A COMPARATIVE ASSESSMENT OF MANUAL VERSUS DIGITAL ANALYSIS OF QUALITY OF TOOTH PREPARATIONS FOR SINGLE CROWNS IN NAIROBI, KENYA

DR ALEXANDER M. MWANGI

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DECLARATION OF ORIGINALITY

I, Dr. Alexander Muchiri Mwangi declare that this thesis titled**: '****A comparative assessment of manual versus digital analysis of quality of tooth preparations for single crowns in Nairobi, Kenya**' is my authentic work that has not been submitted elsewhere for examination or award of a degree.

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Signature ………………………… Date 12th September 2023

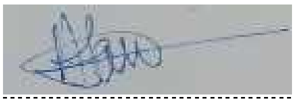
Dr. Alexander Muchiri Mwangi BDS (Nbi)

SUPERVISORS APPROVAL

This proposal has been submitted with our approval as University of Nairobi Supervisors.

Dr. James Muriithi Nyaga, MDS (Prostho.) (Nbi), BDS (Nbi)

Lecturer, Conservative and Prosthetic Dentistry Unit, Department of Dental Sciences, Faculty of Health Sciences, University of Nairobi

Signature:  Date: 12th September 2023

Dr. Fred Otieno MSc (Restor. Dent.) (Newcastle – Upon Tyne), BDS (Nbi),

Lecturer, Conservative and Prosthetic Dentistry Unit, Department of Dental Sciences, Faculty of Health Sciences, University of Nairobi

Signature:  Date: 12th September 2023

Dr. Olivia Awino Osiro, PhD (Dent. Mater.) (Nbi), MSc (Dent. Mater.) (Lond.), Cert. Applied Biostatistics (UW), BDS (Nbi)

Senior Lecturer, Conservative and Prosthetic Dentistry Unit, Department of Dental Sciences, Faculty of Health Sciences, University of Nairobi

Signature  Date: 12th September 2023

DEDICATION

This work is dedicated to my wife Joyce Ngendo, my parents Michael Mwangi and Alice Wangui, and my dear son Jabali Mwangi who have been the pillars in my life

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LIST OF ABBREVIATIONS

BDS – Bachelor of Dental Surgery

X^2 – Chi Square

° – Degrees

FICD – Fellow of International College of Dentists

KNH – Kenyatta National Hospital

mm – millimeters

MDS – Master of Dental Surgery

OC – Occluso-cervical

SDS – School of Dental Sciences

SPSS – Statistical Package for Social Sciences

FDP - Fixed Dental Prosthesis

PFM - Porcelain Fused to Metal crowns

DEFINITION OF TERMS

Most of the definition of terms were sourced from the Glossary of Prosthodontic Terms.

AutoCAD - A computer aided design program used for 2 dimensional and 3-dimensional design, drafting and measurements

Fixed dental prosthesis - Any prosthesis that is securely luted or mechanically attached to natural teeth or tooth analogues and cannot be removed by the patient

Clinical crown - The portion of the tooth that extends from the occlusal surface or the incisal edge to the free gingival margin.

Convergence angles - The angle, measured in degrees, formed between opposing axial walls when a tooth or teeth are prepared for crowns.

Crown - An artificial replacement that restores missing tooth structure by covering part or all of the remaining tooth structure with a material such as cast metal, ceramic or a combination of materials such as metal and porcelain.

Crown margin / finish line - The tooth preparation surface where the gingival extent of the crown rests

Dies - Positive reproduction of the form of a prepared tooth obtained from the final impression.

Short clinical crown - Any tooth with less than 2 mm of sound, opposing parallel walls remaining after occlusal and axial reduction.

Anterior teeth - This includes the maxillary and mandibular central incisors, lateral incisors and canines.

Posterior teeth - This includes the mandibular and maxillary premolars and molars

Geomagic Control X - A 3D inspection and Metrology Software

GOM Inspect Suite - A 3D inspection and Metrology Software

Scanning - The process of using an optical scanner to acquire a 3D image of the surface of the object.

Auxiliary retentive feature - Additional geometric feature that is incorporated in a short/ over-tapered tooth preparation to improve retention. Can either be a slot, groove or a bo

ABSTRACT

Introduction: Tooth preparation refers to the process of removal of diseased and/or healthy enamel and dentin to shape a tooth to receive a crown. The quality of tooth preparation is an important clinician variable as it determines the retention and resistance form of the indirect restoration. Different analogue and digital methods have been used in research to assess the quality of tooth preparations. There is a need to determine which method has greater precision.

Objective: To conduct a comparative assessment of manual versus digital analysis of quality of tooth preparations for single crowns in Nairobi, Kenya

Study design: A laboratory based cross sectional study based in a dental laboratory in Nairobi, Kenya.

Materials and methods: The study was conducted in a dental laboratory in Nairobi Kenya. The laboratory was identified through purposive sampling. One hundred and twenty-five dies for single teeth preparations made from elastomeric material were included in the study. These were conveniently sampled from elastomeric impressions delivered to the laboratory for full coverage crowns fabrications. The buccal-lingual convergence, occlusal cervical height, margin design and the presence/absence of auxiliary retentive features were analyzed using an analogue method by direct measurement on the die and a digital method on scanned dies on a metrology software (GOM Inspect Suite, 2020).

Data analysis and results presentation: The collected data was analyzed using the Statistical Packages for Social Sciences (SPSS) 20.0 for Windows. Descriptive summaries (frequencies, means and standard deviations) and inferential statistics (independent sample t-test, Fischer's test) were used. A 95% confidence level was considered for the study

Results: The overall mean Buccal-Lingual convergence angle assessed using manual method for maxillary anterior, premolars and molars were 21.9, 17.3 and 30 degrees respectively. While using the digital method, maxillary anterior, premolars and molars had mean buccal lingual convergence angles of 23.3, 18.6 and 30.9 degrees respectively

From the manual assessment, the maxillary anterior, premolars, and molars had a mean occlusal cervical height of 4.47mm, 3.22mm, and 3.62mm. In the mandibular arch, anterior teeth, premolars, and molars had a mean of 3.05mm, 3.69mm, and 3.16mm respectively.

In both measurement methods, mandibular molars had the highest number of non-ideal preparation height (86.36%/ 90.91% manual/digital). Maxillary anterior teeth and premolars had most preparations having an ideal occlusal cervical height.

The results for the presence/absence of auxiliary retentive were the same for manual and digital method. Majority of the dies (97.6%) did not have any auxiliary retentive feature.

Majority (77.6%) of these preparations had been made for All- ceramic crowns while 22.4% were for Metal-ceramic crowns. The results for visual assessment of margin design were the same for manual and digital methods. In most of the cases, the all-ceramic crowns had a shoulder margin on the facial aspect (97.9%). A chamfer margin was used on the facial aspect for all ceramic crowns in 2.1% of the cases. For metal ceramic crowns, a shoulder facial margin was consistently used in 100% of cases. On the lingual aspect, all ceramic crowns had a shoulder margin in 95.9% of cases. The chamfer margin for all ceramic crowns was used in 4.1% of cases. For metal-ceramic crowns, the shoulder margin was used lingually in 82.1% of preparations made for PFM while the chamfer was used in 17.9%.

There was no statistically significant difference between the mean of the buccal lingual convergence angle as assessed using manual and digital method ($t = -0.8941$, p-value = 0.3722). No statistically significant difference was found between the mean of occlusal cervical height as assessed using manual and digital methods ($t= 1.4138$ p-value = 0.1587).

There were no significant differences between digital and manual methods when evaluating for both margin design and presence/absence of auxiliary retentive features (Fisher's exact score = 0.00)

Conclusions: Differences in output between manual and digital methods of analyzing the geometry of tooth preparations exist. However, these are not statistically significant for linear and angular measurements. No differences exist between the two methods for visually assessed variables of presence of auxiliary retentive features and the marginal design.

There is a high proportion of non-ideal preparation geometry in Kenya since only 42.2% on manual and 37.8% on digital analysis had the ideal buccal lingual convergence and 38.9% on manual and 35.6% on digital analysis had the ideal occlusal cervical height.

Recommendations: Poor geometry of teeth preparations warrants needs for continuous education among practicing clinicians. Further studies can be done using different metrology software to evaluate differences among systems.

CHAPTER ONE: INTRODUCTION

1.1 Study background

1.1.1 Dental disease and coronal restorations

Damage of the coronal tooth structure is a common sequela of dental disease or trauma which results in pain, altered function and/or poor aesthetics. The commonest disease of dental hard tissues is dental caries with an estimated global average of 29%[(1)]. In Africa, studies have reported prevalence of upto 60% of dental caries [(2)]. The 2015 Kenya National Oral Health Survey reported a dental caries prevalence of 34.3%. There is also high prevalence of fluorosis in Kenya averaged at 23.7% and 41.4% for adults and children respectively. Some areas in Kenya have reported a dental fluorosis prevalence of 100%. Tooth surface loss is reported at 14.6%. When severe, these dental conditions lead to fractures of coronal structure which can necessitate prescription of crowns by dentists[(3)].

Restoration of damaged coronal tooth structure can be achieved by direct or indirect restorations. Direct restorations make use of restorative materials that are directly packed or condensed into the prepared cavity by the operator. The most common of these restorations are amalgam restorations and composite restorations. When used for large restorations, auxiliary retention with pins has been attempted to improve retention in the prepared cavity[(4)]. Indirect restorations are fabricated outside the mouth in the dental laboratory and then luted by the dentist on the prepared teeth. They are usually indicated when damage to coronal structure is extensive[(5)]. They include cast restorations and milled restorations such as inlays, onlays and crowns.

A crown is a restoration that restores missing tooth structure of three or more axial surfaces and the occlusal surface or incisal edge of a tooth with a material such as cast metal alloy, ceramic, resin or a combination. Studies have found that majority of crowns are initially prescribed due to tooth fractures while deteriorating aesthetics and secondary caries were the main reasons for crown replacements[(6–8)]. Crowns can reinforce the remaining tooth structure and their longevity has been reported to average 8.3 years[(9)].

1.1.2. Factors that influence the longevity of coronal restorations

The longevity of coronal restorations is the length of time a restoration survives and is often used as a measure of clinical performance of the restoration(10). The longevity of the restoration is influenced by patient, material and clinician factors(11,12). These factors have an influence on the clinical tooth preparation design and success of the final prosthesis.

Patient variables such as caries index, tooth position, clinical crown length and restoration size influence longevity of single crowns. Patients with high caries index are at risk of biological failures due to secondary caries and periodontal disease(12). It is difficult for patients to adequately perform oral hygiene below the pontics and connectors and on subgingival margins. Therefore, proper axial reduction of the proximal areas where connectors are to be placed should be adequate to prevent over contouring of the restoration in such areas. This is especially important in areas where non-rigid connectors are incorporated on a tooth surface. In patients with short clinical crowns, the walls should be as parallel as possible to improve retention(13). The design of the preparation can incorporate secondary retentive features to improve on retention and resistance. The use of subgingival margins in these teeth to increase preparation height is not recommended. Crown lengthening can be done to increase crown height. The use of self-adhesive resin cement lute although advocated for use in short clinical crowns should be an adjunct to the preparation geometry(14).

Material factors influence several aspects of tooth preparation. Some of the materials used for single crowns include metals which can be noble metals like gold alloys or base metal alloys like cobalt chromium. Porcelain Fused to metal crowns can also be used. Nowadays, all ceramic restorations are widely used for example, polycrystalline materials such as Zirconia and glass ceramics such as Lithium Disilicate and In-Ceram (which maybe spinell, alumina or zirconia(15). The differences in mechanical properties of these materials influence how certain parameters of the preparation are done. These include the amount of tooth preparation which influences the structural durability and the margin design which ensures marginal integrity.

Full metal crowns require minimal reduction of the tooth structure of 0.8mm and a knife edge margin. All ceramic restorations require 1.2mm axial reduction of tooth structure with a shoulder margin to ensure sufficient bulk of material at the interface.

Porcelain fused to metal crowns require 1.5mm of reduction to allow the bulk of metal and porcelain to be incorporated. A shoulder margin is placed on the labial while a lingual chamfer margin is recommended for these restorations. Over-preparation of teeth can result in short crowns that limit retention as well as endodontic problems such as necrosis of the pulp[(16)]. Under-preparation of teeth leads to over-contoured restorations that have adverse effects on the periodontium

Clinician specialization in restorative dentistry and experience have been shown to have more favorable outcomes on longevity of indirect restorations[(17,18)]. This difference in longevity might arise due to a higher skill in specialists and experienced clinicians to precisely execute clinical procedures such as case selection, tooth preparations and impression taking. Knowledge on proper preparation designs as well as the armamentarium for different clinical situations is important when executing clinical tooth preparations. Experienced clinicians and specialists can be able to more self-evaluate and improve their preparations to recommended geometry which can explain the differences in longevity of the restorations with specialization[(18)].

Therefore, patient, material and clinician factors have a direct influence on preparation geometry and eventual longevity of the restoration. Consideration of these factors ensures precise tooth preparations for retention, resistance, structural durability, marginal integrity and aesthetics of the fabricated prosthesis[(19)]. These features of preparation designs have been widely studied and certain values recommended for various parameters of the preparation[(20)]. Despite this, different clinician cohorts have been found to perform preparations with varying dimensions. It is therefore important to analyze the influence of clinician variables in tooth preparations.

1.1.3 Parameters of tooth preparations

The tooth preparation geometry of single crowns needs to have certain features that satisfy the six principles of tooth preparation. These principles include: preservation of tooth structure; retention and resistance form; structural durability of the restoration; preservation of the periodontium; marginal integrity; and, aesthetic requirements. Each of these principles should be achieved in the restoration to ensure long-term success and patient satisfaction[(21)].

Retention and resistance form of the preparation prevent restoration dislodgement in both axial and non-axial loading. Features of the preparation that improve retention and resistance include the taper of the preparation, surface area of the preparation, height of the preparation, width of the preparation, texture of the preparation and secondary retentive features. There are recommended values from previous scholars following extensive clinical and laboratory research for each of these variables(20).

The taper (occlusal convergence) of the preparation and the height are one of the most important aspects of the preparation geometry. The preparation taper refers to the angle formed between opposing walls of the preparation(22). There is an inverse relationship between the preparation taper and the overall retention(23). The recommended occlusal convergence of preparations is 10-20 degrees(20). A tapered preparation allows cast restorations to seat on the prepared tooth as opposed to parallel preparations. An over tapered preparation leads to loss of retention and resistance since the restoration can be dislodged in multiple directions. Such a preparation would also affect the preservation of tooth structure principle since occlusal/incisal over-preparation is present with greater taper.

The margins of the preparation provide an apical seat for the restoration. For longevity of the restoration, its margin should be well adapted to the preparation margin with an adequate bulk of material for structural durability. The finish line preparation design for both location and geometry of the margin is therefore an important aspect of the tooth preparation since it will influence aesthetics, the adaptation to the tooth surface as well as the relationship to the soft tissues. Various studies have been done to assess the features and precision of tooth preparations(23,24). Guth et al evaluated convergence angles, undercuts, interocclusal distance, abutment height and marginal design and found that only 6.6% of the preparations evaluated met at least four of the recommended criteria.

Only one published Kenyan study by Ombuna et al has assessed the geometry of tooth preparations. This study found that only 18.1% of dies had ideal features(25). There is a need for data in this area so as to inform training and continuous professional development of dentists.

1.1.4 Methods of assessing tooth preparations

Different methods have been used to assess tooth preparation geometry. These include manual and digital measuring methods that can be used for assessing either the silhouette or cross section of a die[(26)]. The analogue methods are prone to human error in measurements as well as surface distortion of the gypsum die from repeated measurements. Digital methods require use of sophiscated equipment and software that might not be readily available in resource limited settings.

There has been great diversity in output from the different manual and digital measuring methods for assessing crown preparations[(27)]. It is difficult to make substantive comparisons and conclusions on populations from studies that used different methods. Even on the same preparation, different methods are used to assess the various aspects such as occlusal convergence and taper.

Ombuna et al used photographs to assess occlusal convergence and digital calipers for the preparation height for each die[(25)]. Since the two parameters are measured using different methods, it is difficult to correlate the two variables objectively. This is evident from the limited data in literature that correlates different aspects of tooth preparation. Most studies have evaluated individual parameters separately and given recommendations for each. However, the parameters for retention and resistance are multifactorial and work together and cannot be attributed to one entity. A measurement method which can evaluate multiple aspects of the same tooth preparation is therefore an important tool for researchers and clinicians evaluating preparation geometry[(27)]. The analysis of Stereolithography datasets in 3D inspection software can assess these parameters together using virtual caliper. This method can have a clinical application where clinicians can generate digital impressions at the office and analyze them for recommended geometry before sending them to the dental laboratory. It is therefore necessary to compare the measurement data from the digital and manual measuring methods so as to provide an objective assessment of the two systems of measurement. This would enable researchers to be able to objectively choose a particular method that suits their objectives.

