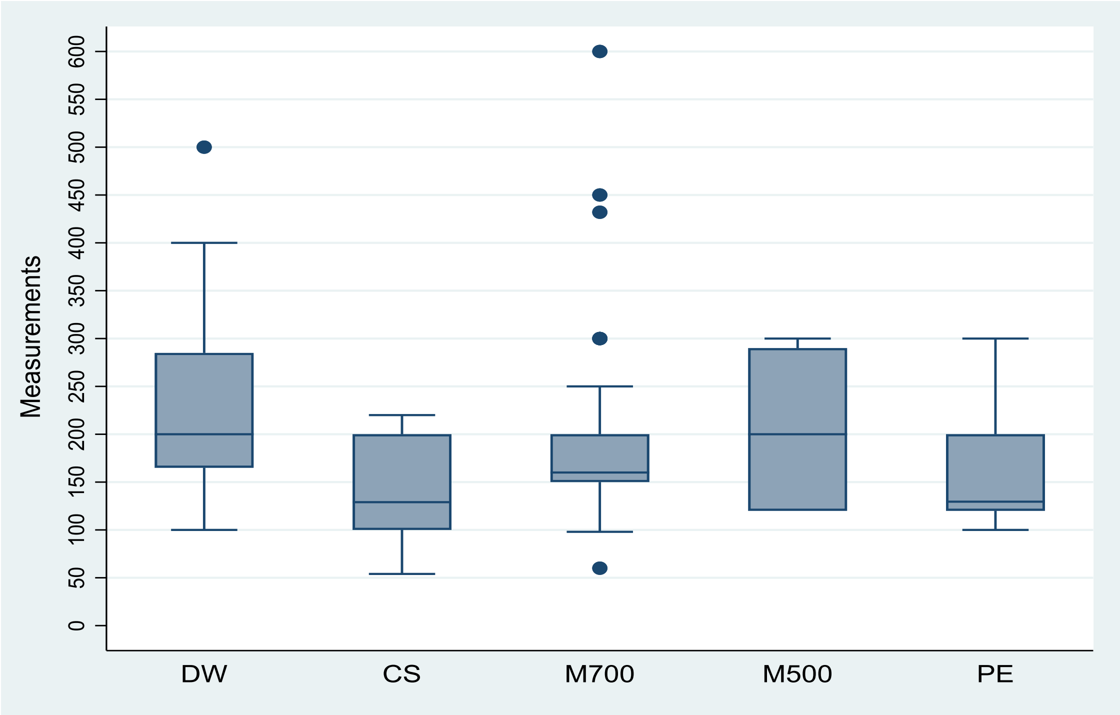

Figure 5.1: Summary of marginal fit determined by median marginal gap measurements of restorations (single crown) fabricated using conventional impression and four digital scanners on models

Figure 5.1 is a bar and whisker plot showing the results of the marginal fit determined by median marginal gap measurements of single crown restorations. For the single crowns, the lowest median marginal gaps were recorded for the conventional (polyether) impressions (120, interquartile range 120 – 200µm) while the highest marginal gaps were recorded for Medit i500 (M500) digital scanner (200, interquartile range 150 – 220µm).

5.4 Objective three: To determine the overall fit of three unit fixed dental restorations (three - unit fixed dental prostheses) fabricated using conventional or digital impressions on models

Table 5.21: Overall fit determined by mean measurements of three-unit restorations fabricated using conventional and digital impressions on models

Crown Type		**Impression method and measurements (µm)**				
		DW	**CS**	**M700**	**M500**	**PE**
Multiple (n=60)	Median (IQR)	200 (165, 285)	129 (100, 200)	160 (150, 200)	200 (120, 290)	129.5 (120, 200)
	Mean (SD)	224.2 (81.7)	146.4 (44.9)	184.3 (86.2)	202.8 (71.1)	153.9 (50.1)
One way ANOVA F statistic = 13.52, p<0.001**						
χ^2 value for Kruskal-Wallis test = 46.64, p<0.001						

As shown in Table 5.22, for multiple crown types, Carestream (CS) digital impressions recorded the lowest mean gap measurements of 146.4±44.9µm followed by polyether impressions (153.9±50.1µm). The highest measurements were recorded for Dental Wings (DW) digital scanner impressions (224.2±81.7µm).

The One way analysis of variance (ANOVA), Kruskal-Wallis and Dunn's post hoc tests showed that the difference between the conventional and digital impression methods was statistically different between Carestream and the other three digital methods (DW, M700 and M500), and between polyether and the same three digital methods (DW, M700 and M500).

