EFFECT OF BUILDING ORIENTATION ON MARGINAL GAP AND INTERNAL FIT OF THE IMPLANT-SUPPORTED 3D-PRINTED PROVISIONAL CROWN

ATITTAYA CHAOWTHAWEE

A Thesis Submitted to the Graduate School of Naresuan University

in Partial Fulfillment of the Requirements

for the Master of Science in Master of Sciences in Dentistry (Prosthodontics) – Type A 2

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By Atittaya Chaowthawee

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Master of Sciences in Dentistry (Prosthodontics) - Type A 2 of Naresuan University

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Title EFFECT OF BUILDING ORIENTATION ON MARGINAL GAP AND INTERNAL FIT OF THE IMPLANT-SUPPORTED 3D-PRINTED PROVISIONAL CROWN

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Academic Paper M.S. Thesis in Master of Sciences in Dentistry (Prosthodontics) – Type A 2, Naresuan University, 2024

Keywords implant, provisional restoration, 3D printing, marginal gap

ABSTRACT

With the increasing popularity of immediate implant placement and restoration, precise fabrication methods for provisional restorations have become crucial since it helps preserving the soft tissue around the implant. 3D-printed PMMA provides cost-effective alternatives despite concerns about polymerization shrinkage. Previous studies have shown that building orientation for 3D-printed methods can affect the marginal gap and internal fit of the restoration. This study aims to examine the effect of building orientation on the marginal gap and internal fit of implant-supported provisional prostheses.

Materials and Methods: The implant-supported provisional restoration of the right maxillary central incisor was designed by complete digital workflow using 3shape software. The virtual implant crowns were fabricated with 3D-printer (DLP technology) in five different building orientations (0°,30°,45°,60° and 90°) with 10 samples per group. The samples underwent post-processing methods according to the manufacturer's recommendation. Marginal gap and internal fit examination were conducted using a digital silicone replica technique and superimposition method. After digitizing the silicone replica into .stl file, the gap distances were measured at sixteen reference points for each sample using Artec Studio 18 software. The degree of discrepancy was reported in color mapping. The measurements were statistically analyzed using One-way ANOVA and multiple comparison with Tukey Post-hoc test.

Results: Statistical analysis revealed significant differences in marginal, cervical, axial, and occlusal gap across the five groups ($p < 0.05$). The 30° and 45° groups (19.08 µm and 19.10 µm, respectively) had a significantly smaller marginal gap than the other groups. Corresponding to the RMSE at the margin of the Ti-base abutment. The RMSE of overall internal fit showed 90° group had the largest cement gap at mean value of 83.57 ± 8.86 µm.

Conclusion: Building orientation in 3D printing significantly affects the marginal gap and internal fit of implant-supported provisional restorations. The 30° and 45° orientation demonstrated the smallest marginal gap and superior internal fit, indicating it as the optimal angle for achieving high precision for 3D-printed implant-supported provisional crown.

ACKNOWLEDGEMENT

I would like to extend my deepest gratitude to my advisors, Dr. Yosnarong Sirimethawong and Dr. Pathranun Chaiamornsup, for their invaluable guidance, steadfast support, and constant encouragement throughout this research journey. Their expertise and dedication have played a crucial role in shaping this study.

I am also sincerely grateful to the members of my thesis committee for their insightful feedback and thoughtful suggestions, which have greatly enhanced the quality of this work.

A special acknowledgment to Dr. Ariya Chantaramanee for his invaluable advice and assistance, particularly in the statistical aspects of this research. His expertise and generosity with his time have been truly appreciated.

My heartfelt thanks go to my friends and colleagues at the Prosthodontics Department of Naresuan University for their unwavering support—both academically and personally—throughout this journey. Their friendship and encouragement have made this experience all the more rewarding.

Finally, I am profoundly grateful to my family and friends, whose support, has been my greatest source of strength throughout my postgraduate studies.

Atittaya Chaowthawee

TABLE OF CONTENTS

Page

List of tables

Page

List of figures

Page

CHAPTER I

INTRODUCTION

Background and rationale of the study

Dental implants have gained remarkable popularity for dental substitution. Their distinguished features, such as exceptional strength, reliable retention, stability, and the capacity to support surrounding structures, not only ensure comfort but also contribute to the preservation of alveolar bone. Additionally, their esthetic resemblance to natural teeth enhances patient satisfaction.(1) Capitalizing on these advantages, patients now hold higher expectations for swift and uncomplicated surgical protocols. Immediate implant placement simultaneous with restoration has now become a widely accepted protocol, particularly in areas with esthetic significance. This technique involves attaching a prosthetic crown or bridge is attached to the dental implant shortly after its surgical placement. This approach offers several benefits in terms of both functional and esthetic outcomes. It provides patients with a continuous dental structure without the need to endure an edentulous phase and less additional surgical procedure from the second stage surgery. Additionally, immediate restoration aids in the preservation of soft tissue architecture, preventing gingival recession and shaping the soft tissue to achieve a proper emergence profile around the implant.(2)

The use of static computer-assisted implant surgery (sCAIS) is widely used in recent implant placement protocols. This technology significantly enhances the accuracy of surgical protocols, even in cases involving immediate implant placement accompanied by the immediate loading of provisional restorations. Consequently, the design and production of a well-crafted provisional restoration can be accomplished prior to the actual surgical appointment.(3) Such provisional restorations, when employed in conjunction with immediate implant placement, not only offer patients a temporary substitute for their extracted teeth but also play a crucial role in facilitating soft tissue healing. Through proper restoration contouring, they have the potential to avert gingival recession post-extraction and aid in shaping the soft tissue to achieve a proper emergence profile.[4-6] In this scenario, the utilization of immediate provisional restorations becomes even more significant, given their prolonged usage throughout the healing period. Thus, provisional restorations should possess an optimal level of strength, reliable dimensional stability, and a satisfactory esthetic appearance.

Traditionally, auto-polymerized polymethyl methacrylate (PMMA) has been the material of choice for crafting provisional restorations.[7] However, this material does come with certain limitations, including exothermic reactions, polymerization shrinkage, and an unpleasant odor.[8, 9] The advent of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has revolutionized the field of restorative dentistry, offering enhanced precision and accuracy in the fabrication of dental prostheses.

There are two approaches for producing provisional prosthesis from CAD/CAM PMMA: by milling or 3D-printing. A milled PMMA undergoes complete polymerization under optimal conditions, resulting in reduced residual porosity and monomer content. Thus, milled PMMA presents better mechanical properties compared to conventional PMMA. [10-12] Although milled PMMA has greater strength and dimensional stability, it involves higher costs in terms of both material and milling tools. On the other hand, 3D-printed or additive manufacturing is a process that builds objects layer-by-layer. Therefore, 3D-printing generates less waste and proves to be a more cost-effective option. However, a primary concern associated with 3D-printed PMMA is polymerization shrinkage during manufacturing process.[13, 14] This shrinkage can lead to dimensional alterations, potentially affecting the precision of the restoration's margin and resulting in discrepancies in both the marginal area and the internal gap fit.

The marginal gap and internal fit are two important factors for the long-term success and durability of a fixed prosthesis. Poor marginal fit and clinical unacceptable gap of the fixed prosthesis can lead to cement dissolution, plaque accumulation and microleakage which compromise the surrounding periodontium and may consequences to a marginal bone loss.[15] Earlier research indicates that the marginal gap of 3D-printed provisional restorations typically falls within the range of 56 – 212 µm.[14, 16, 17] Since the properties of printed PMMA are influenced by various factors, including parameter adjustments derived from CAD design, building orientation, as well as the specific post-rinsing and post-curing protocols applied.

Previous studies have shown that building orientation had an influence on marginal gap and internal fit of the tooth-supported 3D-printed provisional tooth-supported crown and bridge.[18, 19] However, the study about building orientation on marginal gap and internal fit of 3D-printed provisional restoration on implant abutment is insufficient and needs for a further study.

Therefore, this study aims to examine the effect of building orientation on marginal gap and internal fit of the implant-supported provisional prosthesis. The goal is to enhance the precision in fabrication process of provisional implant crowns, ultimately contributing to more favorable treatment outcomes.

Research Question

Does varying the build orientation angles affect the marginal gap and internal fit of 3D-printed provisional restorations for implant-supported single crowns?

Research Purpose

The purpose of this research is to investigate the impact of different build orientation angles on the marginal gap and internal fit of 3D-printed provisional restorations designed for implant-supported single crowns.

Scope of the study

1. Laboratory (in vitro) study aims to evaluate marginal gap and internal fit of the 3D-printed provisional restoration for implant-supported crown fabricated in various build orientation.
2. Independent variable : build orientation angle

3. Dependent variables : marginal gap of the restoration, internal gap of the restoration, root mean square error (RMSE)
4. Control : 3D-printer, printable resin material, layer thickness, post-process method
5. Locations : Research laboratory, NSU 01 Building and Graduate clinic, CAD/CAM laboratory, Faculty of Dentistry, Naresuan University

Research Hypotheses

There is no significant difference in marginal gap and internal fit among 3D-printed provisional restorations fabricated at various building orientation angle.