From the aforementioned, it has been established that there is a great need for coronal restorations in routine restorative dentistry[(6,18)]. The success of these restoration depends on factors such as the tooth type, materials used and clinician skill which influence the quality of tooth preparation. Precise clinical tooth preparations are a requirement for successful restorations with single crowns.

Studies evaluating these parameters have determined that less than 20% of preparations conform to the ideal criteria. Errors in the execution of preparations often lead to loss of the restoration due to lack of retention and resistance. There is limited data in Kenya on clinical tooth preparation by dentists. Moreso, there is little consensus in literature on the choice of the available methods of assessing tooth preparations.

The majority of studies have employed manual techniques. Modern dentistry is migrating to digital techniques but little information is available regarding their validity especially in comparison to conventional techniques. Therefore, the aim of this study was to conduct a comparative assessment of manual versus digital analysis of the quality of tooth preparations for single crowns in Nairobi, Kenya.

1.2 Problem statement

Diseases of the dental hard tissues such as dental caries, traumatic fractures and tooth surface loss can result in extensive damage to the coronal structure. This has been shown to have a negative effect on aesthetics and function[(73)]. Rehabilitation of these extensively damaged teeth with full coverage restorations has been found to have more long-term success as compared to direct restorations[(74)]. To fabricate crowns and fixed partial dentures, the teeth are prepared according to scientific guidelines that ensure the final prosthesis is retentive, aesthetic and durable in the oral environment.

During teeth preparation, clinicians can introduce errors that result in improper geometry of the preparation. Increase of preparation taper can lead to inadequate retention of restoration which can dislodge in function. Under-preparation of the abutment tooth can lead to over contoured restorations that are unaesthetic and predispose to periodontal disease. Over-preparation of the teeth can result in pulpal inflammation and necrosis of the teeth. Improper outline of margins on preparations causes open margins at the tooth -restoration interface which causes plaque accumulation and dental caries.

Therefore, there is need to have a reliable, objective and valid method for clinicians and researchers to assess the tooth preparation. Clinicians can apply such a method immediately after tooth preparation so as to establish whether their preparation is ideal for prosthesis retention and resistance.

Currently, two methods can be used, the digital and manual methods of analysis. However, there is no consensus as to which method is more precise and besides, each requires specific resources for deployment. Hence, it would be prudent to establish whether there is variation in the accuracy of these two methods.

1.3 Study objectives

1.3.1 Broad Objective

To conduct a comparative assessment of manual versus digital analysis of the quality of tooth preparations for single crowns in Nairobi, Kenya

1.3.2 Specific Objectives

1. To describe the type and number of teeth per arch being prepared for single crowns and the types of full coverage crowns being prescribed for these preparations in Nairobi, Kenya
2. To analyze the parameters of tooth preparations using manual methods
3. To describe the features of tooth preparations method using digital methods
4. To determine the rate of adherence of tooth preparations for single crowns to recommended guidelines when assessed by manual versus digital methods
5. To determine whether there is a difference between the analogue and digital measurements of the features of teeth preparation.

1.4 Hypothesis

1. **H_0** Geometric characteristics of tooth preparation of dies for single crowns from selected laboratories in Nairobi do not adhere to recommended guidelines

H_A Geometric characteristics of tooth preparation of dies for single crowns from selected laboratories in Nairobi adhere to recommended guidelines

2. **H_0** There is no difference in analogue vs digital measurements of parameters of tooth preparation

H_A There is a difference in analogue vs digital measurements of parameters of tooth preparation

1.5 Justification

Long term success of single crowns depends on the geometry of the tooth preparation. Teeth preparations with poor retention and resistance form can result in prosthesis that can be easily dislodged during function. Cements are not effective in the long term when the restoration is lacking in retention and resistance form.

In order to avoid errors during teeth preparation, clinicians can benefit from knowledge of the common aspects of the preparations that are inadequately done. This will inform them on the areas to pay more attention as they perform preparations.

Globally, numerous studies assessing geometry of tooth preparations performed by clinicians have found differences in various aspects of the tooth preparation[(47,72)].

There are limited studies in Kenya on geometry of tooth preparations. A study by Ombuna et al found that only 18.1% of dies had ideal geometry[(25)]. This study used two dimensional photographs of dies to assess convergence and direct measurements with calipers for other parameters. Repeated measurements on gypsum dies can introduce surface distortions that can distort measurements. Human errors can also be introduced during these measurements

This study uses a three-dimensional scanned model of the tooth preparations which was digitally assessed in a 3D assessment software. The study findings will add to the existing wealth of knowledge on the quality of teeth preparations for full coverage restorations among dentists in Kenya.

In addition, the study evaluates the precision of manual analysis versus digital analysis of tooth preparations. Future researchers in the area of tooth preparations can use the results of this study to determine the measurement method of choice in their studies. Clinicians can use the results from the study to choose a method of assessment of clinical preparations which can improve quality of teeth preparations for full coverage restorations. Teaching institutions can use information gathered from the study to improve on their training curriculum. The study will also inform on the current tooth preparation geometry by Kenyan dentists and compare to past studies on whether there has been an improvement in quality of preparations.

1.6 Summary and thesis structure

The thesis is presented in sections as follows:

(i) A critical review of relevant literature to identify a research gap and justification for the current study by:

(a) Describing the types of coronal restorations and analyzing the distribution of clinically prepared teeth

(b) A review of various geometric factors assumed to influence retention and resistance of single crowns such total occlusal convergence, height of the preparation, finish line design and auxiliary retentive features

(c) A review of various methods of assessing tooth preparations

(ii) A statement of the research problem, justification, aims and objectives of the study.

(iii) A description of the materials and methods used.

(iv) Presentation of results.

(v) Discussion.

(vi) Conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

A full coverage crown is a cemented or permanently affixed dental restoration that covers the entire outer surface of the tooth-crown[21]. Teeth-preparation for full coverage crowns requires removal of both diseased and healthy tooth structure which has a biological cost. Studies have found that 20% of vital teeth receiving crowns require root canal treatment in 15 years[28].

Full coverage restorations are used on teeth where multiple axial walls are affected by disease and partial coverage restorations cannot be placed with adequate retention and resistance. The full coverage crown should conform to the dental morphology so as to function with minimum stress and maintain the integrity of the remaining dental tissues[29].

This literature review will provide an assessment of the key principles tooth preparation, a review of adherence to these recommended principles as well as an assessment of the methods used to analyse tooth geometry. The scope of this study will be limited to; Literature review on distribution of crowned teeth, a review of the average number of crowned teeth, the total occlusal convergence, height of preparation, the finish line and auxiliary retentive features. A review of measurement methods for assessing tooth preparations will be done. Through this critique, the diversity in tooth preparation quality between different tooth types, populations and using different methods will be elucidated. Previous global and Kenyan research will be critiqued for both study scope and methodology to establish a research gap as regards to tooth preparation quality and the techniques used.

A research gap exists in terms of the paucity of Kenyan data available on quality of tooth preparations and a comparison of analogue versus digital methods which will be established.

2.2. Types of coronal restorations

Full coverage crowns can be classified on the basis of the material from which they are fabricated. They can be made from Acrylic, Resin Composite, Metallic, Porcelain Fused to metal, Layered Zirconia, Monolithic Zirconia and Lithium Disilicate among others. The choice of material depends on the position of the tooth, location of margins and dentist preferences.

Schillingburg has classified full coverage restorations to all-metal, metal-ceramic, resin-metal, all resin and all-ceramic crowns[21].Alternatives to full coverage restorations such as inlays, veneers and indirect composite restorations can be used in select clinical situations. The repair of old crowns should be considered wherever possible as opposed to total replacement.

Dentists have a major role to play in ensuring that patients receive proper restorations that have proper function and longevity. Clinical tooth preparations should be well executed to ensure that the final restoration possesses adequate features of retention and resistance. The seven-year survival rate of crowns in Kenya was found to be 66.7% while some studies have reported over 90% ten year survival rates [(18)].

Retention form is the feature of the restoration that prevents its dislodgement along the path of placement while resistance form refers to features that enhance stability and prevent dislodgement along an axis other than the path of insertion[(30)].

Dislodgement of crowns can result from poorly done tooth preparations that do not impede tensile forces directed against the restoration. Features of the tooth preparation that promote retention are the total occlusal convergence of opposing walls, height of the preparation, surface area of the preparation and roughness of the preparation. Resistance features in a tooth preparation ensure that the luting cement is placed in compression during function[(31)]. These features include the height and width of the preparation, and surface area of the preparation.

2.3Distribution of full coverage restorations depending on tooth type

Studies that have assessed the distribution of tooth preparations as a major objective factor are few. Most studies have described the distribution during evaluation of different factors of crowns and fixed dental prosthesis. Burke and Lucarotti in a ten-year assessment of dental crowns found that more crowns had been placed on the maxillary teeth compared to the mandibular teeth. The maxillary central incisor was the most crowned tooth followed by the maxillary premolar[(32)]. A study by Lynch et al[(6)] found maxillary premolars to be the most commonly crowned teeth at 27% followed by mandibular molars at 25% for initial crown placement. The maxillary incisors had the highest frequency of replacement at 49%. Wilson et al found the maxillary incisor to be the most commonly crowned tooth at 33%[(33]). The decrease in initial crowns for anterior teeth might be related to the availability of alternative and reliable treatment options on the anterior teeth[(6)].

These include the use of direct composites and partial coverage restorations such as indirect veneers which can be used predictably in some cases. These restorations are minimally invasive and can be used for minor labial defects and discolorations that traditionally had crowns prescribed[(34)].

In Kenya, Ombuna et al while assessing the preparation geometry of prepared teeth found that the premolar was the most frequently crowned tooth in both the maxillary and mandibular arch. This was a laboratory study done on study models in a dental school laboratory as well as commercial laboratories[25]. This study included teeth preparations for single crowns and fixed dental prosthesis. The results from this study contrasts with Edalia et al[18] who while retrospectively evaluating the success rates of crowns and fixed partial dentures placed in a dental school in Kenya found that maxillary incisors were the most frequently crowned teeth at 48.1%. Majority of single crowns (51.2%) were in the anterior region while 46.9% were in the posterior region[18]. This could be due to the aesthetic demands in the anterior region that push patients towards correction of fractured teeth and discolored teeth. Further research is required in this area to inform clinicians and other stakeholders in oral health on the frequently crowned teeth.

The above Kenyan studies were conducted in a dental school set up and might not be representative of work done by the general population of dentists in Nairobi. It is therefore important to describe this distribution to a wider variety of clinicians so as to identify the commonly prepared teeth among different clinicians. This can inform clinicians on which teeth are most likely to have crowns placed which can provide guidance while making treatment plans and giving oral hygiene instructions to patients.

2.4. Tooth preparation parameters and techniques of analysis

2.4.1Total occlusal Convergence

Total occlusal Convergence (TOC) refers to the angle measured in degrees as viewed in a given plane, formed by the axial walls when a tooth or machined surface on a metal or ceramic is prepared for a fixed dental prosthesis[30].

Jorgensen evaluated the role of taper on retention using Galalith cones of 8mm in diameter at the base and 8mm height[23]. The cones had 5-degree taper increment from 5 degrees to 45 degrees and machined brass caps were cemented using a similar Zinc phosphate cement. He found that the retention of the brass caps diminished with increased convergence from five degrees to 45 degrees[23]. This was later supported by Schillingburg et.al, Kaufman et al whose research recommended tapers of 2 to 6 degrees[35].

Kaufman et al studied the relationship between taper and preparation height using Aluminium castings of 4mm, 7mm and 10mm(35). For each height, numerous dies of tapers from 1 degree to 20 degrees with 5-degree increments were made. Metallic castings were cemented and unseating attempts made with non-axial forces. It was found that the retention increased with height for similar tapers though the increase was not proportionate for each millimeter increase. Further research by Wilson et al found that although the relationship between occlusal convergence and retention was inverse, the maximum retention did not occur at zero. These researchers recommended tapers of 6 to 12 degrees(36).

Mack assessed dies using a projector silhouette in a clinical simulation and found that that the recommended tapers of 5 degrees were difficult to achieve in a clinical setting and most clinician achieved tapers of 17 degrees(37,38). He postulated that deviations from ideal taper might arise from operator distance to the tooth preparation as well as the use of monocular versus binocular vision when assessing tooth preparations. More ideal tapers were found at a distance of 250mm between the operator eye and tooth preparation and when using monocular vision. The limit to an ideal taper was also postulated to depend on operator experience, the type of preparation performed, location of the tooth in the mouth and the requirement of the clinician to avoid undercut during removal(37).

Various studies have used different methods to assess clinical preparations by different cohorts of clinicians. These include use of diamond cutting instruments(39), goniometric microscopes(40) overhead projector(41), photocopy machines(42), laser scanners(43).

In these studies, there is a consensus that clinicians do not routinely produce total convergence angles ranging from 12 to 30 degrees (22,41,42,44,45). Kent(22) studied the taper of 418 dies prepared by Schillingburg during a period of 12 years and found convergence angles of 15.8 degrees between mesial and distal walls and 13.4 between buccal and lingual walls. This provided an average taper of 14.3 degrees.

A review of dies of teeth prepared in specialist centers in Dubai found convergence angles to range from 34 degrees to 23 degrees(46).This study used photographs analyzed on AutoCAD. In this study, lower values of 23 degrees were found in dies of preparations done in a teaching institution while the higher tapers were recorded in non-teaching institutions. Similarly, Annerstedt et al evaluated the crown preparations done by dental students and general practitioners using 3D scanned data of models(45). This study used a hybrid technique of a digital and analogue method.

The 3D image of the preparations was converted to two-dimension transcriptions which were then printed on paper. A protractor was then used to measure the convergence angles. They found the clinical tapers for students to average 19 degrees whereas those for the general practitioners group was 21 degrees[45]. In contrast, Nordlander et al compared the convergence angles of tooth preparations done by prosthodontists residents and general practice residents while attempting a 4-to-10-degree taper [41]. In this study, an overhead projector was used to get a silhouette which was traced on a paper. Lines were then extrapolated on the axial walls of the tracing and a protractor used to measure the angle at their point of convergence. They found that the tapers for both groups exceeded recommended values from laboratory studies with the general practice residents' group having a 19.6-degree taper while that of prosthodontist residents was 20.1 degrees. There was no significant difference between the two groups.

The complexity in relationship of intraoral forces and loads that is difficult to simulate in laboratories can explain why these prostheses still function despite the higher than recommended convergence angles. Also, other elements of retention such as the luting cement, height of the preparation can improve the retention of the prosthesis.

Comparisons of taper between different tooth types has been evaluated in multiple studies[22,41,45,46]. The taper for the anterior teeth was smaller than for the molars and premolars[41,45]. This could be due to the easier accessibility of the anterior teeth that allows the operator to align the bur along the long axis of the tooth. The mandibular teeth were prepared with greater tapers than the maxillary tooth[41,44,45,47]. This could be due to the lingual inclination of the mandibular teeth[48]. The facial-lingual convergence was found to be more than the mesial-distal convergence in some studies[45]. Kent[22] found smaller taper for the facial-lingual than the mesial-distal planes.

Schillingburg et al recommend convergence angles of 14,19 and 22 degrees for premolars maxillary and mandibular teeth respectively[21]. Goodcare in a comprehensive review recommends tapers of 10-20 degrees in both buccal lingual and mesial distal planes[20].

Patel et al assessed the convergence angles for a fourth-year student cohort using a manual cross section technique where the dies were sectioned in both mesial lingual and distal lingual planes and projected on an overhead projector. This allowed a projected silhouette to be formed[49]. Ghafoor et al used a digital method where the photographs of the die were assessed in AutoCAD software[48]. Both studies were extra oral but there were slightly different results.

Patel et al reported TOC of 24.23 degrees for molars while Ghafoor et al reported 18.2 degrees. The convergence angle may not vary considerably as angular measurements might not be greatly affected by size discrepancy between the object and the photograph. This is supported by the findings in a systematic review that the published values for total occlusal convergence are similar to those published in the early 2000 to 2010(26).