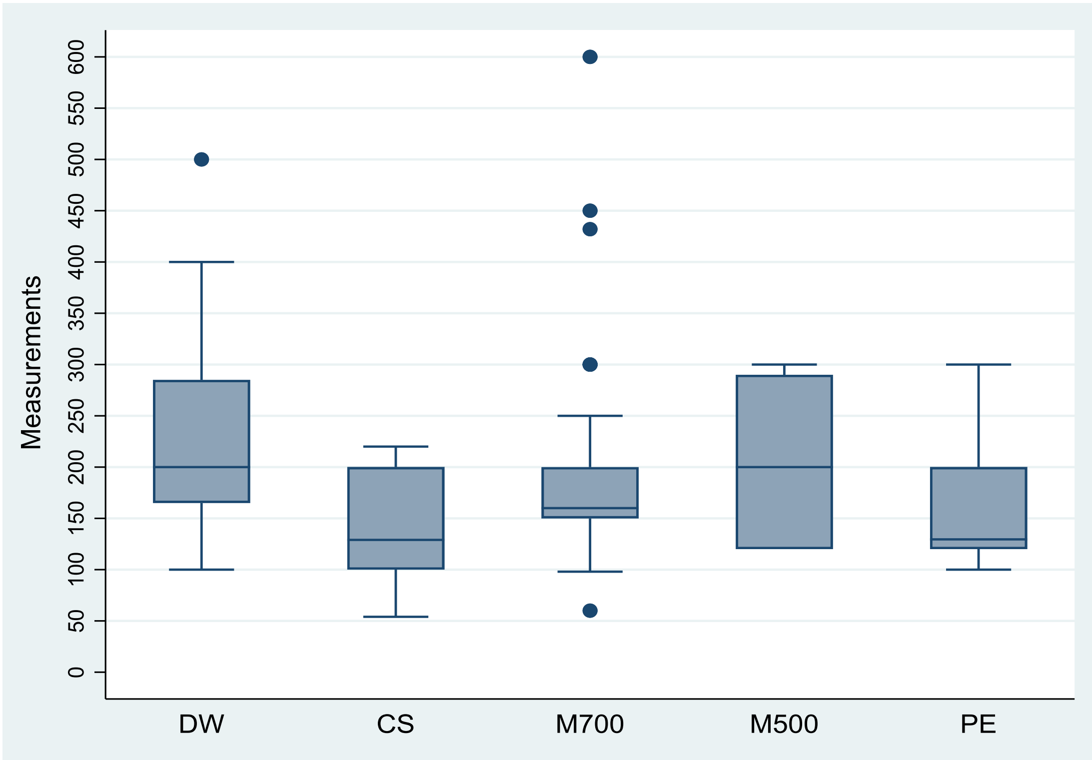

Figure 5.2: Overall fit determined by median gap measurements of restorations (three-unit fixed prostheses) fabricated using conventional and digital impressions on models

Figure 5.2 is a bar and whisker plot showing the results of the overall fit determined by median gap measurements of three-unit fixed prostheses. For the three-unit restorations, the lowest median marginal gaps were recorded for the conventional (polyether) (129.5, interquartile range 120 – 200µm) and Carestream digital impressions (129, interquartile range 100 – 200µm) while the highest marginal gaps were recorded for Dental Wings (DW) (200, interquartile range 165 – 285µm) and Medit i500 (M500) digital impressions (200, interquartile range 120 – 290µm).

5.5 Objective four: To analyze the difference between the two treatment options when used to fabricate short (single crown) and three unit fixed dental (three-unit) fixed dental prostheses

Tables 5.23 to 5.26 show individual comparisons between the conventional impression method (polyether) and each digital impression method.

Table 5.223: Difference between the mean marginal gap measurements of DW and PE for single crown and three unit fixed dental prosthesis (SD in parentheses).

Crown Type	Impression method and measurements (µm)				
	DW	**PE**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	185(63.7)	151.3(60.1)	2.71	0.039	1.7, 65.7
Multiple (n=120)	224.2(81.7)	153.9(50.1)	6.46	<0.001	45.7, 94.7

Table 5.23 shows significant differences in marginal fit measurements between DW and PE impression methods for single (t= 2.71, p=0.039, 95% CI: 1.7, 65.7) and multiple (t= 6.46, p<0.001, 95% CI: 45.7, 94.7) crown types where DW marginal fit measurement were larger than those of PE.

Table 5.234: Difference between the mean marginal gap measurements of CS and PE for single crown and three unit fixed dental prosthesis (SD in parentheses).

Crown Type	Impression method and measurements (µm)				
	CS	**PE**	***t*test value**	**p-value**	**95% CI**

Single (n=60)	177.1 (81.3)	151.3(60.1)	1.40	0.166	-11.6, 62.8
Multiple (n=120)	146.4 (44.9)	153.9(50.1)	-0.86	0.390	-24.7, 9.7

Table 5.24 shows that the average marginal fit measurements were statistically equal ($p>0.05$) between CS and PE impression methods for both single crown multiple crown types.

Table 5.245: Difference between the mean marginal gap measurements of M700 and PE for single crown and three unit fixed dental prosthesis (SD in parentheses).