CHAPTER II

LITERATURE REVIEW

Dental implant

A Dental implant is defined as a "a prosthetic device made of alloplastic material(s) implanted into the oral tissues beneath the mucosal and/or periosteal layer and on or within the bone to provide retention and support for a fixed or removable dental prosthesis; a substance that is placed into and/or on the jaw bone to support a fixed or removable dental prosthesis".[20]

Dental implant therapy has been well documented to have a high success rate to restore partially and fully edentulous patients. With a growing number of patients seeking a quicker shift from their natural teeth to implant-supported prosthetics, the clinician is expected to provide a well-constructed provisional restoration immediately after tooth extraction especially in an esthetic zone. This emphasizes the rising importance of provisional restorations in the overall implant treatment process.[6, 21]

Provisional prostheses

A provisional or temporary prosthesis refers to a fixed or removable dental or maxillofacial device designed to temporarily improve aesthetics, stability, and function. It is intended for short-term use and will eventually be replaced by a permanent prosthesis. These prostheses are often employed to evaluate the effectiveness of a treatment plan or to refine the design and functionality of the final prosthesis[20] The utilization of provisional restorations in dental implant treatments holds a significant role in contemporary dental practice not only serve as placeholders during the healing process but also fulfill essential functions in terms of esthetics, functionality, and phonetics.

The term "immediate restoration" is used when a prosthesis is fixed to the implants within 48 hours without achieving full occlusal contact with the opposing dentition. An immediate provisional restoration offers the patient improved comfort and function during the implant healing period. Studies showed that the advantages of immediate placement of well-designed provisional restoration on implant facilitates healing of the soft tissue and helps preserve both vertical height and contour of the soft tissue at the implant site. [4, 22] Additionally, it plays a crucial role in shaping the peri-implant soft tissue, including interdental papillae, to a desired emergence profile which will enhances the overall clinical outcome, resulting in a natural and esthetically pleasing appearance.[21]

A desired temporary restoration should possess qualities of strength, durability, and esthetic appeal.[23] Provisional for implant restoration is broadly classified into removable and fixed prosthesis.[6] Removable prosthesis, such as acrylic based partial denture or Essix retainer, is more easy-made and widely used as a temporary prosthesis after tooth extraction. However it may reduce effectiveness of any additional surgical bone and gingival augmentation procedure used to optimize the implant site.[21] Also patient may experience some discomfort or speech difficulty due to the thickness of the appliance. Fixed prosthesis, on the other hand, offers more comfortable, stable, and psychological benefit than removable prosthesis. Moreover, it less disturbs the surgical site from transmucosal pressure in the two-stage surgery. Fixed provisional prosthesis can be divided into tooth-supported prosthesis and implant-supported prosthesis.[23]

The implant-supported provisional restoration is conventionally made using temporary abutments directly placed on the implant level. The provisional crown can then be built up in the laboratory on the master cast or chairside by using provisional materials according to the diagnostic wax up. However, this method is time consuming and depends on the skills of the clinician.

Significant progress in the design and production of implant prostheses has been achieved through the integration of digital dentistry. The contemporary approach involves the digital design and CAD/CAM manufacturing of entire implant prostheses and is proven to exhibit good accuracy compared to conventional fabrication methods. This workflow allows to create the prosthesis based on digital implant planning before the actual implant placement, enabling the immediate delivery of provisional prostheses post-implant procedure. This method offers a controlled and reliable protocol, enhancing treatment predictability and reducing clinical time. Moreover, it proves to be patient-friendly, providing immediate function, esthetic restoration, and soft tissue contouring.[3]

CAD/CAM Manufacturing Process

The digital workflow, or CAD/CAM workflow has three main steps: 1) data acquisition, which includes various scanning technologies, 2) computer-aided design (CAD), the data collected is processed using computer software to design a virtual 3D restoration, and 3) computer-aided manufacturing (CAM), in which processed data is used to fabricate structures from the design.[24, 25] Basically, the process starts with drawing a three-dimensional computer-aided design (CAD) model using a CAD software. The model is then saved as an STL file format. STL may stand for “stereolithography language”, or “Standard tesselation language”.

The two main methods in fabricating the restoration from the CAD design are subtractive method and additive method. The early systems relied almost exclusively on cutting the restoration from a prefabricated block called “subtractive method”. This method can create complete shapes effectively, but at the expense of most of the material being wasted. The advent of modern technology, specifically 3D printing, revolutionized this landscape. With 3D printing, the creation of desired shapes occurs through the layer-by-layer deposition of materials like photocurable resins or thermoplastic filaments. This innovation is referred to as the "Additive method".[26]

1. Subtractive manufacturing

   Subtractive manufacturing, also known as machining or milling, is a manufacturing process that involves the removal of material from a solid workpiece to create a desired shape or form. This is achieved by using cutting tools such as drills, mills, or lathes to shave away layers of material until the final object is produced. This technique gives higher accuracy since it uses pre-polymerized blocks. Milled provisional restorations may offer higher mechanical properties (flexural strength and fracture toughness), better esthetic outcomes and superior marginal fit when compared to traditional restorations.[10, 14] However, the milling method utilizes various milling tools and has a much higher cost for production. 3D-printing technology produces less waste and is more cost-effective.(11)

2. Additive manufacturing

According to the ISO/ASTM 52900:2021 standards, there are seven different categories of 3D printing methods: binder jetting(BJT), direct energy deposition(DED), material extrusion(MEX), material jetting(MJT), powder bed fusion(PBF), sheet lamination(SHL), and VAT photopolymerization(VPP).

The "VAT Photopolymerization technique, is a process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization and these layers build up to form a complete 3D object.(27) This technique is commonly used in dental applications to produce an array of products, including surgical guides for implants, dental models, individual trays, dentures, and fixed prostheses. There are several types of VAT photopolymerization technologies such as Stereolithography (SLA), digital light projection (DLP), liquid crystal display (LCD) and continuous direct light processing (CDLP)(11, 28)

2.1 Stereolithography (SLA)

The first world-known 3d printer was created by Charles Hull in 1986 using the stereolithography technology.(28) In this process, a laser source is utilized to initiate the polymerization reaction in photocurable materials. A UV laser traces each cross-section onto a photopolymer resin bath, gradually solidifying the layers. This sequence is repeated until the entire component is complete. Any resin untouched by the laser remains in the vat and can be recycled.[30] The SLA method offers notable advantages, including high precision and the attainment of a smooth surface on the final product.

2.2 Direct light projection (DLP)

Direct Light Projection (DLP) stands out as one of the most widely adopted additive manufacturing processes within the dental industry. The structure of a DLP printer closely resembles that of an SLA printer but with a different light source. The DLP printer use projection technology that the short-wave light is guided through a “digital micromirror device (DMD)” that illuminates the entire cross-section of the object at once in the form of volumetric pixels and the entire layer is produced simultaneously. Consequently, DLP printers often exhibit faster production speeds than SLA printers. The resolution of the DLP printer depends on the resolution of the DMD chip. Since a DMD chip has limited number of these micromirrors, when a build platform is increased in size, it may affect the precision of the object. Nevertheless, DLP printers are renowned for their high printing resolution, often achieving a minimum size of 50 µm, and the capacity to produce objects with a smooth surface.[28, 29]

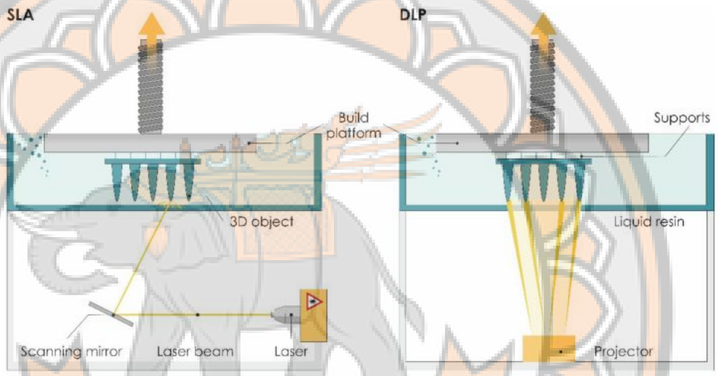

Figure 1 Schematic drawing of SLA and DLP printer

2.3 Liquid crystal display (LCD)

Liquid Crystal Display (LCD) operates on UV-triggered resin solidification. In an LCD printer, the liquid crystal display serves as the imaging system. This bottom-up 3D printing approach offers several advantages in comparison to top-down processes like the DLP printer system. These include the use of a smaller volume of resin in fabrication, the ability to attain high vertical resolution, and shorter curing times. Notable distinctions between DLP and LCD 3D printing lie in printing accuracy and light intensity. LCD 3D printing typically exhibits lower light intensity and, as a result, the precision of LCD printing technology is generally considered to be less refined than that of DLP.[29]