In Kenya, Ombuna et al evaluated convergence angles by using photographs of dies and analyzing them on AutoCAD(25). They found that 18.1% of dies evaluated had ideal convergence angles of 10-20 degrees. 45% of the ideal convergence angles were achieved for premolars while 4% were for maxillary molars. This is in contrast to studies that used scanned models which found anterior teeth to have the ideal preparation parameters(45). Ombuna et al found the mean mesial distal convergence angle for maxillary molars to be 23.8 degrees(25). In contrast, Guth et al while analyzing tooth preparation geometry from stereolithography datasets found the average mesial distal preparation among general practitioners to be 31.7 degrees(24).

In terms of the prepared teeth, Ombuna et al found 58% of the ideal preparations were for single crowns while 23% were for fixed dental prosthesis abutments(25). This in agreement to studies that found greater convergence angles for fixed dental prosthesis preparations as compared to single crown preparations(37). There was a significant relationship in the number of preparations per arch and the quality of preparations. Casts with three teeth preparations had more ideal convergence angles as compared to those with one preparation. This study did not evaluate inter-clinician variability on preparation geometry.

2.4.2 Height of Preparation

The height of the preparation influences retention and resistance of the prosthesis. Increased surface area from a longer preparation increases retention. For adequate retention, the height of the preparation should be a minimum of 4mm for molars and premolars and 3mm for anterior teeth including canines(20). This provides resistance to tipping forces occurring on a fulcrum on a margin opposite to the tipping force(50). The clinician has limited control of the preparation since this can be determined by the extent of disease, extent of previous restorations and the clinical crown height. (51).

Wiskott et al evaluated the effect of tooth preparation height and diameter on the resistance of complete crowns to fatigue loading[52]. Crowns and abutment analogs of different height and width were cemented with different luting cements and dynamic stress applied. They found that both the abutment height and width had a linear relationship to the resistance of dynamic loading[52]. In an evaluation of the resistance form of dislodged crowns and fixed partial denture retainers, Trier found that 42 out of the total 44 preparations lacked resistance form supporting the evidence that resistance form of preparations was crucial for longevity of the restoration[53]. Parker et al calculated the convergence angles of tooth preparations from a prosthodontist and related them to the preparation height[39]. He found that resistance to dislodgement was increased for a 3mm preparation that possessed 17.4 degrees of taper. This convergence angle falls within what has been recommended by various authors for clinical preparations and some authors have postulated that 3mm height of preparation would be ideal[20,54]. Evaluation of retention and resistance of gold casings in different preparations heights with a taper of 6 degrees found that 3mm was the minimum height required to provide resistance to maxillary incisors and mandibular premolars[55]. Leong et al evaluated the influence of the preparation height on teeth with clinically acceptable taper of 20 degrees[56]. The 4mm preparations showed the highest number of cycles to deformation under cyclic loading which indicated the higher resistance of the preparation. A minimum preparation height of 3mm is recommended for anterior teeth and premolars since they are more accessible and clinically acceptable tapers of 10-20 degrees can be achieved. A 4mm abutment height is recommended for posterior teeth where TOC tends to be higher than that of anterior teeth due to difficulties in access[20].

The preparation height has been assessed using different methods. Sato et al evaluated the clinical abutment taper and height of preparations by dental students using silhouettes tracings of dies of the prepared teeth[57]. The mandibular first molars had a height of 5.70mm while maxillary first molars had a height of 5.80mm[57]. Guth while using a digital method of assessing tooth preparations from Stereolithography data found the maxillary first molar preparations to average 4.1mm[24]. Etemadi et al used a dial micrometer to record mesial and distal preparation height and found the molars to average 2.7mm on the mesial and 3.4mm on the distal[25].

Ombuna et al in a Kenyan study used a digital micrometer to measure the occluso-cervical height[25]. They found that 62.6% of dies had ideal occluso-cervical height whereas 37.4% had inadequate occluso-cervical height. The tooth preparations for maxillary anterior teeth had more ideal OC height at 96.4% while maxillary molars were more likely to have non-ideal OC height at 85.7% [25].

2.4.3 Auxiliary retentive features

Restoration of teeth with extensive damage requires clinicians to make a decision on whether to augment the retention and resistance by adding auxiliary retentive features to their preparations[21]. These include axial slots, grooves and boxes that serve to decrease the radius of the rotational path of dislodgement. Proussaefs et al[58] evaluated the efficacy of different auxiliary retentive features on the resistance form of crowns with reduced axial wall and total occlusal convergence. The study was conducted on ivorine teeth prepared with 20-degree convergence and 2.5mm occlusal cervical dimension and a shoulder finish line. Grooves and boxes were then prepared in these dies, metal crowns cemented and subjected to dislodging forces. From this study, the auxiliary retentive features did not significantly increase resistance form when the tooth preparation had higher occlusal convergence[58].

Most literature recommends placement of auxiliary retention features for single crown preparations when occlusal convergence exceeds 20 degrees, occlusal cervical heights of less than 3mm for anterior teeth, 4mm for molars and length to diameter ratio of ≤0.4[20,59,60]. Arora et al(61) found that the most effective method of enhancing resistance form in a preparation is by decreasing the total occlusal convergence on the cervical aspect of the prepared axial walls[61].

Two proximal boxes (3mm facial-lingual) significantly increased the overall resistance form while two grooves on the proximal areas (1mm facial-lingual) did not significantly increase the resistance form[61]. Proximal boxes increase resistance by preventing rotation and increasing surface area of the preparation. The boxes should be confined on sound tooth structure or core without weak adjacent areas that susceptible to fracture[61]. Reisbick and Shillingburg[62] also concluded that resistance form increased significantly with incorporation of boxes in the preparation.

2.4.4 Finish line

The finish line refers to the boundary surface of a tooth preparation where the outer edge of a crown, inlay, onlay or other restoration lies(30). The survival of the restoration in the mouth depends on how well the restoration is adopted to the finish line of the preparation. The margin design determines the shape and bulk of restorative material at the margin as well as the degree of seating of the restoration.

Margins can be placed either supragingival, equigingival or subgingival(63). Supragingival margins are recommended due to ease of access by the dentist for preparation and adaptation as well as the patient for hygiene procedures which minimizes plaque accumulation.

Plaque accumulation can lead to periodontal disease and dental caries due to microleakage(64,65). Subgingival margins can be placed in selected clinical situations such as areas of high esthetic demand when using porcelain fused to metal restorations or when previous caries or restorations were already subgingival. These margins should be placed only 0.4mm subgingival and should be well contoured to prevent irritation to the gingiva(66). Nawaf et al found that 36% of margins in the dies studied were subgingival while 64% were supragingival(67). Sutton and McCord found variable margin positioning with 29% of buccal preparations having subgingival margins(67).

The finish line geometry of cast crowns can be chamfer, shoulder or Knife-edge with various modifications within the categories. Shoulder margin is recommended for all-ceramic restorations(21). Chamfer margins for all ceramic restorations have been found to be prone to fracture and possess less marginal adaptation(68).The chamfer margin has been found favorable for all metal restorations with a recommended depth of 0.3 to 0.5mm. The chamfer margins can be prepared readily and is easy to read both on the impression and the die and was the most prevalent margin design among clinicians(19).

Metal Ceramic restorations can have shoulder margins, chamfer margins, beveled shoulder or beveled chamfer. Various researchers have recommended depths of 1mm to 1.5mm(20). Despite scientific recommendations for depth of shoulder preparations, variations exist in clinical settings have been reported(67,69).

Ombuna et al used a magnifying glass to assess margins of preparations and found that continuous margins were present in 93.2% of the dies(25). The shoulder margin was the most used margin configuration for the labial aspect while the chamfer was mostly used for palatal and lingual aspects.

[25]. Other researchers have used scanned models to evaluate both design and dimension of the margin[24]).

From this review of the features of the tooth preparation, it is apparent that numerous methods are present to evaluate a tooth preparation. Most studies have been conducted using manual silhouettes to measure die outlines. Other researchers have used manual measurements methods such as tracings, photographs or photocopies of dies[22,42,70]. Digital assessment of both the silhouette or cross section of the dies has also been assessed[26,71]. The different measuring methods produce different results that makes it difficult to draw substantial conclusions for tooth preparation parameters based on specific values. Most researchers have used different methods on the same die for assessing taper, occlusal cervical height and finish line design. This is time consuming and introduces bias when a comparative relationship of two parameters is attempted. Repeated measurements on dies can also introduce scratches that can distort the die. When using photographs for linear measurements, a ratio of 1:1 must be maintained to get an accurate measurement from design software[26].

Recently, researchers have evaluated tooth preparations using scanned datasets of the preparations from models[71,72]. The same size dimensions of the object can be measured on a virtual caliper in surface inspection software to get accurate data for both linear and angular measurements.

This method also allows measurements and assessment of various parameters using a common method. Few studies have however compared the data output from this method of using STL data to the earlier methods of measurements. Such a comparison would provide baseline data for future accuracy studies and recommendation of a particular method for assessing tooth preparation taper, height and finish line design.

Therefore, the first objective of this study was to describe the type and number of teeth per arch being prepared for single crowns and the types of full coverage crowns being prescribed for these preparations in Nairobi, Kenya. The second and third objectives of this study were to analyze these tooth preparation parameters using manual and digital methods. The fourth objective was to determine the difference between the two analytical techniques.

2.5. Conclusion

The literature review found conflicting information on the distribution of crowned teeth in Kenya from the available studies. Most of these studies were conducted in a dental school set up and might not be indicative of the population of dentists in Nairobi. To bridge this gap, this study will evaluate dies in a commercial laboratory so as to identify the distribution from a varied pool of dental practitioners.

From this literature review, the importance of precise teeth preparations on the retention, resistance and overall success of single tooth crowns is unequivocal. There however appears to be differences in tooth preparation features based on the measuring method. Very few studies have however attempted to compare two different measuring methods on the same preparation to assess the validity of the numerous methods. This study can provide baseline data on a traditional and a new method to provide an evidence-based choice on which method to choose when analyzing tooth preparations.

Finally, the literature review also found a gap in the available Kenyan studies that have assessed tooth preparations. These are limited in number and have mostly provided descriptive statistics on the preparation by Kenyan dentists. Additionally, no published Kenyan study has compared the different methods of assessing tooth preparations. Therefore, the aim of this study is to conduct a comparative assessment of manual versus digital analysis of tooth preparations for single crowns in Nairobi, Kenya.

3.0 CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Study Design

A laboratory based cross sectional study design was used.

3.2 Study Area

The study was conducted in Nairobi County, the capital city of Kenya. The county has a population of over four million as per the latest census conducted in 2019[75]. It is the county with the highest number of dental clinics and dental practitioners. The largest and oldest dental school in Kenya is located in Nairobi County. The largest referral hospital in Kenya, Kenyatta National Hospital is also in Nairobi. There are over five major commercial laboratories

Both public and private dental institutions often use private dental laboratories for some laboratory procedures. These laboratories also receive impressions for single crowns from clinics outside Nairobi. The varied source of impressions in these facilities are from different clinicians and can be used to assess prevalence of certain clinician factors in the indirect restoration workflow.

In this study, the specific study site was Prime dental laboratory which is one of the major dental laboratories in Nairobi, Kenya.

3.3 Study sample

The study sample comprised of dies for single crown preparations made from impressions of different clinicians who had sent them to a commercial dental laboratory for fabrication of single crowns. The laboratory which consented to the study is prime dental laboratory (Appendix 2 Consent form).

3.4 Inclusion criteria

- Impressions for single tooth preparations for full crowns
- Impressions for single teeth done using elastomeric impression materials.
- Impressions by clinicians in the 2023 Kenya medical and dental practitioners' retention register.

3.5 Exclusion criteria

- Impressions for partial veneer crowns.
- Impressions poured before evaluation
- Impressions made from non-elastomeric materials
- Digital impressions which could not be converted in to dies for analysis.

3.6 Sample Size Calculation

The requirements for an adequate abutment height were met in 92.1% of preparations in a study by Winkelmeyer[71]. Using Fisher's formula for cross-sectional studies, the sample size was enumerated.

$$n = \frac{z^2 * p\,(1-p)}{c2}$$

n = 1.962*0.921(1-0.921)

0.052

= 112 Prepared Dies

3.7 Sampling method

The laboratory was identified through purposive sampling. This is because not all laboratories in Nairobi are able to offer impression scanning. Purposive sampling was used to select impressions that meet the inclusion criteria during the period of the study

3.8 Data collection and instruments

Inspection of preparations on impressions will be done by the principal investigator after disinfection under ambient day lighting to rule out for any obvious impression related errors. One hundred and twenty-five dies for single teeth preparations generated from eighty-two impressions satisfying the inclusion criteria were included in the study. All findings were recorded in the data collection form (Appendix III) for each individual die and measurement method.

3.8.1. Manual method

For the manual method, the impressions were cast in type IV gypsum (Figure 1). The individual dies were mounted on a square shaped hard plaster block to stabilize the dies in a fixed vertical and a horizontal position (Figure 3). Photographs were then taken on the mesial aspect of prepared dies using a 24.2-megapixel digital single lens reflex camera (Nikon D5600, Nikon, Thailand) and a macro lens (Tamron 90mm, Tamron, Japan) using a standardized settings ratio of 1:2.

The photographs were resized to a 1:1 ratio in Adobe photoshop (Adobe Photoshop, 2018) and printed on paper. The gingival third of the buccal and lingual preparation surfaces were extrapolated and the buccal lingual convergence was measured using a protractor at the point of convergence. The occluso-cervical dimension of the prepared dies was measured in millimeters using a non-digital vernier caliper (Mitutoyo, UK). The occluso-cervical measurement was done at the distal proximal wall, midpoint between the facial and lingual surfaces of the die.