Crown Type	**Impression method and measurements (µm)**				
	M700	**PE**	***t*****test value**	**p-value**	**95% CI**
Single (n=60)	157.9 (48.7)	151.3(60.1)	0.47	0.637	-21.6, 34.9
Multiple (n=120)	184.3 (86.2)	153.9(50.1)	2.36	0.020	4.9, 55.9

Table 5.25 shows that the average multiple crown marginal fit measurements for M700 impression method were significantly larger ($t=2.36$, $p=0.020$, 95% CI: 4.9, 55.9) than those of PE. However, the difference was not statistically different for single crown types.

Table 5.256: Difference between the mean marginal gap measurements of M500 and PE for single crown and three unit fixed dental prosthesis (SD in parentheses).

Crown Type	**Impression method and measurements (µm)**				
	M500	**PE**	***t*****test value**	**p-value**	**95% CI**

Single (n=60)	195.9 (61.7)	151.3(60.1)	2.84	0.006	13.2, 76.1
Multiple (n=120)	202.8 (71.1)	153.9(50.1)	4.35	<0.001	26.7, 71.2

Table 5.26 shows that on average, the marginal fit measurements for M500 impression method were significantly larger than those of PE for both single (t=2.84, p=0.006, 95% CI: 13.2, 76.1) and multiple crown types (t=4.35, p<0.001, 95% CI: 26.7, 71.2).

Table 5.267: Difference in the mean and median marginal gap measurements of the five impressions methods for single crown and three unit fixed dental prosthesis.

Crown Type	**Impression method and measurements (μm)**							
		DW	**CS**	**M700**	**M500**	**PE**	**test statistic**	**p-value**
Single (n=60)	Median (IQR)	180 (150, 200)	150 (120, 220)	140 (120, 200)	200 (150, 220)	120 (120, 200)	**14.68***	**0.005**
	Mean (SD)	**185 (63.7)**	**177.1 (81.3)**	**158.0 (48.7)**	**195.9 (61.7)**	**151.3 (60.1)**	**2.54****	**0.042**
Multiple (n=120)	Median (IQR)	200 (165, 285)	129 (100, 200)	160 (150, 200)	200 (120, 290)	129.5 (120, 200)	**46.64***	**<0.001**
	Mean (SD)	**224.2 (81.7)**	**146.4 (44.9)**	**184.3 (86.2)**	**202.8 (71.1)**	**153.9 (50.1)**	**13.52****	**<0.001**

***χ^2 value for Kruskal-Wallis test**

****F test value for One Way ANOVA**

Table 5.27 shows the difference in the mean and median marginal gap measurements of the five impression methods for single crown and three unit fixed dental prosthesis.

Kruskal-Wallis test done showed there was a significant difference in average marginal fit between impression methods for both single crown multiple crown (p<0.01).

Table 5.28: Summary of difference in mean and median marginal gap measurements of restorations fabricated from conventional and digital impressions

Crown Type	**Impression method and measurements (µm, sd in parenthesis)**		***t*test value**	**p-value**	**95% CI**	**ANOVA F statistic**	**Kruskall -Wallis χ^2**	**Dunn's post-hoc p-value**
	DW	**PE**						
Single (n=60)	185 (63.7)	151.3 60.1)	2.71	0.039	1.7, 65.7	Single crown (n=150) F=**2.54** p=**0.042**	Single crown (n=150) F=**14.68** p=**0.005**	<0.01
Multiple (n=120)	224.2 (81.7)	153.9 (50.1)	6.46	<0.001	45.7, 94.7			<0.001
	CS	**PE**						
Single (n=60)	177.1 (81.3)	151.3 (60.1)	1.40	0.166	-11.6, 62.8	Three-unit (n=300) F=**13.52** p<**0.001**	Three-unit (n=300) F=**46.64** p<**0.001**	
Multiple (n=120)	146.4 (44.9)	153.9 (50.1)	-0.86	0.390	-24.7, 9.7			
	M700	**PE**						
Single (n=60)	157.9 (48.7)	151.3 (60.1)	0.47	0.637	-21.6, 34.9			
Multiple (n=120)	184.3 (86.2)	153.9 (50.1)	2.36	0.020	4.9, 55.9			
	M500	**PE**						
Single (n=60)	195.9 (61.7)	151.3 (60.1)	2.84	0.006	13.2, 76.1			<0.001
Multiple (n=120)	202.8 (71.1)	153.9 (50.1)	4.35	<0.001	26.7, 71.2			<0.001

Table 5.28 summarizes the results presented in Tables 5.23 to 5.27. Kruskal-Wallis test done showed a significant difference in average marginal fit between impression methods for both single crown multiple crown (p<0.01). The Dunn's Post Hoc test done showed the significant difference was between PE and DW and PE and M500 for both single crown and three unit fixed dental prosthesis.