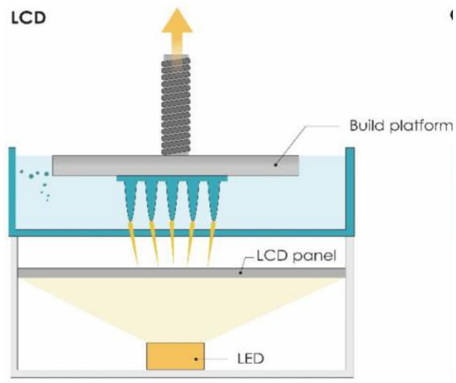

Figure 2 Schematic drawing of LCD printer

2.4 Continuous direct light processing (CDLP)

The Continuous direct light processing technology was first created and patented by Carbon3D™ in 2015 called a continuous liquid interface production (CLIP). The continuous liquid interface production is achieved with an oxygen-permeable window below the ultraviolet image projection plane, which creates a "dead zone" (persistent liquid interface) where photopolymerization is inhibited between the window and the polymerizing part. The result from this continuous production is extremely high build speed with high object precision.[28, 30]

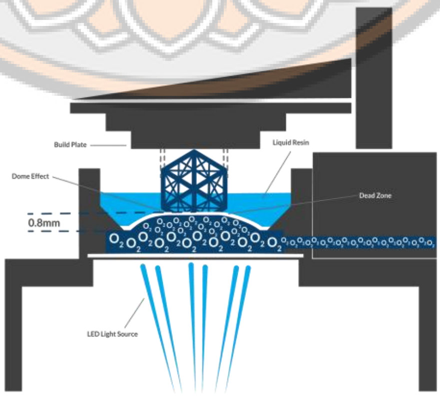

Figure 3 Schematic drawing of CDLP printer

Material used for provisional prostheses

The selection of materials for provisional or interim restorations demands a comprehensive consideration of their biological, mechanical, and physical properties. Specific requirements that need to be considered are biocompatibility, non-irritating interactions with dental pulp and surrounding tissues, limited exothermic reactions, controlled polymerization shrinkage, reduced thermal conductivity, precise marginal fit, dimensional stability, elevated tensile strength, and esthetic appearance.

Presently, a variety of materials is accessible for the construction of provisional restorations, with the majority being resin-based material. These materials are categorized based on their method of polymerization, composition of fillers, and the specific types of monomers employed(8). Prominent among the selection are polymethyl methacrylate (PMMA), polyethyl methacrylate (PEMA), polyvinyl methacrylate, bis-GMA resins, bis-acryl resin composites, and urethane dimethacrylates cured through exposure to visible light (VLC).(8, 9)

Auto-polymerized PMMA was introduced in dentistry around 1940 and became a material of choice for provisional restoration.(7) However, it also has disadvantages, such as high exothermic reactions, polymerization shrinkage, allergic reactions associated with residual methacrylate monomer, short working time, and unpleasant odor.(8, 9) PMMA has been shown to exhibit the greatest strength of the methacrylate acrylic resins and had a high flexural strength relatively equal to composite resin.

CAD/CAM provisional prosthesis material

Various techniques of provisional restoration fabrication have been employed and improved over time, starting from the different conventional techniques using acrylic resins or composites to digital CAD/CAM fabrication methods. The conventional fabrication techniques of provisional restorations have many drawbacks related to the materials' properties and the employment technique. Consequently, digital techniques were introduced to overcome these drawbacks.(31) With the advent of additive manufacturing methods, there is a diverse range of printable resin materials available for dental provisional restoration. The monomers within these printable resins must possess the capability to polymerize rapidly, with acrylates and epoxy monomers being the most utilized. Methacrylate-based resins find application in digital dentistry processes such as stereolithography (SLA) or digital light processing (DLP) 3D printing. Methacrylate-based resins are known for their ability to achieve a smooth surface finish and can be cured using light sources in the printing process.[32]

Mechanical properties of printable resin material can be affected by printing technology itself and also the material compositions. The fact that these materials are polymerized with light, their exposition time and post-curing steps are of vital importance.[32]

Marginal gap and Internal fit

The marginal gap is one of the key factors for the long-term success and durability of a fixed prosthesis. Poor marginal fit and gap of the fixed prosthesis can lead to cement dissolution, plaque accumulation and microleakage which compromise the surrounding periodontium. And may consequences to a marginal bone loss.[14, 15, 33] The marginal discrepancy can be categorized into vertical discrepancy and horizontal discrepancy. The vertical marginal discrepancy measured parallel to the path of withdrawal of the framework is called the marginal gap (MG). The horizontal marginal discrepancy measured perpendicular to the path of withdrawal of the framework is called the marginal discrepancy (MD).The angular combination of the marginal gap and the extension error (overextension or underextension) is called an absolute marginal discrepancy (AMD).[34]

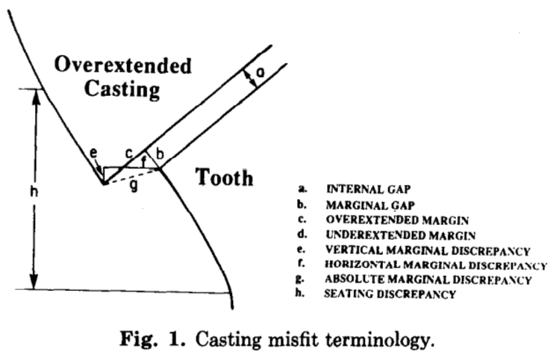

Figure 4 schematic drawing of misfit terminology

Internal fit refers to the extent of mismatch between the inner surface of a dental restoration and the outer surface of the tooth.(35) A consistent internal gap between the restoration and the abutment is necessary to accommodate the cement layer. Achieving optimal internal fit ensures a uniform cement space while preserving the restoration's retention and resistance features. Thus, cement space thickness is the crucial element for accuracy of restoration margin and has a significant impact on retention and flexural strength of the restoration.(36, 37)

Various ranges of acceptable marginal gaps have been reported in the literature, depending on the used cement type, restorative material, and measuring procedure.(38) American Dental Association (ADA) specification No. 8 indicates that the thickness of luting cement for a dental crown should not exceed 25 µm when using type I luting agent or 40 µm when using type II luting agent.(39) McLean and von Fraunhofer examined the marginal fit of fixed restorations over a 5-year period and indicated that a marginal gap less than 80 µm is difficult to detect under clinical conditions and in radiographic examination.(40) However, there is no clear agreement. From a clinical point of view, a marginal opening of 50–120 µm is currently considered acceptable for indirectly manufactured restorations.(11, 31, 41)

Previous research indicates that 3D-printed provisional restorations exhibit a lower marginal discrepancy compared to conventional PMMA, though they still present a higher marginal discrepancy when compared to milled PMMA. Al Deeb et al. conducted a comparative analysis of the marginal fit using micro CT for milled, conventional PMMA, and 3D-printed materials. The reported marginal misfit was 68.2 ± 18.1 µm for the milled material, 283.3 ± 98.6 µm for the conventional PMMA material, and 84.7 ± 27.5 µm for the 3D-printed material.(16) In a study by Karasan et al., the investigation of 3D-printed provisional 3-unit fixed partial dentures, when compared to milled PMMA and conventional bis-acryl restorations, revealed that both 3D-printed and milled provisional FDPs exhibited better adaptation than conventional bis-acryl restorations.(42) Despite controversial results between marginal adaptation of milled and 3D-printed provisional restoration, both types fall within the clinically acceptable range for marginal gap.(16, 36, 43) Furthermore, a recent meta-analysis found that the internal discrepancy of milled and 3D-printed provisional restorations does not significantly differ.[44]

Park et al. conducted a study comparing the marginal and internal discrepancies among conventional thermoplastic resin (CTR), milled Polyetherketoneketone (SPM) and 3D-printed resin (ADL) for implant-supported provisional crown of premolars and molars. The results showed that mean marginal discrepancies of 3D-printed crown was lower than milled or conventional ones.[43]

Many factors can affect the accuracy of 3D-printed provisional restoration including printing technology, light source wavelength, layer thickness, support designing, printing orientation, and post-processing method.[32, 42, 45] Earlier research has highlighted the significant impact of building orientation on the precision of 3D-printed provisional crowns and fixed partial dentures casting pattern, particularly in terms of their marginal accuracy and internal fit. Their findings indicated that a build orientation set at 0 degrees, aligning the occlusal plane of the prosthesis toward the build platform, resulted in the smallest marginal gap.[18, 19]

Ryu et al. verified marginal and internal gap of 3D-printed provisional crown fabricated in various directions: 120, 135, 150, 180, 210, and 225 degrees (180-degree orientation implies the occlusal surface of the restoration is perpendicular to the building platform). Their results revealed that mean marginal gap and cervical gap of 120-degree sample was significantly larger while there was no significant difference of the mean marginal gap among the 150, 180, and 210-degree samples.[19]

Marginal gap and internal fit measurement

There are several methods for measuring the marginal discrepancy and internal gap including direct-view technique by using a high magnification with a stereomicroscope, cross-sectioning technique, replica technique, and micro-CT technique.[46] However, some techniques such as direct cross-sectioning technique is a destructive technique, or some require a specific costly instrument.