Figure 1: Model with preparations

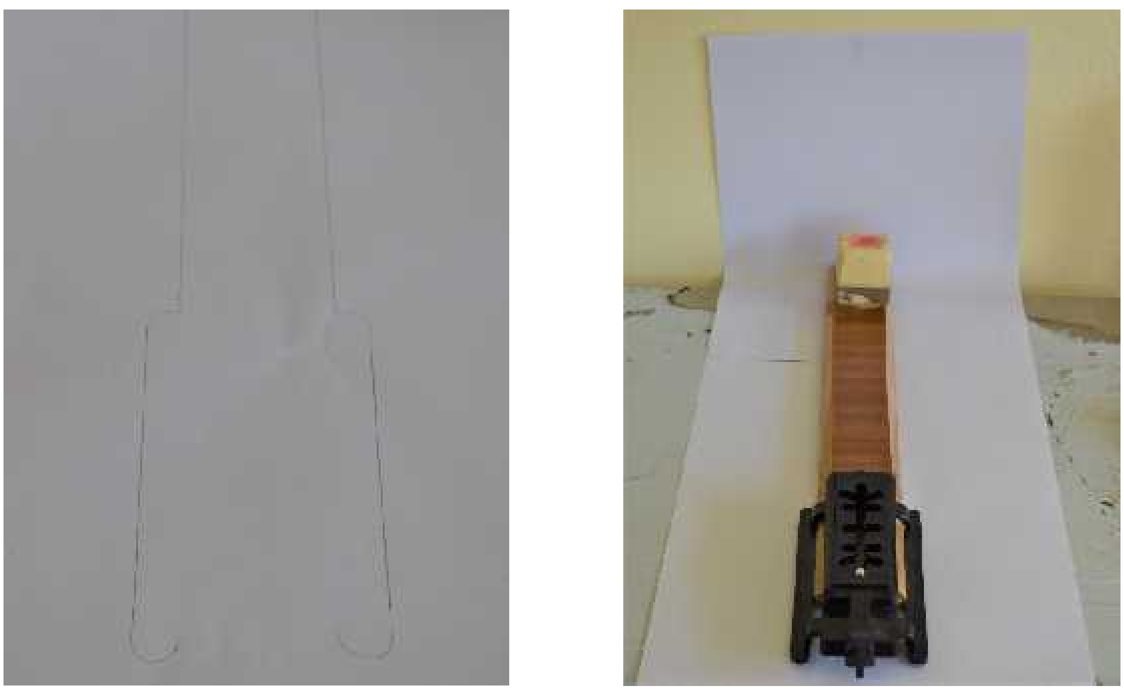

Figure 2: Photography Contraption and positioning

Figure 3: Photography set up

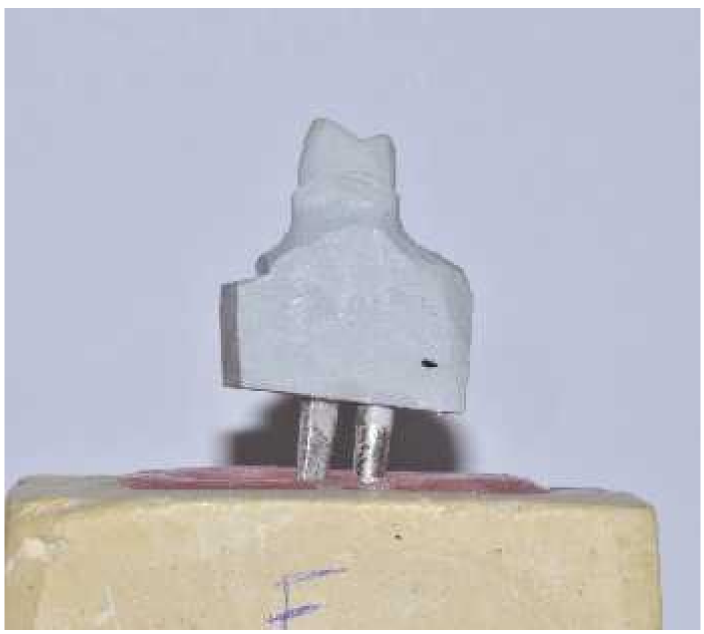

Figure 4: Photograph of die from mesial aspect

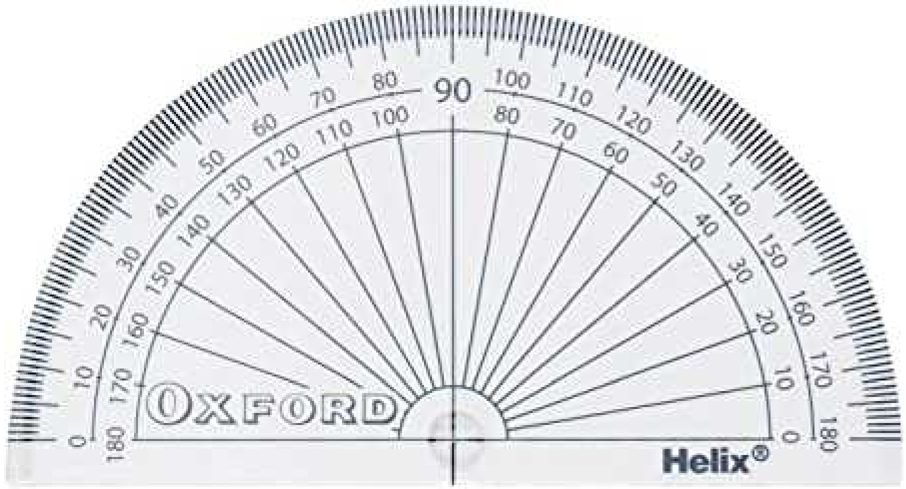

Figure 5: Protractor (Helix Oxford Geometrical Set (Helix, UK)

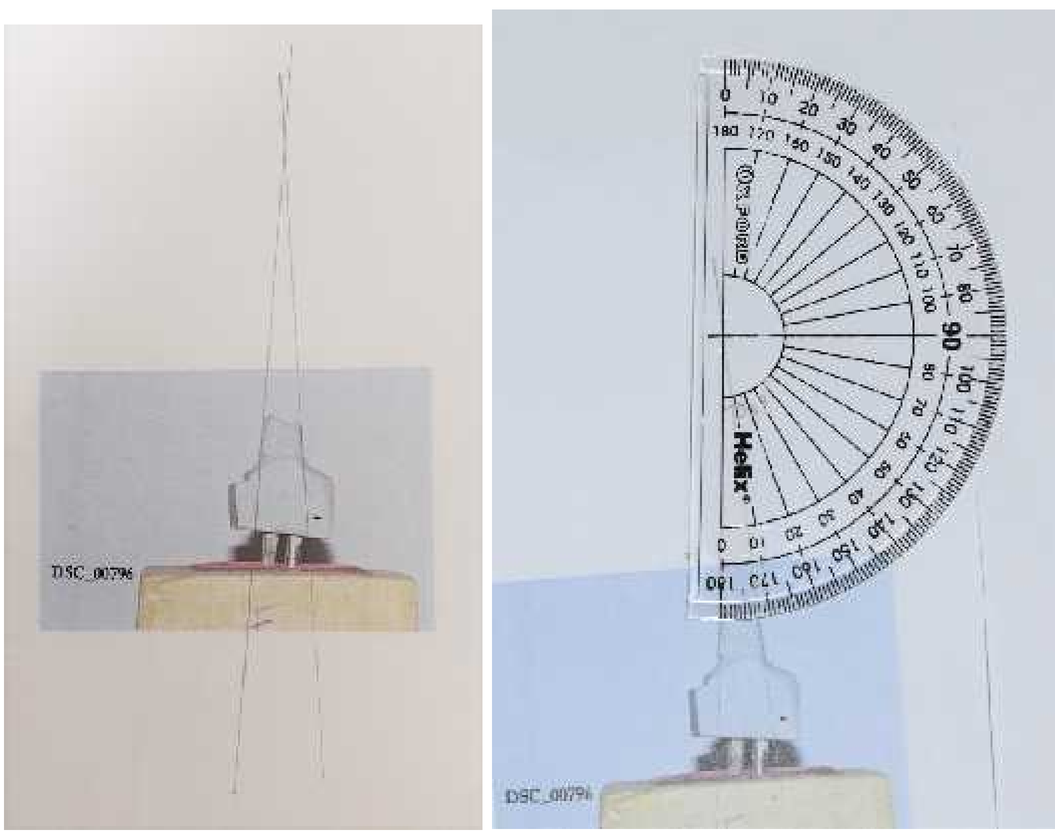

Figure 6: Printed photograph and extrapolation of gingival thirds of the buccal and lingual surfaces

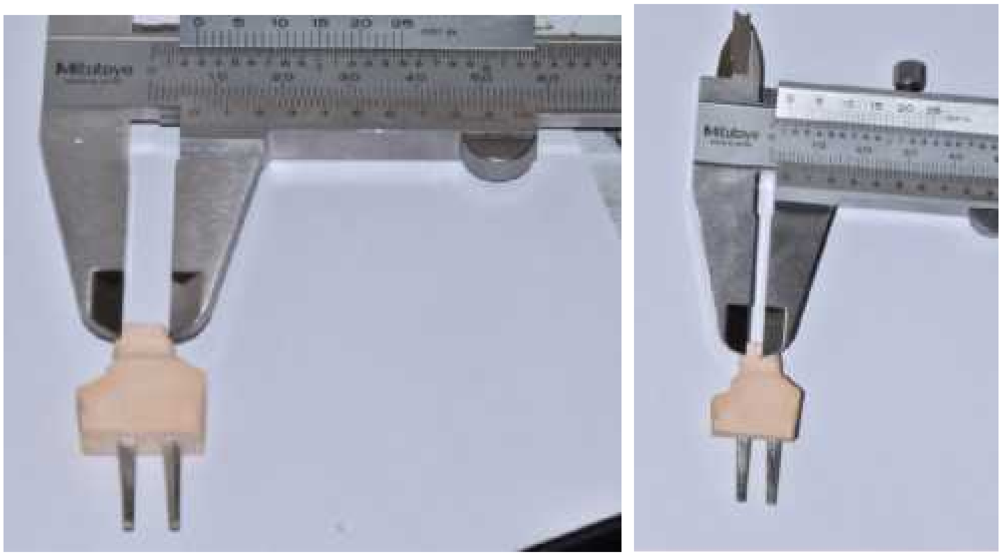

Figure 7: Determination of midpoint on distal surface of the die

Figure 8: Height measurement on vernier

The type of crown margin on the buccal and lingual aspect and the auxiliary retentive features of each prepared die was visually assessed using a Donegan Aspheric X5 handheld magnifying glass (Donegan Optical, USA) and recorded on the data collection form. This was repeated until a sample of 112 tooth preparations was achieved.

Figure 9: Magnifying glass (X5 Donegan Aspheric)

3.8.2 Digital method

For the digital method, the models were scanned by a laboratory desk-top model scanner (Dental wings, Straumann). The Stereolithography (STL) dataset of each die was transferred to a three-dimension (3D) inspection software (GOM Inspect Suite, 2020). Metrological analysis of the STL files was done for similar preparation parameters as in the manual method. Alignment of the digital files was done in the x, y and z axis. For the convergence angle, a buccal-lingual section of the die was digitally made at its most convex area. Linear extrapolations to the buccal and lingual gingival thirds of the section were made to measure the two-direction convergence angle. For the Occlusal cervical height, a midpoint was constructed on the distal proximal wall and a two-point distance from this midpoint was measured to the occlusal/incisal aspect. The margin design and presence/absence of auxiliary features was assessed on the uploaded file.

Figure 10: Laboratory model scanner (Dental wings, Straumann)

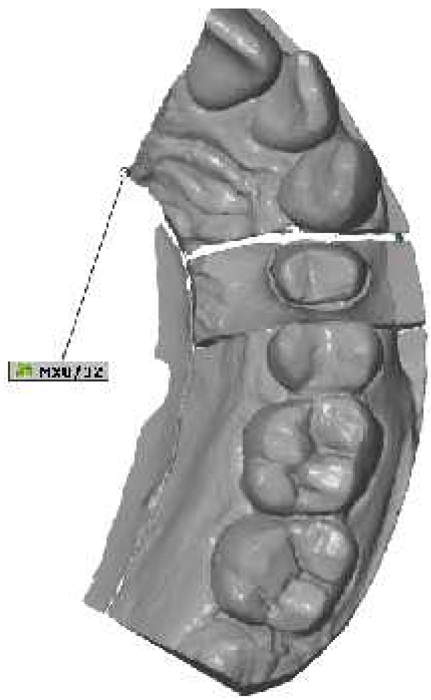

Figure 11: Uploaded STL file of model on GOM inspect software

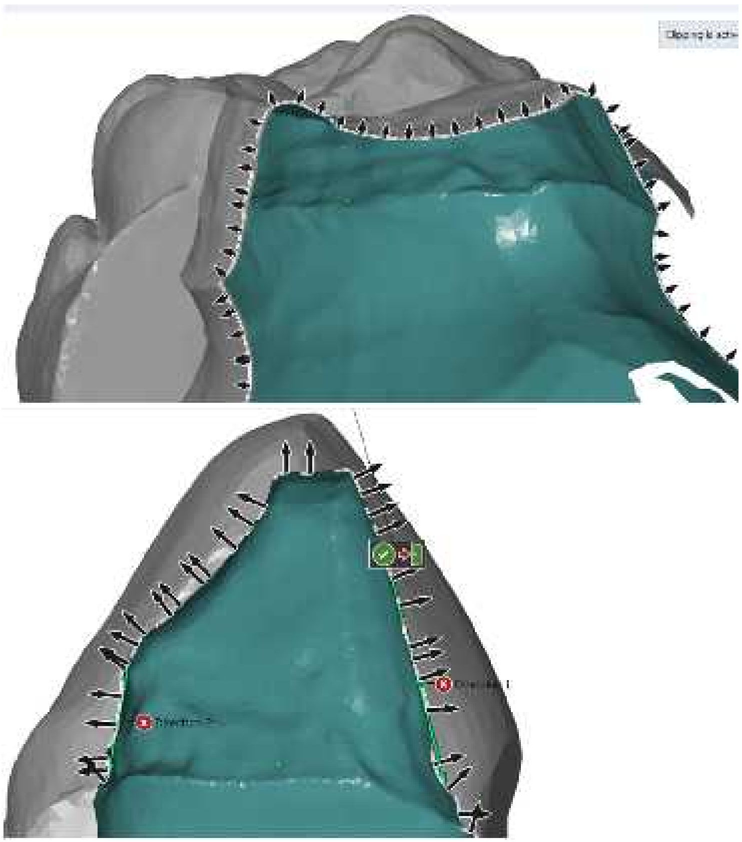

Figure 12: Buccal lingual Sections on mesial of dies made on GOM inspect software