Tables 5.29 to 5.34 show comparisons among the digital impression methods in both single crown three-unit fixed prostheses. Most of the statistically significant differences were observed for the three-unit multiple restorations (DW and CS; DW and M700; CS and M700; and, CS and M500). The only statistically significant difference for the single crown was observed between M500 and M700).

Table 5.279: Difference between the mean marginal gap measurements for DW and CS for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	DW	**CS**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	185 (63.7)	177.1 (81.3)	0.42	0.678	-29.3, 45.6
Multiple (n=120)	224.2 (81.7)	146.4 (44.9)	6.46	<0.001	53.9, 101.6

Table 5.28: Difference between the mean marginal gap measurements for DW and M700 for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	DW	**M700**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	185 (63.7)	157.9 (48.7)	1.85	0.070	-2.3, 56.3
Multiple (n=120)	224.2 (81.7)	184.3 (86.2)	2.59	0.011	9.5, 70.2

Table 5.31: Difference between the mean marginal gap measurements for DW and M500 for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	DW	**M500**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	185 (63.7)	195.9 (61.7)	-0.67	0.502	-43.3, 21.5
Multiple (n=120)	224.2 (81.7)	202.8 (71.1)	1.52	0.129	-6.3, 49.0

Table 5.292: Difference between the mean marginal gap measurements for CS and M700 for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	CS	**M700**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	177.1 (81.3)	157.9 (48.7)	1.11	0.272	-15.5, 53.8
Multiple (n=120)	146.4 (44.9)	184.3 (86.2)	-3.02	0.003	-62.8, -13.1

Table 5.30: Difference between the mean marginal gap measurements for CS and M500 for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	CS	**M500**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	177.1 (81.3)	195.9 (61.7)	-1.01	0.317	-56.1, 18.5
Multiple (n=120)	146.4 (44.9)	202.8 (71.1)	-5.19	<0.001	-77.9, -34.9

Table 5.31: Difference between the mean marginal gap measurements for M700 and M500 for single crown and three unit fixed dental prosthesis.

Crown Type	Impression method and measurements (µm)				
	M700	**M500**	***t*test value**	**p-value**	**95% CI**
Single (n=60)	157.9 (48.7)	195.9 (61.7)	-2.64	0.011	-66.7, -9.2
Multiple (n=120)	184.3 (86.2)	202.8 (71.1)	-1.28	0.202	-47.1, 10.1

Table 5.32: Difference in the mean marginal measurements of the four digital scanner impression methods in both single crown and three unit fixed dental prosthesis restorations

Crown Type	Impression method and measurements (μm)					
	DW	**CS**	**M700**	**M500**	**F statistic**	**p-value**
Single (n=60)	185 (63.7)	177.1 (81.3)	158.0 (48.7)	195.9 (61.7)	1.83*	0.146
Multiple (n=120)	224.2 (81.7)	146.4 (44.9)	184.3 (86.2)	202.8 (71.1)	12.32*	<0.001

***F test value for One Way ANOVA**

Table 5.35 shows the difference in the mean marginal gap measurements of the four digital impression methods for single crown and three unit fixed dental prosthesis. One way analysis of variance (ANOVA) test done showed there was no significant difference in average marginal gap measurements among digital impression methods for single crowns (p=0.146). However, for the three-unit restorations, the difference in average marginal gap measurements was statistically significant (p<0.001).

Table 5.36: Summary of difference in mean marginal gap measurements of restorations fabricated from digital impressions

Crown Type	**Impression method and measurements (μm, sd in parenthesis)**		***t* value**	**p-value**	**95% CI**	**ANOVA F statistic**	**Tukey's post-hoc p-value**
	DW	**CS**					
Single (n=60)	185 (63.7)	177.1 (81.3)	0.42	0.678		Single crown (n=120)	
Multiple (n=120)	224.2 (81.7)	146.4 (44.9)	6.46	<0.001	53.9, 101.6	F=**1.83** p=**0.146**	t=-5.85 p<0.001
	DW	**M700**					
Single (n=60)	185 (63.7)	157.9 (48.7)	1.85	0.070	-2.3, 56.3	Three unit fixed dental prosthesis(n=240)	
Multiple (n=120)	224.2 (81.7)	184.3 (86.2)	2.59	0.011	9.5, 70.2	F=**12.32** p<**0.001**	t=-3 p=0.016
	DW	**M500**					
Single (n=60)	185 (63.7)	195.9 (61.7)	-0.67	0.502	-43.3, 21.5		
Multiple (n=120)	224.2 (81.7)	202.8 (71.1)	1.52	0.129	-6.3, 49.0		
	CS	**M700**					
Single (n=60)	177.1 (81.3)	157.9 (48.7)	1.11	0.272	-15.5, 53.8		
Multiple (n=120)	146.4 (44.9)	184.3 (86.2)	-3.02	0.003	-62.8, -13.1		t=2.85 p=0.024
	CS	**M500**					
Single (n=60)	177.1 (81.3)	195.9 (61.7)	-1.01	0.317			
Multiple (n=120)	146.4 (44.9)	202.8 (71.1)	-5.19	<0.001			t=4.25 <0.001
	M700	**M500**					
Single (n=60)	157.9 (48.7)	195.9 (61.7)	-2.64	0.011	-66.7, -9.2		
Multiple (n=120)	184.3 (86.2)	202.8 (71.1)	-1.28	0.202	-47.1, 10.1		