The silicone replica technique employs a light-bodied silicone material to replicate a cement space similar to that encountered in a clinical scenario. This method can be used to evaluate both internal fit and marginal gap discrepancy. Conventionally, the silicone replica method then be assessed the cement gap through an electron microscope. However, the conventional silicone replica technique can analyze only 2-dimensional measurements, which may not represent the overall fit of the crown.[47, 48]

The advancement in digital protocols and scanner capabilities enables the simplification and enhanced accuracy of the scan. Holst and his colleagues introduced a “triple-scan method” by using an optical scanner to digitalize the surface of the abutment teeth and the intaglio surface of the restoration, then the distance between the two surfaces will be measured in computer using engineering software.[49] Engineering software has been used for several purposes within the dental literature.[31, 45, 49-51] Digital measuring procedures now offer the ability to measure at multiple locations, including three-dimensional measurements which the overall difference can be shown in grading color and calculated the overall surface deviation using root-mean-square-estimations. To enhance accuracy, the digital silicone replica technique has been introduced. The digital silicone replica technique involves scanning the abutment, then scanning the same abutment with a silicone replica attached. The two scans are digitally overlaid and utilized to measure marginal gap and internal fit using engineering software.

In a study by Zeller et al., this technique was employed to investigate the marginal and internal discrepancies of ceramic implant crowns on customized titanium abutments using a fully or interrupted digital workflow. They further validated the accuracy and reliability of the digital method by comparing it to standardized measurements using a scanning electron microscope. The results demonstrated that the digital silicone replica technique was statistically accepted for evaluating the mean marginal gap and internal fit of the crown.[52] Also, A recent systematic review of the reliability of digital measurement methods on the marginal fit of the prosthesis suggested that the digital methods appear to be reliable as an alternative to conventional methods for evaluating the marginal fit of fixed dental prosthesis.[53]

CHAPTER III

REARCH METHODOLOGY

Sample size

The sample size was calculated using G*Power 3.1 (Kiel University, Kiel, Germany). The alpha value (α, probability of a type I error) and power (1-β, probability of not making a type II error) were set to 0.05 and 0.80, respectively. The effect size of this study was calculated based on the pilot study.

The calculation indicated a required sample size of 50 samples across the 5 groups. Thus, 10 samples per group will be used in this study.

Materials and Method

An implant fixture analog (RC analog; Straumann, Basel, Switzerland) was centralized and fixed within 3D-printed acrylic resin block (P Pro Master Model Grey, Straumann, Basel, Switzerland) size 20x20x20 mm designed from CAD software (3D builder; Microsoft, Redmond,WA, USA). The block was designed with reference line across the upper surface as in figure 5.

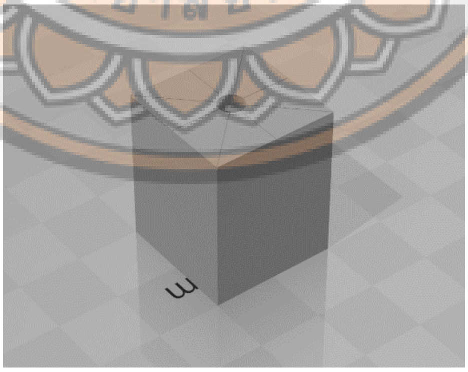

Figure 5 resin block designed from 3D builder software

An implant scan body was inserted into the implant analog, and then the scan body and the resin base were scanned using an intraoral scanner (Trios3; 3Shape, Copenhagen, Denmark). Computer-aided design (CAD) software (Dental System, 3Shape, Copenhagen, Denmark) was utilized to design the provisional restoration for the right maxillary central incisors through a complete digital workflow. The cement gap for the provisional restoration was set at 10 µm, and extra-cement gap at 40 µm.(39) Subsequently, the virtual provisional crown was saved as an STL file for further processing.

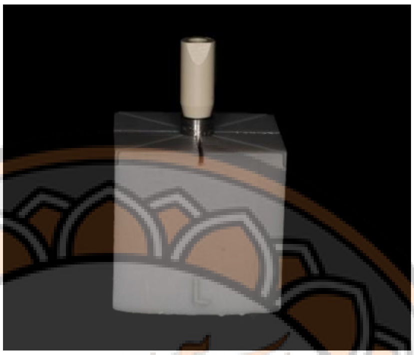

Figure 6 implant scan body inserted into the implant analog

The virtual crown STL file will be assigned into 5 groups according to different building orientation angles.(18, 19) In this context, 0 degrees indicate that the incisal edge of the implant crown is oriented toward the build platform.

- Group 1: 3D-printed crown with build orientation 0 degree
- Group 2: 3D-printed crown with build orientation 30 degree
- Group 3: 3D-printed crown with build orientation 45 degree
- Group 4: 3D-printed crown with build orientation 60 degree
- Group 5: 3D-printed crown with build orientation 90 degree

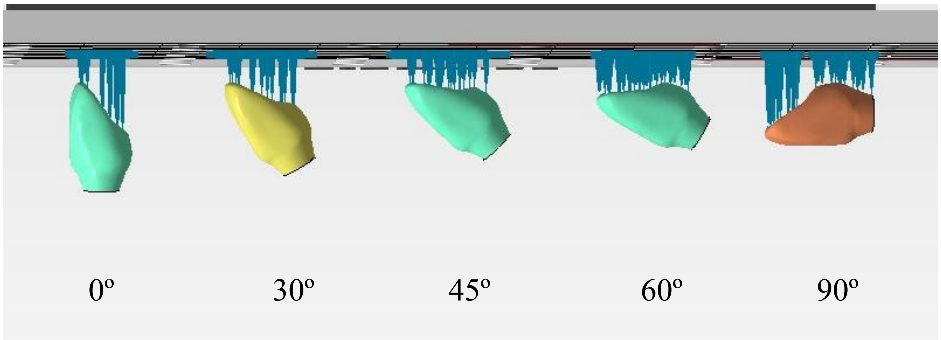

Figure 7 Implant-supported provisional crown set build orientation at various angles

All samples will be produced by DLP printer (P30+; Straumann, Basel, Switzerland) with printable methacrylate-based resin (P-Pro Crown & Bridge; Straumann, Basel, Switzerland) with a curing wavelength of 385 nm and the layer thickness of 100 μm.[54]

All 3D-printed specimens will go through the post-processing steps recommended by the manufacturer.[54] Once printing is complete, the samples will be taken off the platform and individually wrapped in tissue paper. They will then undergo a centrifugation process in a laboratory centrifuge (EBA 20; Hettich, Tuttlingen, Germany), set at 1500 rpm for 2 minutes, to remove an excess uncured resin.

Figure 8 samples in a laboratory test tube for centrifugation

Following this, each sample will receive a secondary exposure using a flash-light curing machine (P cure; Straumann, Basel, Switzerland), set according to the manufacturer's guidelines. Subsequently, the samples will be rinsed with isopropanol alcohol using an automated machine (P wash; Straumann, Basel, Switzerland). The temperature and rinsing time will be set according to manufacturer’s guidelines. Then, left to air dry completely for a minimum of 30 minutes.

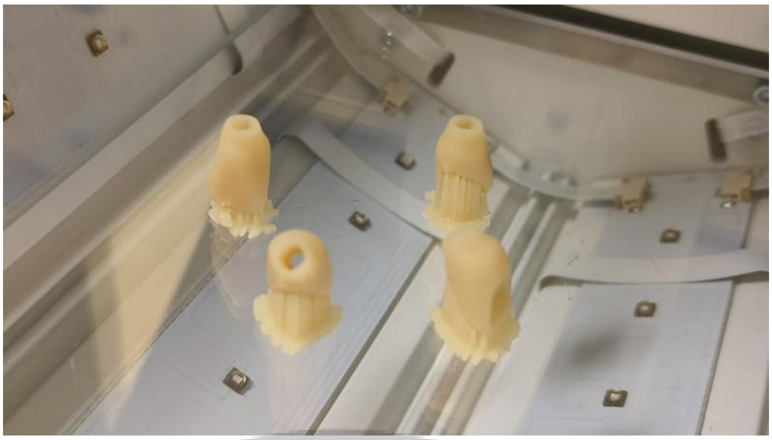

Figure 9 The samples undergo secondary exposure in P cure machine

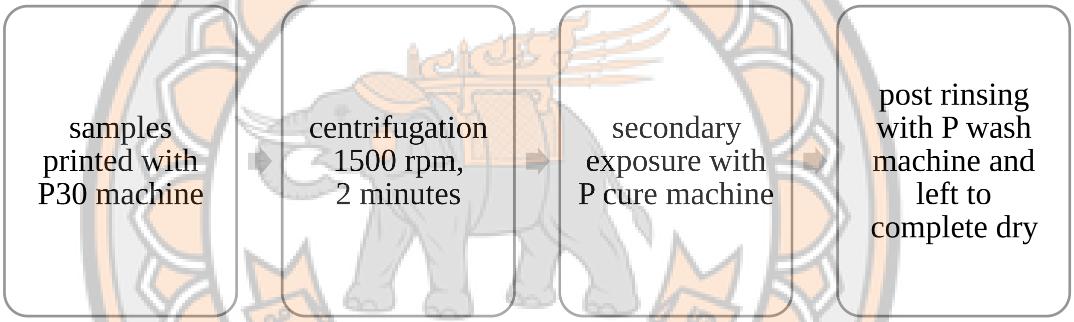

Figure 10 samples production step

To standardize the procedures, 3D printer, automated curing and washing machine will be calibrated according to the manufacturer's recommendations. All procedures will be performed by a single trained researcher.