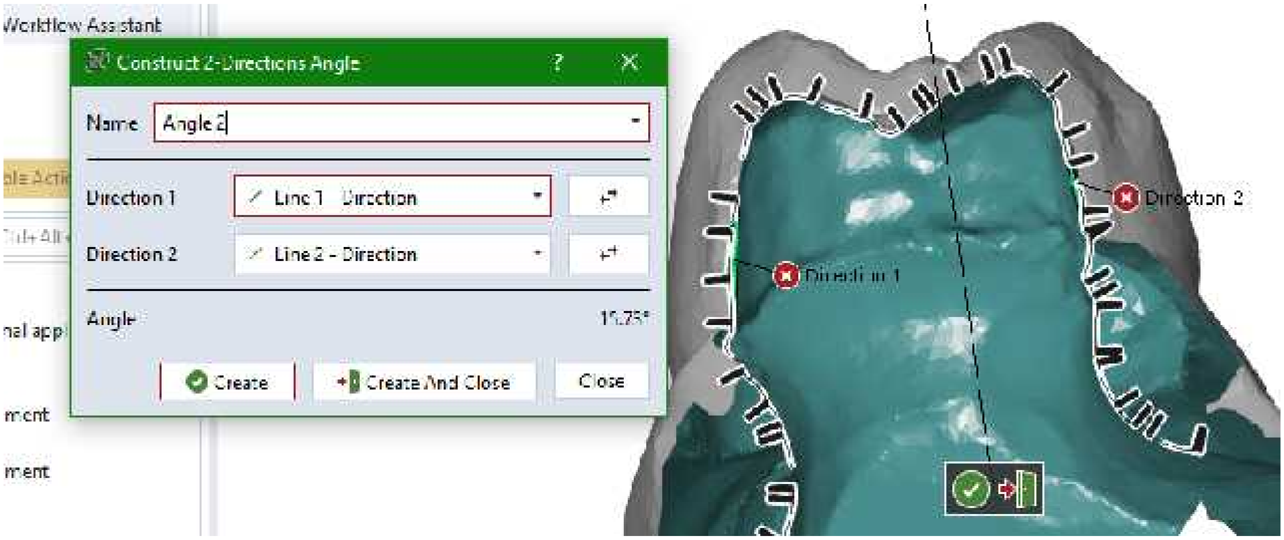

Figure 13: Angular measurement in GOM inspect

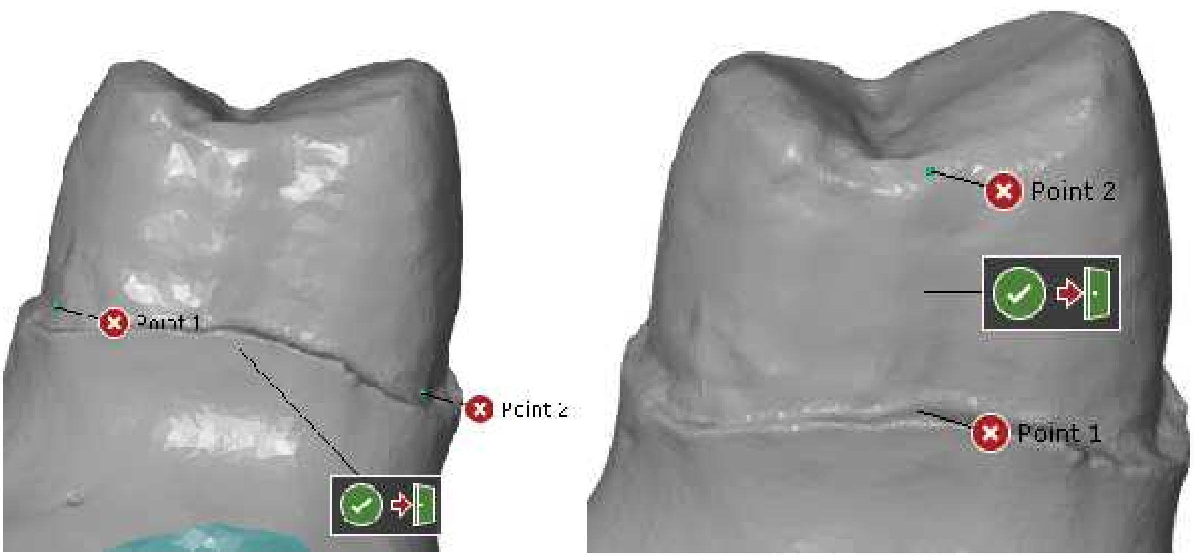

Figure 14: Midpoint determination

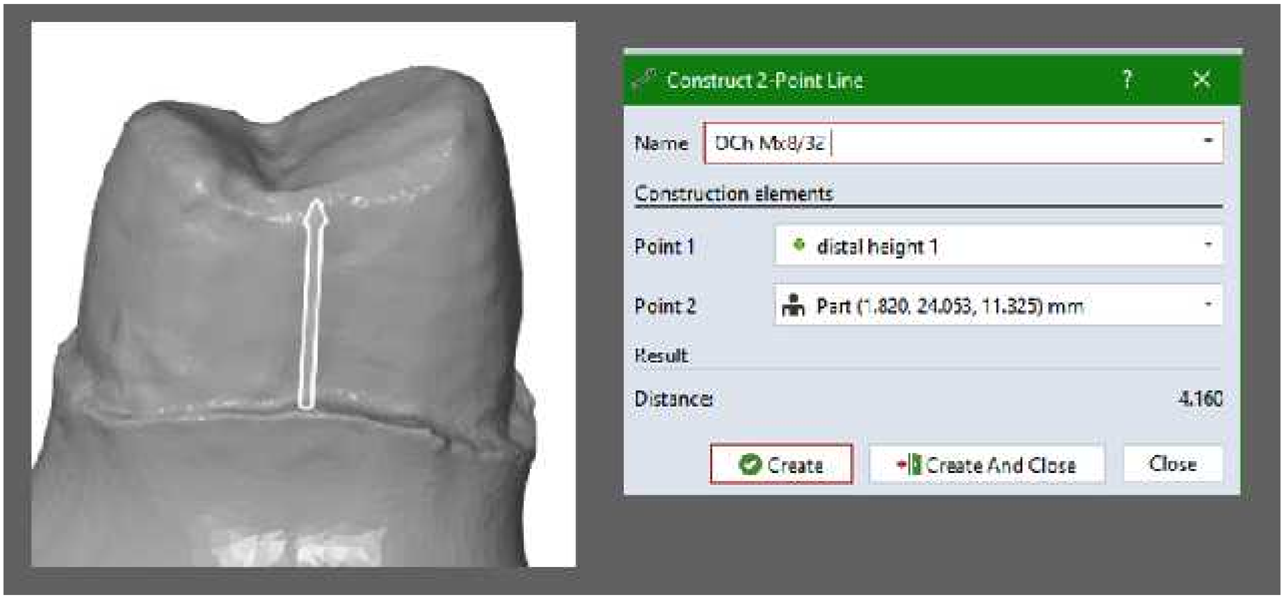

Figure 15:Height measurement on GOM Inspect

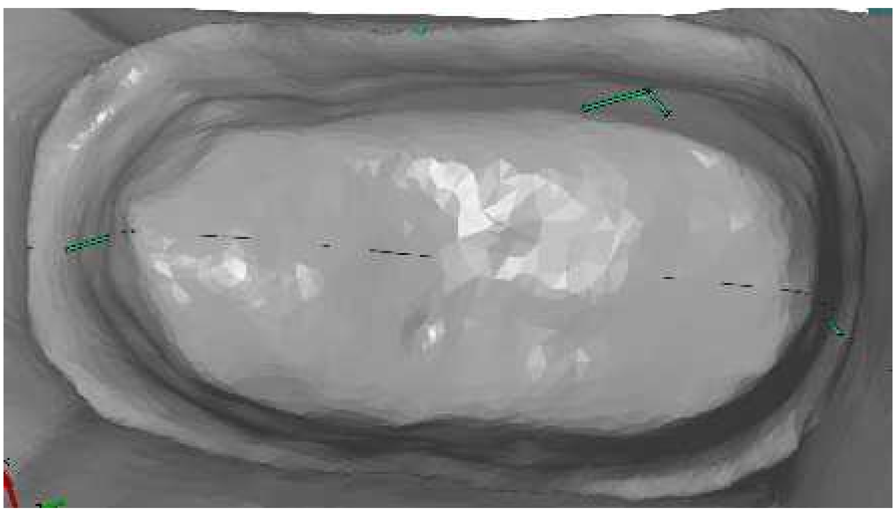

Figure 16: Magnification for assessment of auxiliary retentive features and margin design

3.9 Data reliability and validity

A pilot study was done to evaluate the validity and reliability of the study protocol. The tools used were calibrated by the Kenya Bureau of Standards (BS/MET/7/356/274). The manual dies were prepared by a skilled dental technician using type IV gypsum and allowed to set for 24 hours. To ensure validity, the dies were mounted on a standardized gypsum block for stability and similar orientation of all dies during photography.

The photography and manual analysis were done by the primary investigator. The principal investigator carried out all the measurements on the dies to eliminate inter-examiner variation. The principal investigator re-examined every 10th die on both the manual and digital analysis to evaluate reproducibility of the measurements.

To ensure inter examiner reliability, 5% of the dies were re-examined by a skilled clinician (Co investigator J.N) for both methods to ensure inter examiner reliability. An intra-class correlation coefficient was performed to assess agreement between the two observers for both methods. Additionally, a technician skilled in the metrology software re-examined 5 percent of the dies to confirm inter-examiner reliability.

3.9.1 Inter-rater reliability

Table 1: Buccal lingual convergence angles and occlusal cervical height measurements taken by the principal investigator and the supervisor

Die	Principal Investigator	Supervisor	Measurement	Method	Absolute Difference (Rater1-Rater2)
M10	7.21	7.22	Degree	Digital	0.005
M20	9.01	9.1	Degree	Digital	0.09
M30	7.49	7.5	Degree	Digital	0.01
M40	36.55	36.6	Degree	Digital	0.055
M50	37.3	37.3	Degree	Digital	0
M60	15	15	Degree	Digital	0
M70	34.39	34.3	Degree	Digital	0.09
M80	27	27.2	Degree	Digital	0.2
M90	33.09	33.11	Degree	Digital	0.025
M100	17.1	17.1	Degree	Digital	0
M110	19.45	19.34	Degree	Digital	0.115
M120	23.39	23.3	Degree	Digital	0.09
M10	3.4	3.3	Height	Manual	0.1
M20	2.8	2.78	Height	Manual	0.02
M30	2.4	2.4	Height	Manual	0
M40	3.53	3.52	Height	Manual	0.01
M50	2.74	2.68	Height	Manual	0.06
M60	3.41	3.4	Height	Manual	0.01
M70	2.31	2.32	Height	Manual	0.01
M80	4.77	4.76	Height	Manual	0.01
M90	2.87	2.9	Height	Manual	0.03
M100	3.53	3.54	Height	Manual	0.01
M110	4.36	4.38	Height	Manual	0.025
M120	5.37	5.34	Height	Manual	0.03

Table 2 shows the comparison of measurements taken by the principal investigator and one of the supervisors for both digital and manual methods. The mean difference between the values was 0.041 with a standard deviation of 0.050 ranging from 0 to 0.2. The Pearson's correlation coefficient was $r=0.99$, $p<0.001$. This shows a high level of agreement between the measurements by the principal investigator and the supervisor.

3.10 Study variables

Table 2: Study variables

Variable Name		Category	Type	Measurable outcome
Features of the Preparation	Degree of Convergence of Buccal and Lingual walls	Outcome	Continuous	Measurement in degrees
	Occluso-Cervical height	Outcome	Continuous	Measurement in millimeters
	Finish Line (Buccal and Palatal/Lingual)	Outcome	Nominal	(1) Shoulder (2) Chamfer (3) Knife Edge
	Auxiliary retentive features	Outcome	Nominal	1)Present 2)Absent
Tooth Type		Independent	Nominal	1. Maxillary anterior teeth (Central Incisor, lateral incisor, canine) 2. Maxillary premolar 3. Maxillary molar 4. Mandibular anterior teeth (Central Incisor, lateral, incisor, canine) 5. Mandibular premolar 6. Mandibular Molar
Number of prepared teeth per arch		Independent	Nominal	Number of teeth
Type of full coverage restorations		Predictor	Nominal	1. Porcelain fused to metal 2. All-ceramic crown 3. All metal crown
Method of Analysis		Predictor	Nominal	(1) Analogue (2) Digital

3.10.1 Confounding Variables

Pouring of models- This was avoided by having the models poured by the same technician in the same conditions and following manufacturers recommendation

Scanning errors – Models were scanned and edited by an experienced technician

3.11 Data analysis

The collected data was analyzed using the Statistical Packages for Social Sciences (SPSS) 20.0 for Windows. Descriptive summaries of number and type of teeth, parameters of tooth preparation as determined by digital and analogue analysis were presented in the form of frequencies, means and standard deviations presented in tables and figures. Inferential statistical analysis to establish difference in analytical techniques were conducted using independent t test for continuous binary variables and chi square for categorical binary variable. An alpha level of < 0.05 was considered significant.

3.11.1 Data analysis plan

Data was entered and cleaned in Microsoft Excel spreadsheets and analyzed using STATA, version 16 (StataCorp LLC College Station, Texas, 77845, USA).

Variable name	Descriptive statistics	Inferential statistics
Objectives 1: To describe the type and number of teeth per arch being prepared and types of full-coverage single crowns prescribed for these preparations in Nairobi		
Teeth, type, number of teeth per arch, types of restorations	Frequencies & proportions	
Objectives 2, 3: To analyze the parameters of tooth preparations using manual and digital methods (total occlusal convergence of buccal and lingual walls, occlusal cervical height, auxiliary retentive features and margin design)		
Parameters measured by Manual method	Means, standard deviations	
Parameters measured by Digital method		
Objective 4: To determine the rate of adherence of tooth preparations for single crowns to recommended guidelines when assessed by manual versus digital methods		
Parameters from study	Means, standard deviations	Confidence interval, chi square
Recommended parameters		
Objective 5: To determine whether there is a difference between the analogue and digital measurements of the parameters of teeth preparations		
Manual Method	Means, median, standard deviations	Independent t-test, Fischer's exact test,
Digital methods		

3.12 ETHICAL CONSIDERATIONS

The approval to conduct the study was sought from the Kenyatta National Hospital (KNH) and University of Nairobi (UoN) Ethics and Research Review Committee (P778/09/2021). Written permission to conduct the study was sought from the commercial dental laboratories. Any questions regarding the study were answered appropriately. A written informed consent was obtained from the administrators who permitted the use of their laboratories. The information collected was anonymized and treated with utmost confidentiality and no dentists' names was included in the data collection form.

3.13 Limitations

The study was a laboratory(retrospective) based looking into clinical practice. An in-vivo study would probably yield superior results. Secondly, the study compared only two methods. A comparison of the different methods using different software can add more information Further, the study was done in one laboratory. Incorporation of different laboratories in future studies may improve knowledge on tooth preparations

3.14 Study findings dissemination plan

The findings shall be disseminated through forwarding a copy of the final research thesis report to the University of Nairobi Department of Dental Sciences and the University of Nairobi Library. The final research thesis report will be uploaded to University of Nairobi digital repository. The researcher shall also endeavor to present the findings in appropriate scientific and academic forums, workshops and conventions. The work will also be published in a relevant peer reviewed journal.

4.0 CHAPTER FOUR: RESULTS

4.1 Introduction

The study aimed at assessing different parameters of tooth preparations sent to a dental laboratory by clinicians in Nairobi, Kenya using a manual and a digital method. The study collected data from 125 dies emanating from a total of 83 models.

4.2 Description of the type and number of teeth per arch being prepared for single crowns and the types of full coverage crowns being prescribed for these preparations in Nairobi, Kenya

Of the models analyzed, 57.8% were maxillary arch while mandibular arch contributed to 42.2% (Table 3). The study sought to enumerate the commonly prescribed type of full coverage restoration in a Kenyan population. In the maxillary arch, majority of the crowns had been prepared for the anterior teeth (43.3%) while in the mandibular arch, majority of prepared teeth were molars (62.8%).

In the maxillary arch, the premolars made up 36% while the molars made up 21% of the prepared teeth. In the mandibular arch, the anterior teeth contributed 14% of the prepared teeth, the premolars 23%, and the molars made up 63% of the prepared teeth.

Table 3: Teeth types, number of teeth and crown type per arch

Variable	Arch	
	Maxillary Frequency (%)	**Mandibular** Frequency (%)
Teeth type		
Anterior	39(43.3)	5(14.3)
Premolar	32(35.6)	8(22.9)
Molar	19(21.1)	22(62.8)
Number of teeth per model		
1	43(47.8)	23(65.7)
2	12(13.3)	2(5.7)
3	3(3.3)	6(17.1)
4	4(4.4)	4(11.4)
8	8(8.9)	0
10	20(22.2)	0
Crown type		
All ceramic	**73(81.1)**	**24(68.6)**
Anterior	36(49.3)	3(17.6)
Premolar	25(34.3)	7(41.2)
Molar	12(16.4)	7(41.2)
Metal ceramic	**17(18.9)**	**11(31.4)**
Anterior	5(20.8)	0
Premolar	4(16.7)	4(36.4)
Molar	15(62.5)	7(63.6)

It was found that majority (77.6%) of the crowns requested by clinicians were All- ceramic crowns while 22.4% were Metal-ceramic (Figure 17).

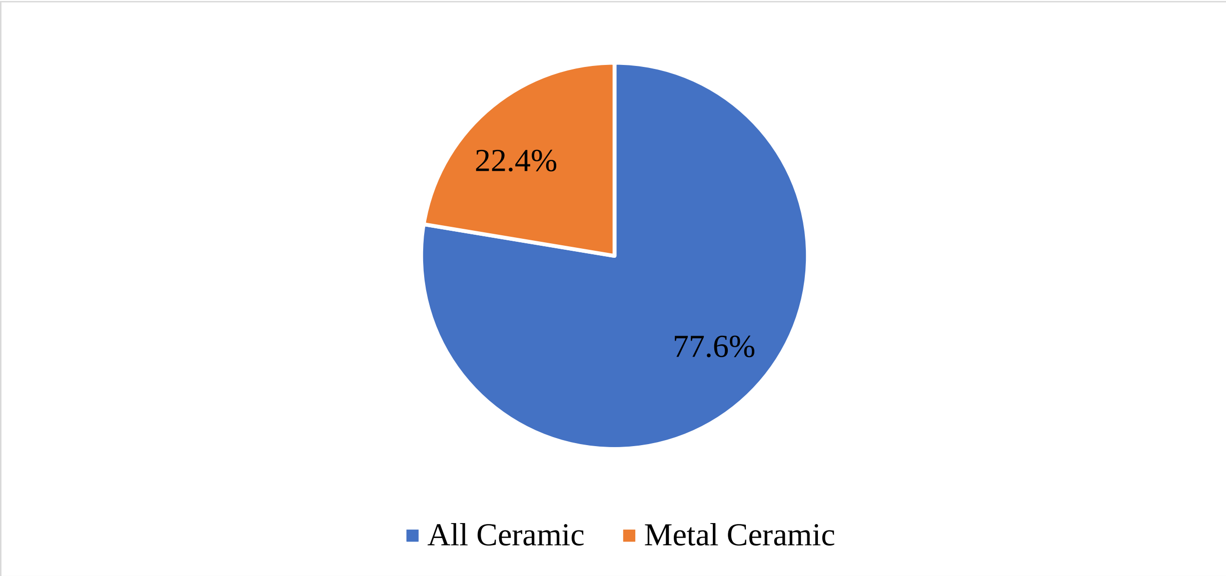

Figure 17: Distribution of type of Crown prescribed by clinicians

4.3 Analysis of the parameters of tooth preparations for single crowns using manual methods (total occlusal convergence of buccal and lingual walls, occlusal cervical height, auxiliary retentive features and margin design)

The study analyzed the parameters of tooth preparations (total occlusal convergence of buccal and lingual walls, occlusal cervical height from the midpoint of the distal proximal wall, the presence/absence of auxiliary retentive features and margin design) using manual and digital methods. The results are presented below.

The means for the Buccal-Lingual convergence angle for maxillary teeth when assessed using manual method were 21.9, 17.4 and 29.6 degrees for anterior, premolars and molars respectively (Table 4). In the mandibular arch, the manual assessment found convergence angles of 28.8, 20.7 and 30.8 degrees for anterior, premolars and molars respectively. The molars and anterior teeth had a higher mean for the Buccal lingual angle than premolars for both arches.

Table 4: Buccal lingual angle (manual)

Arch	N	Minimum	Maximum	Mean (SD)	Median (IQR)
Maxillary position					
Anterior	39	6.5	48.5	21.9 (10.2)	20 (14.5, 31.5)
Premolar	32	5	48	17.4 (9.7)	15.5 (11, 21)
Molar	19	5	57.5	29.6 (15.7)	31 (14, 41)
Mandibular position					
Anterior	5	27	32	28.8 (1.9)	28 (28, 29)
Premolar	8	7	47	20.7 (13.5)	15.5 (12, 28.3)
Molar	22	8	46	30.8 (10.8)	34.5 (23, 38)

The study evaluated the occlusal cervical height of different tooth types as measured from the mid-point of the distal proximal wall. Using the manual method, the study found that maxillary anterior, premolars, and molars had a mean of 4.5mm, 3.2mm, and 3.6mm. In the mandibular arch, anterior teeth, premolars, and molars had a mean of 3.1mm, 3.7mm, and 3.2mm respectively (Table 5).