Table 5.36 summarizes the results presented in Tables 5.29 to 5.36. One way analysis of variance (ANOVA) test showed there was no significant difference in average marginal gap measurements among digital impression methods for single crowns (p=0.146). However, for the three-unit restorations, the difference in average marginal gap

measurements was statistically significant ($p<0.001$). the Tukey's post hoc test showed the significant difference was between: CS and DW ($t=-5.85$, $p<0.001$); M700 and DW ($t=-3$, $p=0.016$); M700 and CS ($t=2.85$, $p=0.024$); M500 and CS ($t=4.25$, $p<0.001$).

5.6 Hypothesis Testing

1. H_0: There was no significant difference in the marginal fit of fixed dental prostheses (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions.

H_A: There was a significant difference in the marginal fit of fixed dental prostheses (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions.

As shown in summary Tables 5.28 and 5.36, significant differences were observed in the marginal fit as determined by marginal gap measurements of fixed dental prostheses (single crown and three unit fixed dental prosthesis) fabricated from conventional and digital impressions. Dunn's and Tukey's pos-hoc tests showed that these differences were between polyether and Dental Wings and M500 digital scanners for both types of restorations. However, among the digital impressions, significant differences were observed between Dental Wings and Carestream, Dental Wings and M700, Carestream and M700 and Carestream and M500 for the multiple restorations.

Therefore, we failed to reject the null hypothesis.

2. H_0: There was no significant difference in the overall fit of three unit fixed dental prostheses fabricated from conventional and digital impressions.

H_A: There was a significant difference in the marginal fit of three unit fixed dental prostheses fabricated from conventional and digital impressions.

As shown in summary Table 5.22, significant differences were observed in the overall fit of three-unit fixed dental prostheses fabricated from conventional and digital impressions. Tukey's post hoc test showed that these differences were between Dental Wings, M700 and M500, and Carestream and polyether impressions (Tables 5.28 and 5.36).

Therefore, we failed to reject the null hypothesis.

CHAPTER SIX

6. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

This study aimed to evaluate the marginal and overall fit o single crown and three-unit fixed dental prostheses fabricated rom conventional or digital impressions in Nairobi, Kenya. Various authors have proposed marginal gap measurements of 75, 100, 160, and even 200 µm to be within the acceptable range [27]. Moreover, recently, a marginal discrepancy of up to 50µm has been suggested as an acceptable limit [28]. In this study, a marginal fit for crowns as determined by mean marginal gap measurements of 150 micrometers (µm) or less was deemed acceptable from a clinical standpoint.

6.1.1 Marginal and overall fit of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional impressions on models.

Conventional impressions produced single crown restorations with mean marginal gap measurements of 151.3±60.1 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 153.9±50.1 µm (Table 5.1). These marginal gap measurements were not significantly excessive of the acceptable measurement of 150µm.

While the overall marginal gap measurements for both crown types were acceptable, comparison of the facial and palatal aspects (Table 5.2), and distal, mesial and middle aspects (Table 5.3) within the individual prostheses showed that significant differences were observed between these aspects only for the three-unit fixed prosthesis but not for the single crown.

Statistically there was no significant difference in mean marginal gap measurements between facial (167.9 ±76.8) and palatal (134.6 ±31.4) aspects in the single crown prosthesis (t=1.56, p=0.131, 95% CI -10.5, 77.2). However, a statistically significant difference was observed between the facial and palatal aspect measurements in the three unit fixed dental prosthesis (t=-3.81, p<0.001, 95% CI -67.8, -21.2) (Table 2).

Likewise, when comparing the marginal fit measurements between distal, mid, and mesial measurement units for conventional impressions, there was no significant difference in mean marginal gap measurements between distal (161.9 ±91.3), middle (168 ±41.3) and mesial (123.9 ±17.7) measurement units in the single crown prosthesis (F=1.65, p=0.210). But there was a significant difference in the marginal gap between the three measurement units in the three unit fixed dental prostheses (F=7.09, p=0.002) (Table 5.3).