Evaluation for the accuracy of the specimens

Once the samples are prepared, their precision using the CAM method will be confirmed through a 3D-deviation investigation. Each group's samples will be digitized with a laboratory scanner (E4, 3Shape, Copenhagen, Denmark) and superimposed onto the STL files of the other samples using engineering software (Artec Studio 18; Artec 3D, Senningerberg, Luxembourg). The samples that exhibit only a green color in the 3D-deviation color mapping will be considered conclusive for the study

Silicone replica technique

For marginal gap and internal fit measurement adapted from the digital silicone replica technique from Zeller et al.[52] First, the Ti-base abutment (Straumann Variobase®, Straumann, Basel, Switzerland) will be sandblasted with 50 µm Al_2O_3 to reduce reflectivity and need for a coating spray. Then the Ti-base abutment will be scanned as a 'abutment scan' (Figure 11) using laboratory scanner (E4, 3Shape, Copenhagen, Denmark). After that, load a polyvinyl siloxane (Aquasil Ultra, Dentsply Sirona, North Carolina, USA) into the sample and seat onto Ti-base abutment. A pressure of approximately 10 N will be applied by a specimen positioner (Instron, Massachusetts, USA) and maintained for 5 minutes according to the setting time from the manufacturer's instruction.[18, 51] Then, the crown will be removed from the abutment, leaving PVS replica adhere to the Ti-base abutment. Scan Ti-base abutment with PVS replica using laboratory scanner (E4, 3Shape, Copenhagen, Denmark). Before repeating all steps for each sample, the silicone replica will be removed completely using a dental laboratory steam cleaner to prevent a silicone remnant from previous sample.

Figure 11 Ti-base abutment scan

Figure 12 Ti-base abutment with PVS replica scan

Marginal gap and internal fit measurement

All 50 Ti-base abutments with PVS replica scan and reference abutment scan will be exported as STL files and imported to engineering software (Artec Studio 18; Artec 3D, Senningerberg, Luxembourg) to analyze marginal gap and internal fit. The abutment scan and the Ti-base with PVS replica scan will be aligned by using "best-fit alignment" function.[31, 55]

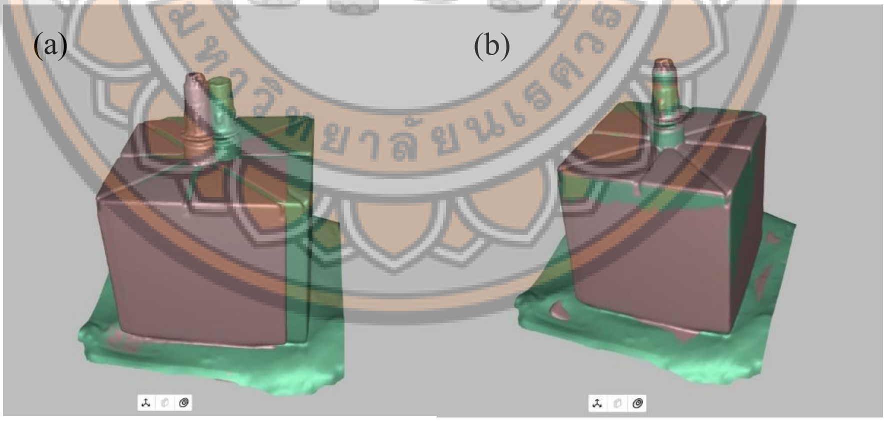

Figure 13 Superimposition protocol using 'best-fit alignment function'
(a) two scans before alignment,
(b) two scans after using 'best-fit alignment' function

Once the reference scan and the sample scan aligned. The scans will be sectioned along the labiolingual and mesiodistal direction using a line on the resin block as a reference line (Figure 14).

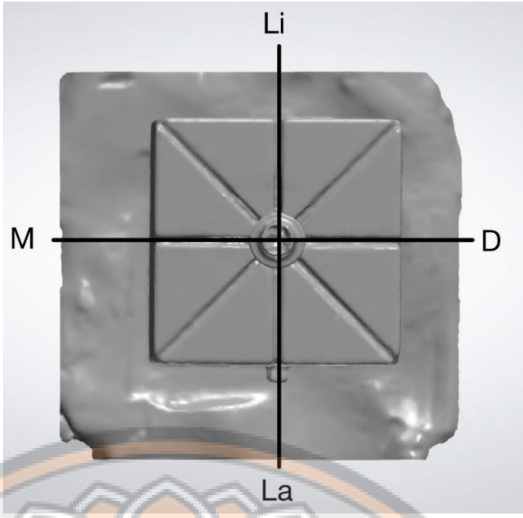

Figure 14 The scans sectioned along the reference line on the resin block

1. Marginal and internal Gap measurements

The discrepancy between the two scans will be evaluated at four specific points, (adapted from Chaiamornsup et al. and Refaie et al.), covering all four aspects: labial, lingual, mesial, and distal. This evaluation will summarize the findings across 16 points for each sample, focusing on:

(1) Marginal gap (perpendicular of the cement space at the margin of the abutment)

(2) Internal gap; which divided into three points

a) Cervical gap (1 mm. medially to margin of the abutment)

b) Middle of the engagement area of the abutment

c) Middle of the flat surface on the upper half of the abutment

As in figure 15

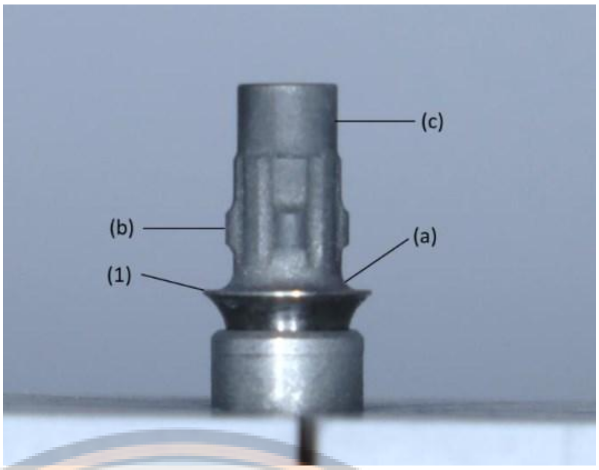

Figure 15 Ti-base abutment labeled with 4 specific points for gap measurement. (1), (a),(b) and (c) represent the positions measured from each aspect of the samples

2. Overall marginal and internal fit

Following gap measurement, the sections below the finish line of the abutment, including the base and other components, will be deleted. To distinguish the difference between the margin area and the axial wall area, the files were sections at the cervical part in the software. The overall discrepancies between the Ti-base abutment with a silicone replica were transformed into a point discrepancy grading represented by color, as illustrated in Figure 16. The program will apply a color spectrum ranging from blue to red. Yellow to red hues signify that the PVS scan has a positive value compared to the Ti-base reference scan, while light blue to navy colors indicates a negative value from the Ti-base reference scan.

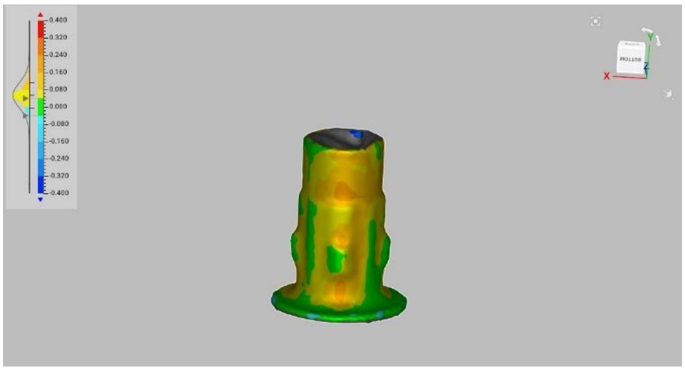

Figure 16 A color mapping of the discrepancy between Ti-base scan and PVS replica scan

Additionally, the overall discrepancy between the two scans will be calculated using the root mean square error (RMSE).

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}$$

Where N = the number of data points

y_i = the observed or measured value

$\hat{y}i$ = the predicted or estimated values

Repeat all steps for each group.