Table 5: Occluso cervical Length (manual)

Arch	N	Minimum	Maximum	Mean (SD)	Median (IQR)
Maxillary position					
Anterior	39	2.3	7.5	4.5 (1.2)	4.5 (3.4, 5.3)
Premolar	32	1.2	4.8	3.2 (0.8)	3.2 (2.9, 3.5)
Molar	19	2.3	5.6	3.6 (1.0)	3.5 (2.7, 4.5)
Mandibular position					
Anterior	5	2.4	4.3	3.1 (0.8)	2.9 (2.6, 3.1)
Premolar	8	2.5	4.5	3.7 (0.6)	3.8 (3.5, 4)
Molar	22	1.5	7.4	3.2 (1.2)	3.0 (2.5, 3.6)

The study evaluated the placement of auxiliary retentive features by clinicians on tooth preparations for single crowns. Majority of the dies (97.6%) did not have any auxiliary retentive feature. Only 3 dies had auxiliary retention (Table 6). All the auxiliary features were present on Molars (1 Maxillary Second Molar) and Two Mandibular first molars. All teeth with auxiliary retention had less than 4mm occlusal cervical height.

Table 6: Auxiliary retentive features (manual)

Variable	Auxiliary retentive features	
	Absent	**Present**
	Frequency (%)	Frequency (%)
Maxillary		
Anterior	39(43.8)	0(0)
Premolar	32(36.0)	0(0)
Molar	18(20.2)	1(100)
Mandibular		
Anterior	5(15.2)	0 (0)
Premolar	8(24.2)	0 (0)
Molar	20(60.6)	2(100)

In the maxillary arch, majority of preparations (97.8%) had a shoulder margin on the facial aspect (Table 7). All preparations in the mandibular arch had a shoulder margin.

Table 7: Margin design - Facial aspect (manual)

Arch	N	Shoulder	Chamfer
		Frequency (%)	Frequency (%)
Maxillary position			
Anterior	39	39 (100)	0 (0)
Premolar	32	31 (96.9)	1 (3.1)
Molar	19	18 (94.7)	1 (5.3)
Mandibular position			
Anterior	5	5 (100)	0 (0)
Premolar	8	8 (100)	0(0)
Molar	22	22 (100)	0(0)

The study assessed the clinician choice of margin design for the facial and lingual aspect of the preparation. On manual assessment, the majority of dies (98.4%) had a shoulder margin on the facial aspect. Only 2% of prepared dies had a chamfer preparation on the facial aspect. In both arches, all the anterior teeth assessed were prepared with a shoulder margin on both facial and lingual aspects (Tables 7,8).

Table 8: Margin design - Lingual aspect (manual)

Arch	N	Shoulder Frequency (%)	Chamfer Frequency (%)
Maxillary position			
Anterior	39	39 (100)	0 (0)
Premolar	32	31 (96.9)	1 (3.1)
Molar	19	16 (84.2)	3 (15.8)
Mandibular position			
Anterior	5	5 (100)	0(0)
Premolar	8	8 (100)	0(0)
Molar	22	17 (77.3)	5 (22.7)

4.4 Analysis of the parameters of tooth preparations for single crowns using digital methods (total occlusal convergence of buccal and lingual walls, occlusal cervical height, auxiliary retentive features and margin design)

As seen in table 9, the means of the Buccal-Lingual convergence angles for maxillary teeth when assessed using the digital method were 23.3, 18.6 and 30.9 degrees for anterior, premolars and molars respectively. In the mandibular arch, the digital assessment found convergence angles of 29.8, 22.2 and 32.3 degrees for anterior, premolars and molars respectively. The molars in both arches had higher convergence angles than the anterior teeth.

Table 9: Buccal lingual Convergence angle (digital)

Arch	N	Minimum	Maximum	Mean (SD)	Median (IQR)
Maxillary position					
Anterior	39	8.8	47.4	23.3 (10.2)	22 (16.3, 31.7)
Premolar	32	6.5	48.3	18.6 (9.6)	16.2 (12, 22.2)
Molar	19	3.7	58	30.9 (16.1)	33 (15, 41)
Mandibular position					
Anterior	5	26.7	33.2	29.8 (2.4)	29.5 (29, 30.8)
Premolar	8	8.2	48	22.2 (13.2)	17.8 (13.6, 29.4)
Molar	22	8.8	48	32.3 (11.3)	36 (26, 38.9)

Using the digital method, the study found that maxillary anterior, premolars, and molars had a mean height of 4.4mm, 3.0mm, and 3.3mm respectively. In the mandibular arch, anterior teeth, premolars, and molars had a mean of 3mm, 3.3mm, and 2.9mm respectively (Table 10).

Table 10: Occluso cervical Length (digital)

Arch	N	Minimum	Maximum	Mean (SD)	Median (IQR)
Maxillary position					
Anterior	39	2.1	7.9	4.4 (1.3)	4.5 (3.4, 5)
Premolar	32	1.2	4.4	3.0 (0.8)	3 (2.5, 3.3)
Molar	19	1.9	5.3	3.3 (1)	3.2 (2.4, 4.3)
Mandibular position					
Anterior	5	2.3	4.2	3 (0.7)	2.9 (2.7, 2.9)
Premolar	8	2.1	4.3	3.3 (0.6)	3.4 (3, 3.4)
Molar	22	1.2	7.4	2.9 (1.3)	2.7 (2.1, 3.3)

The study evaluated the placement of auxiliary retentive features by clinicians on tooth preparations for single crowns using a digital method. As seen in table 10, only 3 dies had auxiliary retention. All the auxiliary features were present on Molars (1 Maxillary Second Molar) and Two Mandibular first molars. All teeth with auxiliary retention had less than 4mm occlusal cervical height.

Table 11: Auxiliary retentive features (digital)

Variable	Auxiliary retentive features	
	Absent	**Present**
	Frequency (%)	Frequency (%)
Maxillary		
Anterior	39(43.8)	0 (0)
Premolar	32(36.0)	0 (0)
Molar	18(20.2)	1(100)
Mandibular		
Anterior	5(15.2)	0 (0)
Premolar	8(24.2)	0 (0)
Molar	20(60.6)	2(100)

In the maxillary arch, majority of preparations (97.8%) had a shoulder margin on the facial aspect. All preparations in the mandibular arch had a shoulder margin (Table 12).

As seen in table 12, 100% of the anterior teeth in the maxillary arch had a lingual shoulder margin. On digital assessment, the majority of dies (95.6%) in the maxillary arch had a shoulder margin on the facial aspect. Only 4.4% of prepared dies in the maxillary arch had a chamfer preparation finish on the facial aspect. In both arches, all the anterior teeth assessed were prepared with a shoulder margin on both facial and lingual aspects (Tables 12, 13).

Table 12: Margin design - Facial aspect (Digital)

Arch	N	Shoulder	Chamfer
		Frequency (%)	Frequency (%)
Maxillary position			
Anterior	39	39 (100)	0 (0)
Premolar	32	31 (96.9)	1 (3.1)
Molar	19	18 (94.7)	1 (5.3)
Mandibular position			
Anterior	5	5 (100)	0 (0)
Premolar	8	8 (100)	0 (0)
Molar	22	22 (100)	0 (0)

Table 13: Lingual aspect (digital)

Arch	N	Shoulder Frequency (%)	Chamfer Frequency (%)
Maxillary position			
Anterior	39	39 (100)	0 (0)
Premolar	32	31 (96.9)	1 (3.1)
Molar	19	16 (84.2)	3 (15.8)
Mandibular position			
Anterior	5	5 (100)	0 (0)
Premolar	8	8 (100)	0 (0)
Molar	22	17 (77.3)	5 (22.7)

4.5 Description of the rate of adherence of tooth preparations for single crowns to recommended guidelines when assessed by manual versus digital methods

The study sought to determine whether the buccal lingual convergence was adhering to parameters recommended in literature. In this regard, a buccal lingual convergence of 10-20 degrees was deemed ideal[20]. Using the manual method, the study found that 47.4% of Maxillary anterior teeth had ideal buccal lingual convergence. Using the digital method, 47.1% of the maxillary teeth were found to have ideal buccal lingual convergence. For both methods in the mandibular arch, 100% of anterior teeth had non-ideal buccal lingual convergence. Both maxillary and mandibular premolars had the highest numbers of ideal preparations when assessed by both methods (Table 14).

Table 14: Adherence to Buccal lingual convergence angle

	Buccal lingual angle			
	Manual Frequency (%)		**Digital Frequency (%)**	
Arc	**Ideal**	**Not ideal**	**Ideal**	**Not ideal**
Maxillary position				
Anterior	18(47.4)	21(40.4)	16(47.1)	23(41.1)
Premolar	17(44.7)	15(28.8)	15(44.1)	17(30.4)
Molar	3(7.9)	16(30.8)	3(8.8)	16(28.6)
Mandibular position				
Anterior	0 (0)	5(18.5)	0 (0)	5(18.5)
Premolar	4(50)	4(14.8)	4(50)	4(14.8)
Molar	4(50)	18(66.7)	4(50)	18(66.7)

Confidence intervals were performed to evaluate the difference of the obtained buccal lingual convergence to the recommended guidelines. In the manual measurement the maxillary and mandibular molars did not adhere to recommended values with higher values than recommended.

Table 15: Buccal-lingual convergence manual measurement compared to recommended parameters

			Observed values	
Tooth category	**Recommended Value**	**N**	**Mean** ±SD	**95% CI**
Maxillary anterior	10-20	39	21.9 ±10.2	18.55 – 25.17
Maxillary premolar	10-20	32	17.4 ±9.7	13.89 – 20.86
Maxillary molar	10-20	19	29.6 ±15.7	22.02 – 37.14*
Mandibular anterior	10-20	5	28.8 ±1.9	26.41 – 31.19*
Mandibular premolar	10-20	8	20.7 ± 13.5	9.38 – 31.99
Mandibular molar	10-20	22	30.7 ±10.8	25.95 – 35.55*

*Significantly different from recommended values

Buccal lingual convergence digital and manual measurement for maxillary molar, mandibular anterior and mandibular molar were not adherent to the recommended guidelines of 10-20 degrees. They had significantly high values than the recommended (Table 16).

Table 16: Buccal-lingual convergence digital measurement compared to recommended parameters

			Observed values	
Tooth category	**Recommended Value**	**N**	**Mean** ±SD	**95% CI**
Maxillary anterior	10-20	39	23.3 ±10.2	19.96 – 26.60
Maxillary premolar	10-20	32	18.6 ±9.6	15.16 – 22.11
Maxillary molar	10-20	19	30.9 ±16.1	23.18 – 38.68*
Mandibular anterior	10-20	5	29.8 ±2.4	26.87 – 32.81*
Mandibular premolar	10-20	8	22.2 ±13.2	11.19 – 33.25
Mandibular molar	10-20	22	32.3 ±11.3	27.30 – 37.35*

*Significantly different from recommended values

For the manual method, the highest number preparations with non-ideal convergence angles (66.67%) were found when more than three preparations were present (Table 17). For the digital method, the highest numbers of non-ideal preparations were tied at 66.67% for one, three and more than three prepared teeth per model.

Table 17: Distribution of ideal and non-ideal buccal-lingual convergence angle measurements depending on the number of dies prepared in each cast as assessed by Manual and Digital Methods

	Manual Method Frequency (%)		Digital Method Frequency (%)	
Number of dies prepared in each cast	**Ideal**	**Non-Ideal**	**Ideal**	**Non-Ideal**
1	23 (34.85)	43 (65.15)	22 (33.33)	44 (66.67)
2	5 (35.71)	9 (64.29)	5 (35.71)	9 (64.29)
3	3 (33.33)	6 (66.67)	3 (33.33)	6 (66.67)
More than 3	15 (41.67)	21 (58.33)	12 (33.33)	24 (66.67)
Total	**46 (36.80)**	**79 (63.20)**	**42 (33.60)**	**83 (66.40)**

In the assessment for adherence to occlusal cervical height, the ideal occlusal cervical height of minimum 3mm for anterior teeth (including canines) and minimum 4mm for molars were used as references[20,25].

In the maxillary arch, 55.4% of the teeth that met requirements for ideal occlusal cervical height were anterior teeth while premolars were 35.4% (Table 18). Using the manual method, the study found that in the mandibular arch, premolars had the highest number of ideal preparation height (58.3%).

Table 18: Adherence to recommended occluso cervical height

	Occluso cervical height			
	Manual Frequency (%)		Digital Frequency (%)	
Arc	**Ideal**	**Not ideal**	**Ideal**	**Not ideal**
Maxillary position				
Anterior	36(55.4)	3(12)	39(61.4)	4(12.1)
Premolar	23(35.4)	9(36)	17(29.8)	15(45.5)
Molar	6(9.2)	13(52)	5(8.8)	14(42.4)
Mandibular position				
Anterior	2(16.7)	3(13)	1(11.1)	4(15.4)
Premolar	7(58.3)	1(4.4)	8(66.7)	2(7.7)
Molar	3(25)	19(82.6)	2(22.2)	20(76.9)

A confidence interval was calculated to determine the difference of obtained occlusal cervical heights to recommended range of acceptable measurements.

For the manual method, the occlusal cervical lengths for maxillary premolars and mandibular molars differed significantly compared to their recommended values (Table 19).

Table 19: Occluso cervical length manual measurement compared to recommended guidelines

		Observed values		
Tooth category	**Recommended Value**	**N**	**Mean** ±SD	**95% CI**
Maxillary anterior	≥3mm	39	4.5 ±1.2	4.06 – 4.87
Maxillary premolar	≥4mm	32	3.2 ±0.8	2.94 – 3.51*
Maxillary molar	≥4mm	19	3.6 ±1.0	3.15 – 4.09
Mandibular anterior	≥3mm	5	3.1 ±0.8	2.10 – 4.00
Mandibular premolar	≥4mm	8	3.7 ±0.6	3.20 – 4.18
Mandibular molar	≥4mm	22	3.2 ±1.2	2.61 – 3.71*

*Significantly different from recommended values

For the digital method, the occlusal cervical lengths all premolars and molars differed significantly compared to their recommended values.

Table 20: Occluso cervical length digital measurement compared to recommended guidelines

		Observed values		
Tooth category	**Recommended Value**	**N**	**Mean** ±SD	**95% CI**
Maxillary anterior	≥3mm	39	4.4 ±1.3	3.95 – 4.76
Maxillary premolar	≥4mm	32	3.0 ±0.8	2.69 – 3.26*
Maxillary molar	≥4mm	19	3.3 ±1.0	2.85 – 3.79*
Mandibular anterior	≥3mm	5	3.0 ±0.7	2.12 – 3.89
Mandibular premolar	≥4mm	8	3.2 ±0.6	2.73 – 3.77*
Mandibular molar	≥4mm	22	2.9 ±1.3	2.36 – 3.52*

*Significantly different from recommended values

Using the manual and digital methods, majority of non-ideal occlusal-cervical heights were present when one preparation was present. A higher percentage of ideal preparations (83.3%) was present in models that had three preparations (Table 21).

Table 21: Distribution of ideal and non-ideal occlusal cervical height measurements depending on the number of dies prepared in each cast as assessed by manual and Digital Methods

	Manual Method Frequency (%)		Digital Method Frequency (%)	
Number of dies prepared in each cast	**Ideal**	**Non-Ideal**	**Ideal**	**Non-Ideal**
1	47 (71.21)	19 (28.79)	37 (56.06)	29 (43.94)
2	11 (78.57)	3 (21.43)	10 (71.43)	4 (28.57)
3	8 (88.89)	1 (11.11)	8 (88.89)	1 (11.11)
More than 3	30 (83.33)	6 (16.67)	24 (66.67)	12 (33.33)

In this assessment, non-adherent dies were those with lower than recommended auxiliary cervical height and lacking auxiliary retentive features and those with recommended occlusal cervical heights that had auxiliary retentive features.

As seen in table 22, overall, the adherence to placement or lack of placement of auxiliary retentive in the maxillary arch was highest for maxillary anterior teeth (56.3%) while mandibular anterior teeth (14.35%) had lowest adherence to placement of auxiliary retentive features in the mandibular arch.