However, comparison of the measurements for the two prostheses showed that the measurements for the three-unit prostheses were significantly higher than those for the single crowns for the palatal (t=-3.13, p=0.003, 95% CI -68.3, -14.8) and mesial aspects (t=-3.37, p=0.002, 95% CI -98.2, -23.9) only (Table 5.4). Measurements for the single crowns were significantly higher than those for the three-unit prostheses for the middle aspect (t=2.27, p=0.031, 95% CI 3.3, 63.2). Nonetheless, there was no statistically significant difference in the overall marginal gap measurements of the single crown and three unit fixed dental prostheses produced from conventional impressions (t=-0.22, p=0.825, 95% CI -26.5, 21.2).

Polyvinyl siloxane and polyether are presently the recommended conventional impression materials for prosthodontic treatment due to their accuracy, fine detail reproduction and dimensional stability. Polyether has the additional advantage of being hydrophilic hence ideal in the moist oral environment [29, 33]. The acceptable marginal gap measurements of restorations produced from polyether in this study confirmed its suitability as a control for comparison of the newer digital systems. The accuracy was further ensured by utilizing the impression material with a custom tray as recommended [39].

6.1.2 Marginal and overall fit of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional impressions on models.

Because several digital scanning techniques are available in the market presently [1, 42, 47, 48, 50, 51, 52, 53, 54, 55, 56, 57, 58], in this study, four digital scanning systems that are commonly used in the Kenyan market were selected for evaluation.

Dental Wings (DW) digital scanner produced single crown restorations with mean marginal gap measurements of 185.0±63.7 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 224.2±81.7 µm (Table 5.5). These marginal gap measurements were significantly excessive of the acceptable measurement of 150µm.

While the overall marginal gap measurements for both crown types were significantly higher than is acceptable, comparison of the facial and palatal aspects (Table 5.6), and distal, mesial and middle aspects (Table 5.7) within the individual prostheses showed that there were no significant differences observed between these aspects for both the single crown as well as the three-unit fixed prostheses.

However, comparison of the measurements for the two prostheses showed that the measurements for the three-unit prostheses were consistently higher than those for the single crown (Table 5.8). Significant differences were observed in the palatal aspects ($t=-7.86$, $p=0.021$, 95% CI -92.1, -7.9), middle aspects ($t=-2.68$, $p=0.012$, 95% CI -85.6, -11.4) and the overall marginal gap measurements ($t=-2.30$, $p=0.024$, 95% CI -73, -5.3).

Carestream 3600 (CS) digital scanner produced single crown restorations with mean marginal gap measurements of 177.1±81.3 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 146.4±44.9 µm (Table 5.9). While the marginal gap measurements for the single crowns were higher than the acceptable measurement of 150µm, those for the three-unit prostheses were lower. Comparison of the facial and palatal aspects (Table 5.10), and distal, mesial and middle aspects (Table 5.11) within the individual prostheses showed significant differences between the distal, mesial and middle aspects for the three-unit fixed prostheses ($F=4.01$, $p=0.023$).

However, comparison of the measurements for the two prostheses showed that the measurements for the single crown were consistently higher than those for the three-unit prostheses except in the distal aspect (Table 5.12). Nonetheless, this difference was significant only in the middle aspect ($t=4.95$, $p<0.001$, 95% CI 64.9, 156.4) and the overall marginal gap measurements ($t=2.31$, $p=0.023$, 95% CI 4.3, 57.1).

Medit i700 (M700) digital scanner produced single crown restorations with mean marginal gap measurements of 158.0±48.7 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 184.3±86.2 µm (Table 5.13). These measurements were excessive of the acceptable measurement of 150µm. Comparison of the facial and palatal aspects (Table 5.14), and distal, mesial and middle aspects (Table 5.15) within the individual prostheses showed significant differences observed between the distal, mesial and middle aspects for both the single crown ($F=12.05$, $p<0.001$) and the three-unit prostheses ($F=3.20$, $p=0.048$).

However, comparison of the measurements for the two prostheses showed that the measurements for the three-unit prostheses were consistently higher than those for the single crown except in the mesial aspect (Table 5.16). Nonetheless, this difference was significant in the distal ($t=-2.11$, $p=0.043$, 95% CI -146.8, -2.2), middle ($t=-2.29$, $p=0.029$, 95% CI -118.7, -6.7) and mesial aspects ($t=3.28$, $p=0.003$, 95% CI 21.8, 94.4) but not the overall marginal gap measurements ($t=-1.55$, $p=0.124$, 95% CI -60.1, 7.4).

Medit i500 (M500) digital scanner produced single crown restorations with mean marginal gap measurements of 195.9±61.7 µm and three-unit fixed restorations with mean marginal and overall gap measurements of 202.8±71.1 µm (Table 5.17). These marginal gap measurements were significantly excessive of the acceptable measurement of 150µm.

Comparison of the facial and palatal aspects (Table 5.18), and distal, mesial and middle aspects (Table 5.19) within the individual prostheses showed significant differences observed between the distal, mesial and middle aspects only for the three-unit fixed prostheses ($F=13.75$, $p<0.001$).