Statistic Analysis

For the descriptive statistics, the means and standard deviations of the marginal and internal gaps, along with the root mean square error (RMSE) for internal fit, will be calculated for each group in the study. Subsequently, a one-way analysis of variance (ANOVA) will be conducted to assess the impact of the building orientation angle on the marginal gap and internal fit of implant-supported 3D-printed provisional crowns within each group. To further explore any significant differences, multiple comparisons will be performed using the Tukey post-hoc test. The chosen level of significance for these analyses is set at $\alpha = 0.05$. All statistical analyses will be executed using statistical software, specifically SPSS 17.0 (SPSS Inc. in Illinois, USA.)

CHAPTER IV

RESULTS AND DISCUSSION

Results

Marginal and internal gap

The mean circumferential of marginal and internal gaps for different locations (marginal, cervical, axial, and occlusal gaps) of an implant-supported prostheses at five orientations are presented in Table 1. A one-way ANOVA and Tukey post-hoc test revealed that the building orientation significantly influenced the marginal gap, cervical gap, axial gap, and occlusal gap, as depicted in Figure 17-20.

Location	Mean gap ± SD (µm)					P value
	0°	30°	45°	60°	90°	
Marginal gap	29.78 ± 1.68	19.08 ± 1.23	19.10 ± 1.10	38.67 ± 2.44	35.68 ± 2.90	< 0.001
Cervical gap	57.95 ± 3.27	67.22 ± 2.20	71.35 ± 4.07	89.50 ± 4.30	101.2 ± 4.26	< 0.001
Axial gap	23.38 ± 1.58	13.18 ± 0.92	18.75 ± 1.36	12.62 ± 0.85	30.85 ± 3.20	< 0.001
Occlusal gap	80.65 ± 1.91	75.55 ± 4.07	73.93 ± 3.42	65.15 ± 2.39	89.20 ± 5.31	< 0.001

Table 1 Mean value of marginal gap, cervical gap, axial gap, and occlusal gap of implant-supported single crown in five different building orientations.

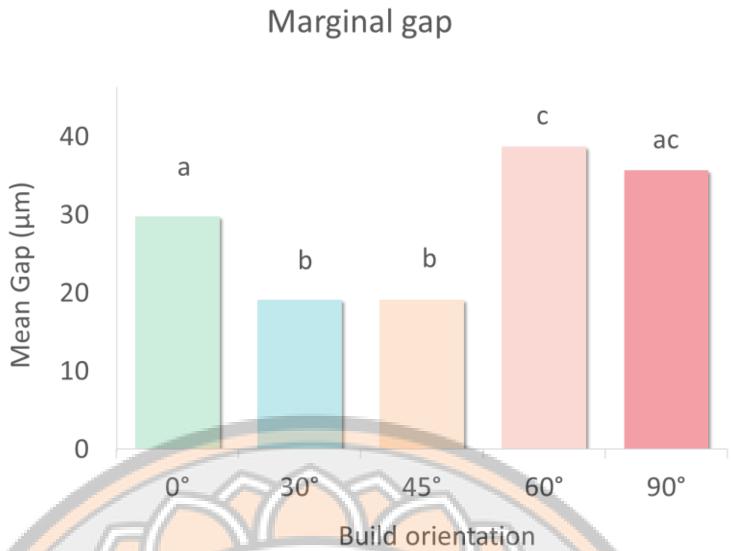

Figure 17 Mean values of marginal gap in five build orientation groups. Post-hoc tests revealed significant differences between the following pairs: 0° vs. 30° (p = 0.002), 0° vs. 45° (p = 0.002), 0° vs. 60° (p = 0.0016), 30° vs. 60° (p <0.001), 30° vs. 90° (p <0.001), 45° vs. 60° (p <0.001), 45° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

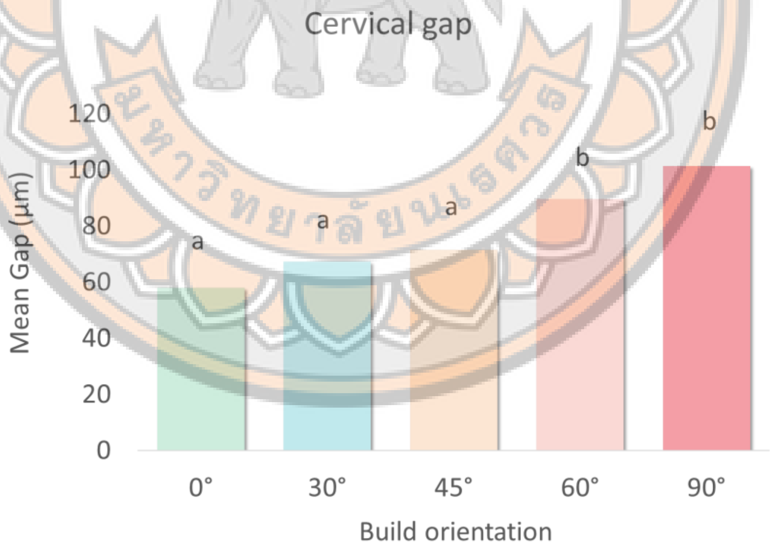

Figure 18 Mean values of cervical gap in five build orientation groups. Post-hoc tests revealed significant differences between the following pairs: 0° vs. 60° (p <0.001), 0° vs. 90° (p <0.001), 30° vs. 60° (p <0.001), 30° vs. 90° (p <0.001) 45° vs. 60° (p = 0.006), 45° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

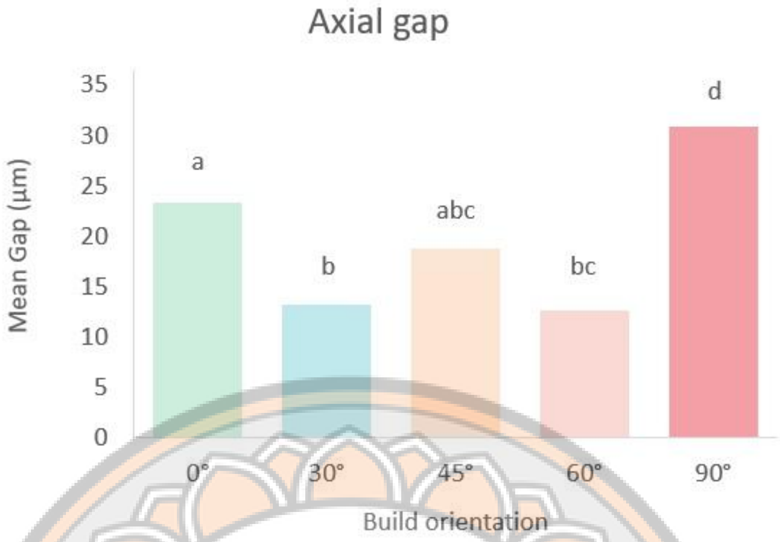

Figure 19 Mean values of axial gap in five build orientation groups. Post-hoc tests revealed significant differences between the following pairs: 0° vs. 30° (p = 0.001), 0° vs. 60° (p <0.001), 0° vs. 90° (p = 0.030), 30° vs. 90° (p <0.001), 45° vs. 90° (p <0.001), 60° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

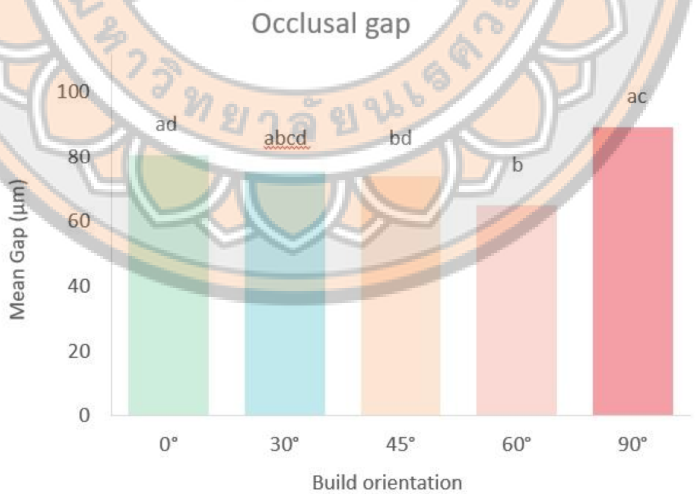

Figure 20 Mean values of occlusal gap in five build orientation groups. Post-hoc tests revealed significant differences between the following pairs: 0° vs. 60° (p = 0.024), 45° vs. 90° (p = 0.027), 60° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

The Post-hoc analysis indicated significant differences across the orientations. Specifically, the mean marginal gaps for the 30° and 45° groups (19.08 µm and 19.10 µm, respectively) were not statistically different but were significantly smaller than those observed in the 0°, 60°, and 90° groups. When analyzing the results by individual aspects, as the results shown in Table 2, The results showed that the marginal gap in 30° and 45° were smaller than those in 60° and 90° at almost every aspect.