Table 22: Adherence to placement of auxiliary retentive features

	Auxiliary retentive features			
	Manual Frequency (%)		Digital Frequency (%)	
Arc	**Adherent**	**Non-adherent**	**Adherent**	**Non-adherent**
Maxillary position				
Anterior	36(56.3)	3(11.5)	35(60.3)	4 (12.5)
Premolar	23(35.9)	9(34.6)	17(29.3)	15(46.9)
Molar	5(7.8)	14(53.9)	6(10.3)	13(40.6)
Mandibular position				
Anterior	2(14.3)	3(14.3)	1(9.1)	4(16.7)
Premolar	7(50)	1(4.8)	6(54.5)	2(8.3)
Molar	5(35.7)	17(80.9)	4(36.4)	18(75)

In this assessment, the recommendations for the adherent margin design was a shoulder on the facial and lingual for all ceramic crowns and a shoulder on the facial with a lingual chamfer for metal ceramic crowns[(21]).

As seen in table 23, 93.8% of the all-ceramic crowns were adherent to recommended margin geometry by having a shoulder margin all round. The chamfer margin for all ceramic crowns was used in the lingual aspect in 4.1% of cases and on the facial in 2.1% of the all-ceramic preparations.

For metal-ceramic crowns, the shoulder margin was used facially in 100% of preparations made for PFM. In the lingual aspect, a chamfer margin was used in 17.9%. Therefore, 82.1% of the preparations for metal ceramic crowns were not adherent to recommended guidelines.

Table 23: Distribution of margin design for different crown types

		Manual Method Frequency (%)		**Digital Method** Frequency (%)	
	Margin location	**Chamfer**	**Shoulder**	**Chamfer**	**Shoulder**
All Ceramic	Facial	2 (2.1)	95 (97.9)	2 (2.1)	95 (97.9)
	Lingual	4 (4.1)	93 (95.9)	4 (4.1)	93 (95.9)
Metal ceramic	Facial	0 (0)	28 (100)	0 (0)	28 (100)
	Lingual	5 (17.9)	23 (82.1)	5 (17.9)	23 (82.1)

Chi Square goodness of fit tests done revealed a significant test result ($p<0.05$) for margin design and auxiliary retentive measures. The proportions of dies that adhered to margin design and auxiliary retentive measures was statistically different from the expected proportion of 100% for both manual and digital assessment.

Table 24: Comparison of adherence of auxiliary retentive features placement and margin design to recommended guidelines.

Variable	Expected counts	Observed counts	χ^2	p-value
Adherence to manual auxiliary retentive	125	78	17.67	<0.001
Adherence to digital auxiliary retentive	125	69	25.09	<0.001
Adherence to manual margins	125	98	5.83	0.016
Adherence to digital Margins	125	98	5.83	0.016

4.6 Statistical analysis for differences between the analogue and digital measurements of the parameters of teeth preparations

As presented in table 23, independent t tests failed to reveal a statistically significant difference between analogue and digital mean measurements (p ≥0.05) when analyzed for individual tooth categories summarized in table 25 and combined for all teeth summarized in table 26. For all the teeth, there were no significant differences between the manual and digital methods for the measurement of buccal-lingual convergence angle.

Table 25: Buccal lingual convergence – Individual teeth

		Type of measurement			
Tooth category	**N**	**Manual**	**Digital**	**t**	**p-value**
Maxillary anterior	39	21.9 ±10.2	23.3 ±10.2	-0.613	0.541
Maxillary premolar	32	17.4 ±9.7	18.6 ±9.6	-0.520	0.605
Maxillary molar	19	29.6 ±15.7	30.9 ±16.1	-0.263	0.794
Mandibular anterior	5	28.8 ±1.9	29.8 ±2.4	-0.755	0.472
Mandibular premolar	8	20.7 ± 13.5	22.2 ±13.2	-0.229	0.822
Mandibular molar	22	30.7 ±10.8	32.3 ±11.3	-0.471	0.640

The study used a t-test to establish whether there was a significant difference between the mean of the buccal lingual convergence angle as assessed using manual and digital methods.

The study found a t value of -0.8941 with a p-value of 0.3722 indicating that there was no statistically significant difference between the mean of the buccal lingual convergence angle as assessed using manual and digital method (Table 26).

Table 26: Difference between Manual and Digital Measurements of Overall Buccal lingual convergence

Variable	N	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
					Lower	Upper
Manual	125	23.652	1.089928	12.18576	21.49473	25.80927
Digital	125	25.03896	1.103902	12.342	22.85403	27.22389
Combined	250	24.34548	.775339	12.25919	22.81842	25.87254
Difference		-1.38696	1.551303		-4.442369	1.668449
				Degrees of freedom= 248	t= -0.8941	

The study used a t-test to establish whether there is a significant difference between the mean of occlusal cervical height as assessed using manual and digital methods. As seen in table 27, there were no statistically significant differences between manual and digital measurement of occlusal cervical height (p ≥0.05).

Table 27: Differences between manual and digital assessment of occlusal cervical height for-individual tooth categories

		Type of measurement			
Tooth category	N	Manual	Digital	t	p-value
Maxillary anterior	39	4.5 ±1.2	4.4 ±1.3	0.401	0.690
Maxillary premolar	32	3.2 ±0.8	3.0 ±0.8	1.264	0.211
Maxillary molar	19	3.6 ±1.0	3.3 ±1.0	0.957	0.345
Mandibular anterior	5	3.1 ±0.8	3.0 ±0.7	0.099	0.924
Mandibular premolar	8	3.7 ±0.6	3.2 ±0.6	1.460	0.166
Mandibular molar	22	3.2 ±1.2	2.9 ±1.3	0.572	0.570

The study used Fisher's exact test to establish whether there is a significant difference between the auxiliary retentive features as assessed using manual and digital method. The study found a significant Fisher exact test implying that auxiliary retentive features as assessed using manual method is not independent from the auxiliary retentive features as assessed using digital method (Table 28).

Table 28: Difference between Manual and Digital assessment for the presence of auxiliary retentive features

		Digital Method		
		Absent	**Present**	**Total**
Manual method	**Absent**	122	0	122
	Present	0	3	3
	Total	122	3	125

Fisher's exact = 0.000

The study used Fisher's exact test to establish whether there is a significant difference between the margin design as assessed using manual and digital methods. The study found a significant Fisher exact test implying that facial aspect margin design as assessed using the manual method is not independent of facial aspect margin design assessed using the digital method (Table 29).

Table 29: Difference between Manual and Digital assessment of Facial Aspect Margin Design

		Digital Method		
		Chamfer	**Shoulder**	**Total**
Manual Method	Chamfer	2	0	2
	Shoulder	0	123	123
	Total	**2**	**123**	**125**

Fisher's exact = 0.000

The study used Fisher's exact test to establish whether there is a significant difference between the lingual margin design as assessed using manual and digital methods. The study found a significant Fisher exact test implying that lingual aspect margin design as assessed using the manual method is not independent of lingual aspect margin design assessed using the digital method (Table 30).

Table 30: Difference between Manual and Digital assessment of Lingual Aspect Margin Design

		Digital Method		
		Chamfer	**Shoulder**	**Total**
Manual Method	Chamfer	9	0	9
	Shoulder	0	116	116
	Total	**9**	**116**	**125**

Fisher's exact = 0.000

4.7 Hypothesis Testing

1. **H_0 Geometric characteristics of tooth preparation of dies for single crowns from selected laboratories in Nairobi do not adhere to recommended guidelines**

H_A Geometric characteristics of tooth preparation of dies for single crowns from selected laboratories in Nairobi adhere to recommended guidelines

laboratories in Nairobi adhere to recommended guidelines

Chi Square goodness of fit tests done revealed a significant test result (p<0.05) for margin design and auxiliary retentive measures (Table 23). For the buccal lingual convergence and occlusal cervical height, specific tooth categories (molars) had the average of both parameters significantly outside the confidence intervals when compared to the ideal guidelines (Tables 13,14, 17 and 18). The proportions of those who adhered to recommended geometry was statistically different from the expected proportion of 100%. Hence, we fail to reject the null hypothesis.

2. **H_0 There is no difference in analogue vs digital measurements of parameters of tooth preparation**

H_A There is a difference in analogue vs digital measurements of parameters of tooth preparation

As shown in the results (Table 18-24) there were no significant differences in the manual versus digital methods. When assessing for buccal lingual convergence an independent t test found values of t= 0.8941, p+ 0.3722. When assessing for differences in measurement of occlusal cervical tests, an independent t test found values of t=1.4138 with a p-value of = 0.1587. However, Fischer's test done to evaluate for differences in the assessment of presence or absence of auxiliary retentive features and margin design found values of 0.00.

Therefore, we failed to reject the null hypothesis.

5.0 CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Introduction

The study evaluated the geometry of tooth preparations made by clinicians in Nairobi, Kenya by an analogue and digital technique and sought to find out if there were any differences of the features as analyzed by the two methods. Geometric features put into consideration were the Buccal-lingual convergence angle, Occlusal cervical height measured from the midpoint of the distal proximal wall, presence/absence of auxiliary features and the margin geometry on the facial and lingual walls. The conformity of the preparation geometry of dies to recommended guidelines was evaluated. In this regard, the recommendations by Goodcare et al for a 10-20 degree convergence, 3mm height for anterior teeth and 4mm for posterior teeth was used(20). Recommendations by Schillingburg for margin geometry for all ceramic and metal-ceramic crowns and placement auxiliary retentive features were also used(21). This information was derived from examination of the prepared dies. Other information on the crown type prescribed was derived from the clinician instructions on prescription form.

From the data gathered and analyzed, it was possible to make inference on the general features of tooth preparations made by dentists in Kenya. Additionally, the presence of any differences in a manual versus digital measurement method could be reported as a baseline for future studies in the same area.

5.1.2 Number of prepared teeth per model

Most of the examined models (80.7%) had only 1 tooth prepared. The highest number of teeth preparations in a single arch was found to be ten which was found in (2.4%) of the models. The majority of prepared teeth were found in the maxillary arch (57.8%%) while the mandible contributed for (42.2%). This is similar to previous studies(6,18,25,32). Within the maxillary arch, the anterior teeth (Incisors and canines) contributed to the commonly prepared teeth at 43%. This was postulated to be as a result of their prominence in the patient smile and a desire by most patients to improve their appearance.

In, the mandibular arch, more than half (63%) of the preparations were in the molar position with mandibular anterior teeth contributing to only 14%. In a standard smile, the mandibular anterior teeth are minimally visible. The demand for more restorations in the molar region of the lower jaw can be due to the demand for improved chewing efficiency. Additionally, the lower first molar erupts at an early age of 6 years and is exposed to post eruptive stress of mastication longer than any other tooth. A British study by Lynch et al found maxillary premolars (27%) and mandibular molars (25%) to be the most commonly crowned teeth(6). Just like in the present study, these authors found that most patients (90%) had only one crown placed or replaced in the duration of the study. In a Nigerian retrospective study that audited single crowns and fixed dental prosthesis delivered in a teaching hospital, the authors found that the most commonly crowned teeth were incisors (44%) followed by premolars (23%)(76). In similarity to the present study, majority of the crowned teeth (64%) were from the maxillary arch. Previous findings by Ombuna et al(25) and Edalia et al(18) in Kenya also found that in the lower jaw, molars were the most frequently prepared teeth with a prevalence of 46% and 72.2% respectively.

5.1.3 Crown type

The study evaluated the commonly prescribed restoration based on the material. It was found that majority (77.6%) of the crowns requested by clinicians were all- ceramic crowns while 22.4%. Most all ceramic crowns were in the anterior region while the Metal-ceramic crowns were in the posterior region.

Metal-ceramic crowns have had a long track record in dentistry with good longevity reported. Presently, the advancements in dental ceramics have brought to the fore materials with acceptable mechanical for use in both anterior and posterior regions(77,78). These include Lithium disilicate, Layered zirconia and monolithic zirconia.

In a study among clinicians in Germany, Rauch et al found that most clinicians (92.2%) prescribed all ceramic materials for single crowns while only 18.2% favored PFM crowns(79). These findings are similar to those of an American study where Lithium dislicate and Zirconia were the preferred material for anterior and posterior single crowns respectively(80).

In contrast, a Nigerian retrospective study done in a tertiary healthcare institution found 80.3% of the crowns delivered were porcelain fused to metal crowns while all ceramic crowns were prescribed in 0.8% of the cases[81].

In the Kenyan study by Edalia et al, it was found that Metal-Ceramic crowns attributed to 96.3% of crowns reviewed with all ceramic restorations attributing 3.7%[18]. Differences in the present study to that by Edalia at al can be attributed to two things. First, Edalia et al reviewed crowns placed between 2009 – 2015. Since then, great improvements in ceramic properties have occurred with more clinicians being more confident in prescribing all ceramic crowns. Secondly, the Edalia et al study evaluated crowns in a teaching institution where all ceramic crowns were not routinely done while the present study evaluated crowns prescribed by clinicians outside a dental school setting.

5.1.4 Convergence angle

The average convergence angle in the study was 23.65 and 25.04 degrees when assessed by the manual and digital method respectively. Various authors[40,42] have found different convergence among different cohorts of clinicians. The difference can also point to different methodology in assessment between different studies. A study in Saudi Arabia found the convergence angles to range from 22.9 to 34.4 degrees[46]. In a European study, Guth et al in an analysis using the GOM metrology software employed in the present study found that 55.7% had an ideal total occlusal convergence. However, this study evaluated ideal convergence based on an ideal of 6-20 degrees. Their study population also involved abutment teeth prepared for fixed dental prosthesis. Aleisa et al[82] found that single crown preparations had a lower taper than preparations on abutment teeth for FDP. This is because abutment preparations for fixed dental prosthesis have to consider the common path of insertion. This might explain difference in recent study to that by Guth et al[72]. In a South African laboratory study that evaluated the convergence angle among undergraduate students on artificial teeth, it was found that the overall mean convergence was overall mean convergence angle of $15.38° \pm 6.68°$[83].

In the Kenyan study by Ombuna et al, the mean buccal-lingual convergence angle was 26.7° which is close to findings from the present study[25]. This average is still beyond the recommended convergence angle and thus points a need for improved clinician education in this aspect.

However, when compared to past Kenyan research, there was an improvement in the number of preparations with ideal buccal-lingual preparations. An ideal Buccal lingual convergence angle was found in 36.8% of prepared dies in the current study when assessed by the manual method.

Digital evaluation found 33.6% of the dies to have ideal buccal lingual convergence. In the Kenyan population, this was an improvement from previous study where only 18.1% of prepared teeth had ideal convergence[25]. This might point to an improvement following education on clinician by the past research. Ombuna et al also assessed preparations from a dental school setting.

When differences for convergence angles between teeth type were evaluated premolars and anterior teeth were found to have a lower convergence angle than molars. This corroborates findings from various studies[25,47,82]. Accessibility to anterior teeth and premolars for tooth preparations can allow clinicians to generate a smaller buccal lingual convergence. However, the higher number of non-ideal convergence angles of mandibular anterior teeth (100%) in this study point to the clinical difficulty in achieving an ideal tooth preparation. Some studies have reported high buccal-lingual convergence angles of 37.48 and 25.6 degrees for mandibular and maxillary molars respectively[46]. This has been postulated to be due to the anatomical position of the teeth, slight lingual inclination of mandibular molars as well as clinician orientation of the bur to avoid injury to the tongue and cheeks[46].

From the maxillary dies examined, 42.2% had ideal buccal convergence angles compared to 22.9% of the mandibular dies assessed. This could be related to better accessibility by clinicians for the maxillary arch. Some studies have found no significant differences in the overall tapers for the maxillary and mandibular arch[46].

5.1.5 Occlusal cervical Height

In the maxillary arches, the mean occlusal cervical height for anterior teeth was higher than for posterior teeth. Anatomically, this was acceptable as maxillary anterior teeth tend to have a higher crown height than posterior teeth[(84)].

Guth et al using a digital assessment method of STL datasets found that overall,7.9% of preparations did not meet ideal occlusal height. In this study, measurements were made to cuspal height and might explain difference in findings to the current study. Clinicians have little control over the height of preparation due to initial crown height or significant tooth destruction from previous pathology[(85)].

Overall, 72.4%of prepared teeth had ideal occlusal cervical height when assessed by the manual method. Mandibular teeth had the most non-ideal occlusal height when assessed for both manual and digital methods. This conforms to a finding by Ombuna et al which found only 15% of lower anterior teeth to have ideal occlusal cervical height. Inconsistencies in Occlusal cervical height measurements can also occur due to different measuring points for this parameter especially when manual methods are employed.