However, comparison of the measurements for the two prostheses showed that the measurements for the three-unit prostheses were consistently higher than those for the single crown except in the mesial aspect (Table 5.20). This difference was significant only in the mesial aspect (t=2.72, p=0.011, 95% CI 8.6, 61.2) but not the overall marginal gap measurements (t=-0.45, p=0.652, 95% CI -37.2, 23.4).

Dental Wings is a digital product from the Straumann Group, a Canadian Company. The CS 3600 (Carestream Dental, Atlanta, Georgia, USA) intraoral scanner, is one of the latest powder-free intraoral scanners enabling dental professionals to scan patients' teeth to create color 3D images[1]. Like the CEREC BlueCam, it is a click-and-point system, requiring the user to keep the wand still during capturing[57].

Medit500 is a Korean intraoral scanner marketed as an 'easy entry into digital dentistry' due to its affordability as compared to other systems. However, unlike systems like CEREC, Dental Wings and Carestream that offer a complete digital workflow, Medit500 is supplied only as a laboratory scanner. The intraoral scanner from the same company is Medit700, with superior specifications to the laboratory scanner. The Medit500 is the initial model, first manufactured in 2012 as compared to Medit700 which was manufactured in 2015. The latter is an improvement on the former. Studies that are available in the manufacturer's website [65, 66] imply that even though both give results that are still within the acceptable range in terms of marginal fit, Medit700 has superior qualities in terms of marginal fit and this is for both single crown and three unit fixed dental prosthesis /restorations. The Medit digital scanners are compatible with a wide range of applications that use software that allows import of STL, PLY and OBJ files.

All these digital systems boast clinician and patient convenience by using computerized, laser, optical and miniaturization technologies to synchronize intraoral and laboratory processes to enable single appointment fixed prostheses [1, 37].

For single crowns, none of the digital systems recorded marginal gap measurements within the acceptable limit of 150 µm, unlike crowns produced from polyether.

For three-unit fixed dental prostheses, only Carestream 3600 digital scanner recorded marginal gap measurements within the acceptable limit of 150 µm, like crowns produced from polyether.

6.1.3 Comparison of marginal and overall fit of restorations (single crown and three unit fixed dental prosthesis) fabricated using conventional and digital impressions on models.

Comparison of marginal and overall gap measurements of single crown and three-unit fixed dental prosthesis revealed significant differences.

The overall fit of the three-unit prosthesis was significantly different among the five impression methods, both digital and conventional ($F=13.52$, $\chi^2=46.64$, $p<0.001$) (Tables 5.22 and 5.28) and among the four digital methods ($F=12.32$, $p<0.001$) (Table 5.36).

Dunn's (Table 5.28) post hoc test showed that the difference in overall fit between the conventional and digital impression methods was statistically significant between polyether and three digital methods (DW – $p<0.001$, M700 – $p=0.02$ and M500<0.001) but not CS.

The Tukey's post hoc test (Table 5.36) showed that the difference in overall fit among the digital impression methods was statistically significant between Carestream and the other three digital methods (DW – $p<0.001$, M700 – $p=0.024$ and M500 – $p<0.001$) and Dental Wings and M700 ($p=0.016$).

The marginal fit of the single crown prosthesis was significantly different among the five impression methods, both digital and conventional ($F=2.54$, $p=0.042$, $\chi^2=14.68$, $p=0.005$) (Table 5.27) but not among the four digital methods ($F=1.83$, $p=0.146$) (Table 5.36).

Dunn's (Table 5.28) post hoc test showed that the difference in marginal fit between the conventional and digital impression methods was statistically significant between polyether and two digital methods (DW – $p<0.01$ and M500 – $p<0.001$) but not CS or M700.

Literature is inconclusive on the difference between conventional and digital impression methods to produce fixed restorations, particularly regarding the restoration span. With imminent problems such as dental caries and loss of retention [61], marginal and overall fit of the fixed prostheses are crucial considerations.

Howell et al. [64] found that the digital impression approach using Encode abutments resulted in casts that were less accurate than those produced from conventional impressions. Andressien et al. [26] found that the iTero scanner produced inaccurately fitting supra-structures for mandibular bar overdentures.

Yet contrarily, Su and Sun [65] reported that marginal and internal fit values of digitally produced three-unit ceramic fixed dental restorations were significantly smaller than those conventionally produced. Moreover, Cheng at al. [66] was able to demonstrate the time efficiency of the digital systems. However, one study by Eliasson and Ortorp [25] determined that both digital and conventional methods were associated with inaccuracies.

In this study, both digital and conventional impressions were shown to have acceptable clinically simulated outcomes when fabricating restorations for both single crowns and three-unit fixed partial prosthesis. Specifically, conventionally produced restorations were within acceptable mean margins of 150 µm for both short and three unit fixed dental prostheses, while Carestream was acceptable for the three unit fixed dental prosthesis but not the single crown prostheses and M700 was acceptable for the single crown but not the three unit fixed dental prostheses. On considering the mean values and standard deviations, all methods demonstrated some measurements within clinically acceptable values of 150 µm.