For the cervical gap, the mesial aspect at 90° group exhibited the largest cervical gap with a mean of 112.90 ± 28.31 µm. The mean circumferential showed smaller gap in group 0°, 30° and 45° with no significant difference within these three groups. In contrast, the 60° and 90° groups demonstrated significantly larger gaps especially at the labial and mesial aspect (P-value < .001).

The axial gap exhibited significant differences among the groups, except in the distal aspect. The 90° group demonstrated a significantly larger mean circumferential gap compared to the other groups (P < .001). Notably, in the lingual aspect, the mean gap for the 90° group was 39.20 ± 16.14 µm, whereas the other groups showed smaller gaps, ranging from approximately 13.50 to 17.50 µm.

Conversely, for the occlusal gap, the 60° group exhibited the smallest mean circumferential gap (65.15 ± 2.39 µm), which was significantly smaller than that of the 0° group (80.65 ± 1.91 µm). Additionally, the 90° group demonstrated a significantly larger gap compared to the 45° and 60° groups, particularly in the lingual aspect, where the gap for the 90° group measured 101.40 ± 27.06 µm.

Location	Aspect	Mean ± SD (µm)					P value
		0°	30°	45°	60°	90°	
Marginal gap	Labial	32.30 ± 11.42^{acd}	21.30 ± 6.46^{bc}	14.50 ± 8.00^{b}	46.40 ± 16.40^{a}	36.90 ± 18.78^{ac}	< 0.001
	Lingual	28.50 ± 9.72^{ab}	18.50 ± 9.72^{a}	19.50 ± 6.35^{a}	34.20 ± 8.31^{b}	33.70 ± 16.72^{b}	0.002
	Mesial	25.80 ± 11.72^{ab}	21.90 ± 8.44^{a}	22.30 ± 5.79^{a}	39.60 ± 17.56^{b}	34.80 ± 14.31^{ab}	0.006
	Distal	32.50 ± 9.63^{ab}	14.60 ± 5.81^{a}	20.10 ± 6.10^{ab}	34.50 ± 16.64^{b}	37.30 ± 24.83^{b}	0.003
Cervical gap	Labial	56.60 ± 14.42^{a}	68.60 ± 16.47^{ab}	65.00 ± 25.94^{a}	96.80 ± 30.95^{b}	96.10 ± 25.75^{b}	< .0001
	Lingual	67.80 ± 25.23^{a}	68.60 ± 12.88^{a}	72.60 ± 26.48^{a}	81.00 ± 28.34^{a}	98.50 ± 25.60^{a}	0.04
	Mesial	55.70 ± 16.41^{a}	66.20 ± 15.98^{a}	73.70 ± 23.60^{ac}	99.10 ± 25.02^{bc}	112.90 ± 28.31^{b}	< 0.001
	Distal	51.70 ± 24.01^{a}	65.50 ± 12.69^{a}	74.10 ± 29.61^{ab}	81.10 ± 22.12^{ab}	97.30 ± 27.71^{b}	0.002
Axial gap	Labial	25.60 ± 8.88^{a}	13.50 ± 6.75^{a}	18.40 ± 10.84^{a}	13.10 ± 6.06^{a}	27.10 ± 20.50^{a}	0.025
	Lingual	17.50 ± 8.36^{a}	14.70 ± 4.03^{a}	15.50 ± 4.93^{a}	13.50 ± 6.77^{a}	39.20 ± 16.14^{b}	< 0.001
	Mesial	26.50 ± 13.08^{b}	8.80 ± 5.41^{ac}	20.40 ± 7.83^{abc}	11.50 ± 2.99^{a}	27.70 ± 17.80^{b}	< 0.001
	Distal	23.90 ± 7.42^{ab}	15.70 ± 4.95^{ab}	20.70 ± 9.80^{ab}	12.40 ± 5.64^{a}	29.40 ± 25.95^{b}	0.052
Occlusal gap	Labial	81.70 ± 14.19^{a}	88.50 ± 26.91^{a}	80.90 ± 25.70^{a}	61.00 ± 16.34^{a}	91.70 ± 33.80^{a}	0.065
	Lingual	79.00 ± 13.10^{ab}	70.20 ± 21.56^{a}	69.40 ± 19.90^{a}	63.70 ± 10.20^{a}	101.40 ± 27.06^{b}	0.001
	Mesial	78.50 ± 10.18^{a}	66.80 ± 19.78^{a}	72.70 ± 19.36^{a}	61.70 ± 15.60^{a}	81.80 ± 35.54^{a}	0.240
	Distal	83.40 ± 11.83^{a}	76.70 ± 31.37^{a}	72.70 ± 22.79^{a}	74.20 ± 15.74^{a}	92.40 ± 33.03^{a}	0.367

Table 2 Mean value of marginal gap, cervical gap, axial gap, and occlusal gap of implant-supported single crown divided by 4 aspects (labial, lingual, mesial, and distal) across different building orientations.

Root mean square error(RMSE) and color mapping

The mean RMSE values for the marginal and internal areas are summarized in Table 3. One-way ANOVA and Tukey's post-hoc test revealed significant differences in both regions as shown in Figure 21-22. The Color mapping from each group were presented in Figure 23. Since the PVS substitutes for the cement space, only positive deviations, shown in green to red hues, were demonstrated.

Location	Mean RMSE ± SD (μm)					P value
	0°	30°	45°	60°	90°	
Marginal gap	31.02 ± 7.81	20.39 ± 5.95	20.14 ± 7.34	40.58 ± 8.82	36.31 ± 8.35	< 0.001
Internal gap	52.72 ± 12.53	49.94 ± 8.41	51.96 ± 7.18	60.96 ± 8.34	83.57 ± 8.86	< 0.001

Table 3 The mean RMSE value of the marginal and internal area across five different build orientations.

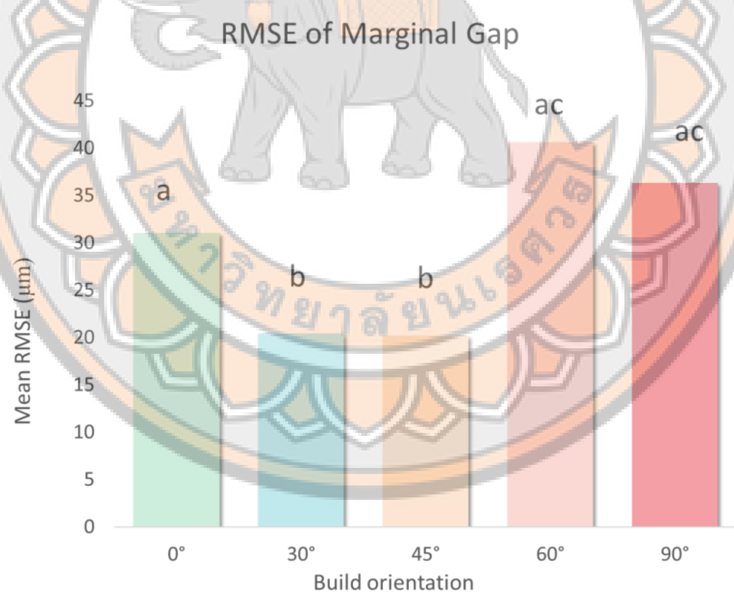

Figure 21 Mean values of root mean square error (RMSE) of the marginal gap in five build orientation groups.
Post-hoc tests revealed significant differences between the following pairs: 0° vs. 30° (p = 0.028), 0° vs. 45° (p = 0.023), 30° vs. 60° (p <0.001), 30° vs. 90° (p <0.001), 45° vs. 60° (p <0.001), 45° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

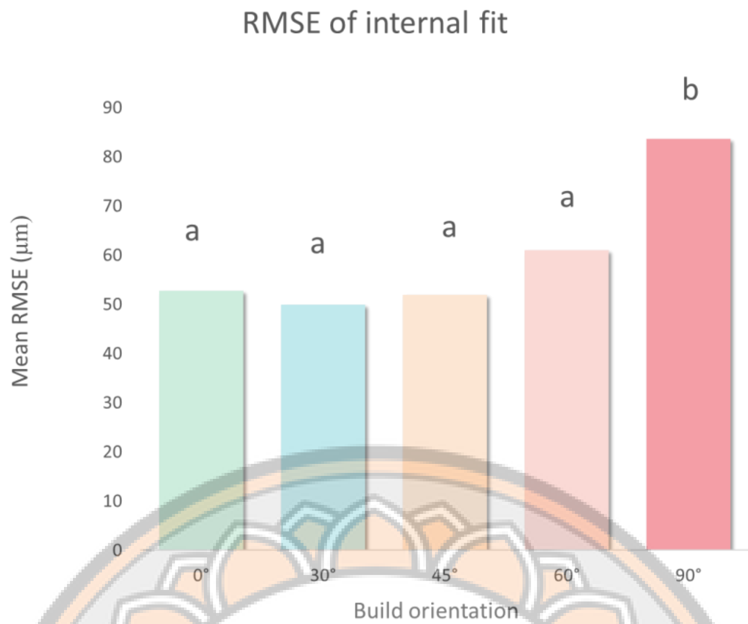

Figure 22 Mean values of root mean square error (RMSE) of the internal fit in five build orientation groups.
Post-hoc tests revealed significant differences between the following pairs: 0° vs. 30° (p = 0.028), 0° vs. 90° (p <0.001), 30° vs. 90° (p <0.001), 45° vs. 90° (p <0.001), 60° vs. 90° (p <0.001). Different letters indicate statistically significant difference.