5.1.6 Auxiliary retentive features

Only 4.76% of preparations had a retentive auxiliary feature. These were present only on molars with an occlusal cervical height of less than 4mm. This corroborates findings by Ombuna et al where only 1.9% of analyzed dies had auxiliary retentive features. Retentive features aid clinicians improve retention and resistance. Although many dies did not adhere to the ideal geometry, clinicians rarely employed auxiliary retentive features. This could be due to clinicians having a conservative approach to tooth preparation where they deem auxiliary retentive features as a sacrifice of additional tooth structure. However, it can also point to lack of clinician knowledge and skill on when and how to place these features.

5.1.7 Margin design

The shoulder margin was commonly prescribed on the facial and lingual aspect for most restorations. Among the preparations for porcelain fused to metal crowns, clinicians used a facial shoulder margin in 100% of preparations. This is in line with clinical recommendation where a PFM preparation should have shoulder margin on the facial and a chamfer finish on the lingual[(21)]. For all ceramic restorations, a facial and lingual shoulder margin were prescribed in majority of preparations. Ideally ceramics need a shoulder margin so as to have adequate bulk of material for structural durability[(68)].

A few clinicians prescribed chamfer margins for all ceramic restorations in 2.1% of the cases. A systemic review by Hao et al(68) found that all ceramic restorations with rounded shoulder margins were shown to have better marginal adaption than those with chamfer margin. The margin design is the most predictable factor that affects marginal adaptation of the restoration since it is under control of the clinician(86). Some studies have postulated that clinicians choose a margin configuration based on clinician choice. The shoulder finish line as assessed by Borelli et al(87) was found to be the most invasive and this could explain why a few clinicians favored the conservative chamfer margin even for ceramic restorations.

In the previous study by Ombuna et al, the shoulder margin was frequently prescribed for the labial surface in 80.6% of cases while the palatal surface had a chamfer margin in 88.1% of dies(25). Since no information was availed from the study on the crown type prescribed, it could be that most of the preparations performed were for PFM crowns. The marginal integrity was found to have the lowest excellence and clinical acceptability in a retrospective Kenyan study(18). This area therefore needs more research and clinician education to ensure scientifically proven margin placement for different preparations among clinicians

5.1.8 Comparison of Manual versus Digital measurements

The mean convergence angles of the manual and digital methods were 23.7 degrees and 25 degrees respectively. This difference was not statistically significant when an independent t test was performed. The measurement method is an important variable when assessing tooth preparation geometry. Seo et al(88) evaluated the reliability of a manual versus digital analysis of tooth preparations. In the manual method, a method similar to this study was used while AutoCAD software was used for the digital analysis. The CAD method showed higher intra-rater and inter-rater reliability than the manual method. However, both methods had high inter rater and intra rater reliabilities (ICC 0.88, P 0.05). They also found that the values for buccal lingual convergence when measured by the digital method were slightly lower compared to the traditional tracing method. In this study, the average of the digital measurements was higher than the manual measurements.

This can be attributed to differences in measurement method. Additionally, AutoCAD assesses photographs of dies whereas this study employed STL datasets of the respective dies.

The slight differences in the mean angle values on digital versus manual measurement method could also be explained by differences in tracing the two extension lines on the axial walls. For the manual method, these extensions were manually made based on a photograph of the die. The lines were drawn to follow lower gingival third plane of the greatest convexity on the axial surfaces. In this method, errors can also arise from the manual drawing and the protractor used.

In some cases, these lines converge outside the drawing paper and can create room for errors. In the digital method, measurements could be made without extrapolation by picking surface data – points on a buccal lingual section of the most convex part of the die. This angle could be digitally calculated eliminating errors of axial plane extensions and reading protractor measurements.

The mean occlusal cervical height was 3.68mm and 3.46mm for manual and digital techniques respectively. This difference was not statistically significant when a t test was performed. The manual measurement method involved direct measurement for a midpoint position on an actual die. This can lead to errors first in location of a midpoint as well as in actual height measurement when using a manual caliper. Scratching of dies when marking these reference points can also cause measurement errors. The linear measurement for the digital measurement was easier to calculate since reference points could be placed digitally with no risk of damage to the die even with repeated measurements. The digital method also allows use of a similar tool for both angle and linear measurements which is not possible with the manual method.

Similarities in both methods were found when assessing for auxiliary retentive features and margins design. A Fischer's exact test found no difference for the margin design and presence/ absence of auxiliary retentive features. This can be attributed to the fact that these were both visually assessed parameters for both methods and sufficient magnification of the preparation was possible. The manual method used a x5 magnification while the digital method allowed over x100 magnification and provided better visibility of margins and auxiliary features(72).

The differences in geometric variables of tooth preparation for this study and past studies performing digital techniques(72,88) can also be explained by the clinician cohort among studies, the reference ranges for ideal geometry used, as well as the different software among different studies.

Son et al evaluated the accuracy of scan data using different three dimensional analysis(89). Three software were used - Geomagic control X, GOM Inspect, Cloudcompare, and Materialise 3-matic.

It was found that when different software was used for analysis of single tooth preparations significant differences were still found.

This study underscores the role of third-party software for analysis of tooth preparations by clinicians. Most of the methods used for assessing tooth preparation are mostly applicable in research and not clinical settings where visual assessment is used. For an assessment of their preparations, clinicians can assess their preparations on a model before final impression making. Since the use of intra-oral scanners is on the rise, clinicians can perform a quick analysis of their tooth preparation quickly using their scan STL files and adjust them accordingly.

Teaching institutions can also improve teaching by allowing students to self-evaluate their preparations. Some manufacturers of dental scanning software have incorporated this feature into their programs to allow clinicians to assess their tooth preparations.

5.2 Conclusion

Within the limitations of the study, the following conclusions were made;

1. Majority of the models examined had only one tooth preparation. The most commonly prepared teeth in the maxillary arch were anterior teeth while molars were the most commonly prepared teeth in the mandibular arch. Among these preparations, all ceramic crowns were more frequently prescribed than porcelain fused to metal crowns.
2. There is a high proportion of non-ideal preparation geometry in Kenya when analyzed by both manual and digital methods.
3. Although differences in the measurements from manual versus digital methods exist, they are not statistically significant for linear and angular measurements.
4. The digital method offers more straightforward measurement without need for physical methods/measuring tools.

5.3 Recommendations

1. High percentage of non-ideal preparation geometry warrants need for continuous education among clinicians
2. There is need for more comparative studies between other different techniques used for evaluating tooth preparations so as to evaluate for differences among the different methods.
3. Further research is needed to evaluate for differences and reliability among various software used for assessing teeth preparations.

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APPENDICES

Appendix I: Consent Form

I, Dr. Alexander Muchiri Mwangi of the University of Nairobi, Department of Dental of Dental Sciences, am conducting a study a comparative assessment of manual versus digital analysis of the quality of tooth preparations for single crowns in Nairobi, Kenya

VOLUNTARINESS OF PARTICIPATION: Participation in the study is voluntary and you are at liberty to decline your participation without any consequences at any point intime.

RISKS: there are no risks involved in the study. The data will be collected indirectly from the scanned impressions studied and laboratory instruction sheets, without reference to the identities of clinicians involved, or the patients from whom the impressions are taken. Hence, no psychological or physical trauma is anticipated

BENEFITS: Information gathered from this study will help us understand whether there is any difference in using an analogue versus digital method when assessing parameters of tooth preparation. Additionally, the precision with which Kenyan dentists are preparing tooth preparations with reference to laid down recommendations will also be evaluated. It will also give an insight to clinicians on which aspects of the tooth are often imprecisely prepared so as to be able to self-evaluate and improve their tooth preparations.

Confidentiality: The information obtained will be treated with utmost confidentiality. In case of any concerns on ethical issues, please contact: Dr Alexander Muchiri Mwangi (+254 727 491 948, email address- mwangimuchiri26@gmail.com. Kenyatta National Hospital/University of Nairobi Ethics, Research and Standards Committee- Secretary contact telephone numbers 2726300 extension 44102, email- uonknh_erc@uonbi.ac.ke.

CONSENT

I have read and understood the provided information and have had the opportunity to ask questions. I understand that the participation of my laboratory is voluntary and that as a facility, we are free to withdraw at any time, without giving a reason and without incurring any cost. As the lab representative, I understand that I will be given a copy of this consent form. On behalf of my laboratory, I hereby voluntarily agree to take part in this study.

Participant's signature (Laboratory representative)

Date ____.

Investigator's declaration statement

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has willingly and freely given his/her consent. I will conduct the trial as specified in the proposal. I will not commence with my role in the study before written authorizations from the ethics committee. I have not previously been involved in a study which has been closed due to failure to comply with ethical practice. I will submit all required reports within the stipulated time-frames

Investigator’s name and signature____________________

Date __________

Appendix II: Data Collection Form

TITLE: A COMPARATIVE ASSESSMENT OF MANUAL VERSUS DIGITAL ANALYSIS OF QUALITY OF TOOTH PREPARATIONS FOR SINGLE CROWNS IN NAIROBI, KENYA

Date: ___________________ Serial No: _____________________ (**Manual/ Digital)**

1. Type of crown ☐ full metal ☐ metal ceramic

☐ all ceramic

Other Specify ________________________

2. Number of prepared teeth present per arch ________________________

3. Position of the prepared tooth

a) Maxillary ☐1 ☐2 ☐ 3 ☐ 4 ☐5 ☐6 ☐7 ☐8

b) Mandibular ☐1 ☐2 ☐ 3 ☐ 4 ☐5 ☐6 ☐7 ☐8

6. Convergence angle: -

i. Bucco-lingual (^{o}) ______________________

7. Occluso-cervical length (mm)________________

10. Auxiliary retentive feature 1) Present 2) Absent

11. Type of crown margin

i. Facial aspect ________________________

ii. Lingual aspect ________________________

Appendix III: Ethical Consent form

UNIVERSITY OF NAIROBI
FACULTY OF HEALTH SCIENCES
P O BOX 19676 Code 00202
Telegrams: varsity
Tel:(254-020) 2726300 Ext 44355

KNH-UON ERC
Email: uonknh_erc@uonbi.ac.ke
Website: http://www.erc.uonbi.ac.ke
Facebook: https://www.facebook.com/uonknh.erc
Twitter: @UONKNH_ERC https://twitter.com/UONKNH_ERC

KENYATTA NATIONAL HOSPITAL
P O BOX 20723 Code 00202
Tel: 726300-9
Fax: 725272
Telegrams: MEDSUP, Nairobi

Ref: KNH-ERC/A/100

15th March, 2022

KENYATTA NATIONAL HOSPITAL APPROVED 15 MAR 2022 KNH/UoN-ERC P.O. BOX 20723-00202 NAIROBI

Dr. Alexander Muchiri Mwangi
Reg. No. V60/37275/2020
Dept. of Dental Sciences
Faculty of Health Sciences
University of Nairobi

Dear Dr. Mwangi,

RESEARCH PROPOSAL: A COMPARATIVE ASSESSMENT OF MANUAL VERSUS DIGITAL ANALYSIS OF QUALITY OF TOOTH PREPARATIONS FOR SINGLE CROWNS IN NAIROBI, KENYA (P778/09/2021)

This is to inform you that KNH-UoN ERC has reviewed and approved your above research proposal. Your application approval number is **P778/09/2021.** The approval period is 15th March 2022 – 14th March 2023.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by KNH-UoN ERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to KNH-UoN ERC 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to KNH-UoN ERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to KNH-UoN ERC.

Protect to discover

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://research-portal.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

DR. BEATRICE K.M. AMUGUNE
SECRETARY, KNH-UoN ERC

c.c. The Dean, Faculty of Health Sciences, UoN
The Senior Director, CS, KNH
The Chairperson, KNH- UoN ERC
The Assistant Director, Health Information, KNH
The Chair, Dept. of Dental Sciences, UoN
Supervisors: Dr. James Muriithi Nyaga, Conservative & Prosthetic Dentistry Unit, UoN
Dr. Fred Otieno, Conservative & Prosthetic Dentistry Unit, UoN
Dr. Olivia Awino Osiro, Conservative & Prosthetic Dentistry Unit, UoN

Appendix IV: Calibration certificate

ORIGINAL

Kenya Bureau of Standards
P.O Box 54974-00200
NAIROBI
Tel:(+254 020) 6948000
info.metrology@kebs.org
Website: www.kebs.org

KEBS

Calibration Certificate

Page 1 of 2 pages

REQUESTED BY	:	UNIVERSITY OF NAIROBI, FACULTY OF HEALTH SCIENCES
ADDRESS	:	P.O. BOX 30197-00100, NAIROBI
EQUIPMENT	:	VERNIER CALLIPER
TYPE / MODEL	:	RANGE 0-150 mm , RESOLUTION 0.02 mm
SERIAL No.	:	22028996
MANUFACTURER	:	MITUTOYO
LABORATORY	:	LENGTH
DATE OF CALIBRATION	:	2022-11-03
CERTIFICATE No.	:	BS/MET/7/3/56/274
CALIBRATION LABEL No.	:	86463

1.0 REFERENCE STANDARDS AND EQUIPMENT USED

1.1 ISO 13385-1: Geometrical product specifications (GPS) - Dimensional measuring equipment - Part 1: Callipers; Design and metrological characteristics of callipers.

1.2 Universal Measuring Machine Sip 414M

1.3 Gauge blocks S/No. 35

2.0 METROLOGICAL TRACEABILITY

2.1 This calibration certificate documents traceability to the National Standards, which realize units of measurement according to the International System of Units (SI). KEBS is a signatory of the CIPM Mutual Recognition Arrangement (CIPM MRA) and where there is no published CMC, KEBS has documented the traceability of the standard equipment used.

3.0 CALIBRATION METHOD

3.1 The instrument was calibrated according to Doc No.: MET-01-CP-01 - Calibration Procedure for callipers.

4.0 VALIDITY

4.1 This certificate is valid until 2023-11-03

Calibrated by: Eunice Mwangi Date: 2022-11-03

Checked by: .... Date: 2022-11-03

Signed: .... Date: 2022-11-03

For: Director - Metrology and Testing

Calibration certificate without signature and official stamp is not valid. This certificate has been issued without any alteration and may not be reproduced other than in full except with the approval of the Managing Director KEBS.
If undelivered please return to the above address.

5.0 RESULTS

5.1 Table 1 below shows the calibration results.

Table 1: Calibration results

Parameter	Standard reading (mm)	Calliper reading (mm)
External measurements	2	2.00
	10	10.00
	40	40.00
	100	100.00
	140	140.00
Internal measurements	5	4.98
	30	29.98
Depth measurements	40	39.98
Step measurements	40	40.00

6.0 REMARKS

6.1 The results mentioned in 5.0 above only relate to the equipment calibrated as described in page 1.

6.2 The uncertainty of measurement is ± 17 µm. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %. This is in accordance with publication JCGM 100:2008 (GUM).

6.3 The calibration was carried out at an ambient temperature of (20 ± 1)°C and a relative humidity of (50 ± 10)% RH.

6.4 Certain of KEBS certificates are consistent with the capabilities that are included in Appendix C of the MRA drawn up by the CIPM. Under the MRA, all participating institutes recognise the validity of each other's calibration and measurement certificates for the quantities and ranges and measurement uncertainties specified in Appendix C. For details see https://www.bipm.org.

END

Appendix V: Work Plan

Activity	**Oct 20 – Mar 21**	**July 21 – Mar 22**	**May 22- Aug 22**	**Jan - Feb 23**	**Mar - May 23**	**Ma y 23**	**July 23**	**Nov 23**	**Nov 23**
Proposal defense	■								
Ethical approval		■							
Pilot Test		■							
Development, scripting, procurement and finalization of survey tools			■						
Data Collection				■					
Data Analysis					■				
First Report Draft						■			
Revision/Completi on of Report							■		
Thesis Defense								■	
Corrections and Completion									■

Appendix VI: Research budget

Activity	Cost (ksh)
Airtime and internet	10000
Transport	20000
Ethics committee fee	3000
Building contraption for fixed point photography	5000
Mitutoyo vernier calipers	9000
Donegan Aspheric x5 magnifying glass	6000
Photography consultation and training	5000
GOM Inspect metrologist consultation and training	25000
Printing and binding costs	13000
Research assistants	56000
Data analysis	50000
Total	**202 000**

Appendix VII: Plagiarism report

A COMPARATIVE ASSESSMENT OF MANUAL VERSUS DIGITAL ANALYSIS OF QUALITY OF TOOTH PREPARATIONS FOR SINGLE CROWNS IN NAIROBI, KENYA

ORIGINALITY REPORT

9%	6%	4%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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