Similar research done by Gimenez et al. [51] showed that both digital and conventional impression materials can be used to accurately produce acceptable restorations for marginal fit. However, in terms of the span of the restorations whether short or long single unit and three unit fixed dental prosthesis, the current study showed that this was dependent on the digital system. Moreover, this may further be dependent on the user experience to improve outcome. Patzelt et al. [54] also investigated the relationship between the span length and digital or conventional impression methods and concluded that for single crowns, digital impressions did better than the conventional impressions. These findings were in tandem with the results observed for M700 in the current study.

Although the high cost of these systems still hinders their introduction into clinical reality, this study is invaluable in advising dental clinicians and technologists about the ideal impression materials. This is especially relevant when choosing between conventional or digital impressions to fabricate single crown or three unit fixed dental prosthesis as in the case of three unit l fixed partial prosthesis.

6.2 Conclusion

Within the limitations of this study, the subsequent conclusions were made:

1. Conventional impressions produced restorations within clinically acceptable marginal gap limits of approximately 150µm for both single crowns and three-unit fixed dental prostheses.

2. Carestream produced restorations within clinically acceptable marginal and overall gap limits of approximately 150µm for three-unit fixed dental prostheses.
3. Medit700 produced restorations within clinically acceptable marginal gap limits of approximately 150µm for single crowns prostheses.
4. Significant differences were observed between the conventional and digital impression techniques, which were dependent on the specific technique and possibly user experience. The marginal fit of the single crown prosthesis was significantly different among the five impression methods, both digital and conventional ($F=2.54$, $p=0.042$, $\chi^2=14.68$, $p=0.005$) but not among the four digital methods ($F=1.83$, $p=0.146$). Dunn's post hoc test showed that the difference in marginal fit between the conventional and digital impression methods was statistically significant between polyether and two digital methods (DW – $p<0.01$ and M500 – $p<0.001$) but not CS or M700.
5. The overall fit of the three-unit prosthesis was significantly different among the five impression methods, both digital and conventional ($F=13.52$, $\chi^2=46.64$, $p<0.001$) and among the four digital methods ($F=12.32$, $p<0.001$). Dunn's post hoc test showed that the difference in overall fit between the conventional and digital impression methods was statistically significant between polyether and three digital methods (DW – $p<0.001$, M700 – $p=0.02$ and M500<0.001) but not CS. Tukey's post hoc test showed that the difference in overall fit among the digital impression methods was statistically significant between Carestream and the other three digital methods (DW – $p<0.001$, M700 – $p=0.024$ and M500 – $p<0.001$) and Dental Wings and M700 ($p=0.016$).

6.3 Recommendations

The study's findings necessitate the proposition of the following recommendations:

1. Both digital and conventional impression methods are accurate impression methods when fabricating restorations for fixed dental prosthesis.
2. Conventional impressions are suitable for producing accurate fixed restorations and may be used for both short and long span.
3. Systems with complete digital workflows such as Carestream 3600 may be better for intraoral scanning for multiple or three unit fixed dental prosthesis as compared to those that rely on separate applications such as the Medit brand.
4. Systems that depend on exported files on compatible software such as the Medit brand may be better for intraoral scanning for single crown restorations. Further, intraoral scanners and laboratory scanners should not be used interchangeably.
5. More research is needed to correlate the above observations by scrutinizing the various digital techniques present in the market today to ascertain their accuracy.

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APPENDICES

Appendix I: Research Budget

ITEM	TOTAL COST (KSHS)
Hiring of the 4 scanners	100,000
Zirconia blocks	
	150,000
Labor in the lab	
	70,000
Photography	
Research assistant	50,000
Polyether impression material	
	50, 000
Dental stone	
	50,000
Data Analyst Wages	20,000.00
Photography	
Printing and Binding Reports	10,000.00
Total	**600,000.00**

Appendix II: Work Plan

Activity	Aug 20	Oct-Dec20	Jan - Apr 21	May - Jun21	Aug 21	Dec21	Apr. - Jul22	Aug22
Proposal defense	■							
Ethical approval		■						
Pilot Test		■						
Data Collection			■					
Data Analysis				■				
First Report Draft					■			
Revision/Completion of Report						■		
Thesis Defense							■	
Corrections and Completion								■

Appendix III: Data Collection Form

Crown type	Impression technique and Marginal fit measurements (µm)				
	Digital Group samples				
	P1	P2	P3	P4	P5
Short-span					
Long-span					
	Conventional Group samples				
	P1	P2	P3	P4	P5
Short-span					
Long-span					
	Impression technique and overall fit measurements (µm)				
	Digital Group samples				
	P1	P2	P3	P4	P5
Long-span					
	Conventional Group samples				
Long-span					