For the marginal area, the 30° and 45° groups demonstrated significantly lower RMSE values compared to the other groups, consistent with the mean marginal gap results. The color mapping for the 30° and 45° groups predominantly displayed green hues. In contrast, the 0° and 60° groups exhibited a mix of green and yellow hues, while the 90° group was characterized by predominantly yellow hues, reflecting the larger marginal gaps.

Conversely, the overall RMSE for the internal gap in the 90° group was significantly higher than in the other groups, with no significant differences observed among the remaining groups. This finding was supported by the color mapping, which showed a predominance of yellow hues covering the abutment across all aspects in the 90° group.

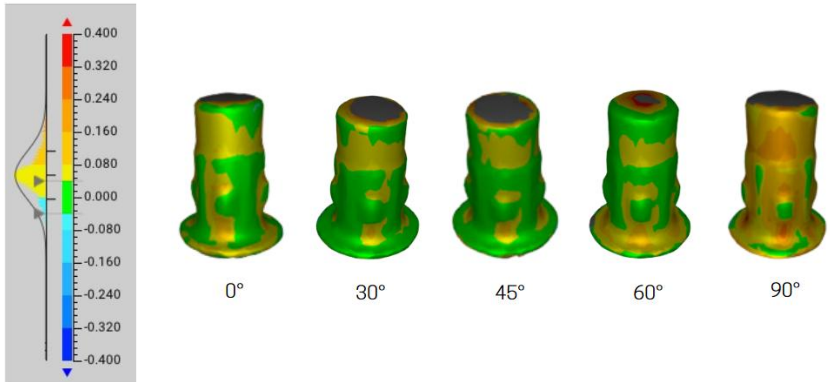

Figure 23 color mapping of the cement space in each group.
The discrepancy of samples and reference file were demonstrated in color, ranging from green to red, indicating small to large gaps.

Discussion

This study aimed to evaluate the marginal gap and internal fit of the implant-supported provisional crown produced by 3D-printed technology in various building orientations. The results showed that the building orientation had an influence on marginal gap and internal fit of the 3D-printed implant-supported provisional crown at various locations.

A range of marginal gaps in 3D-printed provisional restorations using DLP technology has been documented in prior research. Ryu et al. reported gaps for 3D-printed crowns between 58-113 µm(19), while Park et al. observed 52-61 µm for implant-supported crowns.(56) Although Farag et al. reported a higher fit of marginal gap of the provisional crown printed by SLA printer than those by DLP printer. Yet, the results showed that the marginal gap of provisional crown from SLA printer was range between 40-72 µm.(57) This study found marginal gaps ranging from 19-39 µm, which is notably lower than previously reported figures. This may be because this study implied the whole digital workflow and design the provisional crown from the abutment library provided in the CAD software, which can reduce the error of the scanning process of the abutment. McLean and von Fraunhofer analyzed the fit of fixed restorations over five years and concluded that a gap under 80 µm is clinically acceptable.(40) Consequently, the marginal gaps identified in this study fall within acceptable clinical range.

In this study, the 30° and 45° group had the lowest marginal gap coincided with the results from Park et al. who studied 3D-printed implant-supported 3-unit bridge in 5 build angles (0°, 30°, 45°, 60°, 90°) and found a lowest absolute marginal discrepancy at 30°, 45°, and 60° group.[56] Similarly, Osman et al. evaluated the accuracy of 3D-printed provisional crowns at various angles, discovering that 135° (corresponding to 45° in this study) showed the lowest discrepancies.[58] However, Chaiamornsup et al. reported significant larger marginal discrepancies in 3-unit fixed partial denture casting patterns printed at a 45° orientation than those in 0° and 30°.[18] These differing results may be attributed to variations in prosthesis type and design, including tooth-supported versus implant-supported restorations, the number of crowns involved, type of resin material and cement gap configuration in CAD software.

Several factors contribute to the impact of building orientation on the accuracy of 3D-printed restorations, including polymerization shrinkage, z-axis accuracy, and support structure design.[18, 19, 56, 58] In the 3D printing process, the resin cures as the light source transforms the resin from liquid to a solid phase. This curing process results in volume contraction due to the shortening of intermolecular distances. Shrinkage occurs both within each individual layer and between successive layers. Specifically, the newly cured layer contracts within the boundaries of the previously cured layer, leading to a distortion on the final structure from the CAD design.[59, 60] In this study, the specimen featured a cylindrical space in the center for the abutment and the screw access channel. During printing, the shape of the central hole of uncured resin varied across groups. In 0° group, this hole is nearly circular; however, it became increasingly elliptical with greater tilt degree and eventually nearly rectangular at the 90° group led to separated cured of the mesial and distal part of the crown. Such changes in shape influence the form and degree of polymerization shrinkage, as well as the direction of the shrinkage. The greater the tilt angle, as seen in the 60° and 90° groups, the larger the internal gap due to increased distortion from polymerization shrinkage. In particular, the 90° group exhibited the most pronounced effect, where independent shrinkage of the mesial and distal sides may have contributed to a larger internal gap at the center of the crown.

The building orientation also impacted the z-axis length, with longer lengths observed at lower tilt angles. The 0° group, having the longest z-axis length, may have experienced reduced accuracy along this axis. Unkovskiy et al. investigated the accuracy of rectangular bars printed in various building orientations, finding that Z-axis accuracy decreases as specimen length increases.[61] This decreased accuracy in the Z-axis may contribute to the inaccuracy of the margin of the 0° group in this study. Additionally, the 0° group exhibited the lowest cervical gap, potentially leading to an improper seat of the crown on the abutment. These factors together might account for the larger marginal gap in the 0° group compared to the 30° and 45° group.

Moreover, another important factor is the support structures designing. changing in building orientation angle also effect the numbers and position of the support structures on the crown. The support structures not only hold the object in place during printing, but they also help stabilize different parts and reduce shrinkage.[19] A greater number of support structures generally improves accuracy and reduces the risk of printing failures, ensuring a more precise final product. In the 0° group, fewer support structures were present, which may have contributed to the larger marginal gap observed in this group. Additionally, not only the number but also the position of the support structures attached to the crown can influence accuracy. In the 90° group, more support structures were attached near the margin of the prosthesis compared to the other groups.

However, the results showed that the 60° and 90° groups had larger marginal gaps than the 0°, 30°, and 45° groups, despite having shorter z-axis lengths. Furthermore, while the 60° group exhibited a lower axial gap than the other groups—though not significantly—it may have still influenced the seating stability of the restoration. A smaller axial gap could increase friction during crown placement, making it more challenging to achieve a fully seated restoration, which may influence the marginal fit and overall adaptation, ultimately contributing to a larger marginal gap compared to the 30° and 45° groups. This suggests that polymerization shrinkage as the result of varying build orientation had a greater impact on printing accuracy than z-axis length and distribution of support structure.

The findings of this study indicated that a 30° and 45° building orientation yields the smallest marginal gap and best internal fit. However, considering that the 45° orientation has a shorter z-axis length and allows for a larger surface area for support structures, it appears to be the most favorable choice for printing implant-supported provisional crowns. The improved accuracy at this angle suggests that it may offer greater stability and reduced distortion during the printing process, ultimately enhancing the fit and clinical reliability of the restoration.

Despite these encouraging findings, certain limitations should be acknowledged. The specific geometry and height of the Ti-base abutment used in this study may not be representative of all implant systems. This study utilized a Ti-base abutment with a unique and complex design, specifically, the engagement button on the side of the abutment may have contributed to a reduced axial gap, potentially affecting the proper seating of the restoration. Future study to evaluate Ti-base abutments with different shapes, dimensions, and heights would be needed to clarify their impact on marginal and internal fit in 3D-printed restorations.

Moreover, These outcomes may not be applicable to all DLP printer configurations. Additionally, various factors, such as the design of the prosthesis, number of the teeth involved, the type of printing material, and post-processing methods, can affect the results. Recognized limitations of this study include the restricted generalizability due to variations in printer specifications and materials.

CHAPTER V

CONCLUSIONS

Conclusions

The 30° and 45° orientation demonstrated the smallest marginal gap and superior internal fit, indicating it as the optimal angle for achieving high precision for 3D-printed implant-supported provisional crown. Therefore, this technique is recommended for implant-supported provisional restorations, particularly in immediate implant placements within esthetic zones, where enhanced precision and tissue compatibility are crucial for promoting soft tissue healing and ensuring favorable clinical outcomes.

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