Comparison Accuracy of Complete Denture Base Fabrication by CAD/CAM Milled Technique and 3D-Printed: An *In Vitro* Study

Kanyakorn Charoenphol

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Oral Health Sciences
Prince of Songkla University
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Author	Miss Kanyakorn Charoenphol
Major Program	Oral Health Sciences

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This is to certify that the work here submitted is the result of the candidate' s own investigations. Due acknowledgement has been made of any assistance received

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I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

....…………..……………….Signature
(Miss Kanyakorn Charoenphol)
Candidate

ชื่อวิทยานิพนธ์ เปรียบเทียบความถูกต้องของฐานฟันเทียมทั้งปากระหว่างผลิตด้วยวิธีการกลึงด้วยเทคนิคแคดแคมและการสร้างต้นแบบเร็ว (พิมพ์สามมิติ): การศึกษาในห้องปฏิบัติการ

ผู้เขียน นางสาวกัลยกร เจริญผล

สาขาวิชา วิทยาศาสตร์สุขภาพช่องปาก

ปีการศึกษา 2565

บทคัดย่อ

วัตถุประสงค์: การศึกษานี้ทำเพื่อเพื่อเปรียบเทียบความถูกต้องของฐานฟันเทียมทั้งปากผลิตด้วยวิธีการกลึงและการพิมพ์สามมิติ

วัสดุและวิธีการ: นำแบบจำลองอ้างอิงสันเหงือกไร้ฟันบนมาแปลงข้อมูลดิจิทัลโดยสแกนด้วยเครื่องแสแกนนอกช่องปาก กลุ่มตัวอย่างทั้งหมด 20 ชิ้น แบ่งออกเป็น 2 กลุ่ม ได้แก่ ผลิตด้วยวิธีการกลึง และผลิตด้วยการพิมพ์สามมิติ ผลิตตามคำแนะนำของผู้ผลิต วัดความถูกต้องด้วยโปรแกรมสามมิติโดยการซ้อนทับเอสทีแอลไฟล์ระหว่างด้านเนื้อเยื่อของฟันเทียมและแบบจำลองอ้างอิง โดยแบ่งบริเวณออกเป็น 3 บริเวณ 1. บริเวณทั่วทั้งฐานฟันปลอม 105 จุด 2. บริเวณขอบโดยรอบและส่วนกั้นท้ายเพดาน 72 จุด และ 3. บริเวณส่วนรองรับปฐมภูมิ 140 จุด วิเคราะห์ข้อมูลทางสถิติด้วยสถิติทดสอบที

ผลการทดลอง: ในบริเวณทั่วทั้งฐานฟันเทียมการผลิตด้วยวิธีการกลึงให้ค่าความถูกต้อง 0.0964 ซึ่งดีกว่าวิธีการพิมพ์สามมิติให้ค่าความถูกต้อง 0.1219 ที่ระดับนัยสำคัญที่ $p<0.001$ ในบริเวณขอบโดยรอบและส่วนกั้นท้ายเพดานปากค่าความถูกต้องวิธีการพิมพ์สามมิติได้ค่าความถูกต้อง 0.1635 ซึ่งดีกว่าวิธีการกลึง 0.839 ที่ระดับนัยสำคัญที่ $p=0.009$ และบริเวณรองรับปฐมภูมิค่าความถูกต้องด้วยวิธีการกลึง 0.0207 ดีกว่าการผลิตด้วยวิธีพิมพ์สามมิติ 0.0498 ที่ระดับนัยสำคัญที่ $p<0.001$

สรุปผลการทดลอง: การสร้างฐานฟันเทียมทั้งปากบนวิธีการกลึงมีค่าความถูกต้องที่ดีกว่าการพิมพ์สามมิติในบริเวณทั่วทั้งฐานฟันเทียมและบริเวณรองรับปฐมภูมิ ในขณะที่บริเวณขอบโดยรอบและส่วนกั้นท้ายเพดานปากการพิมพ์สามมิติให้ความถูกต้องที่ดีกว่า

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ABSTRACT

Background and objectives: With the advent of computer-aided design and computer-aided manufacturing, a novel technique for fabricating complete dentures has evolved. Digital complete denture fabrication can be accomplished by an additive or subtractive approach which minimal distortion during processing contributes to effective denture base adaption, which leads to good denture retention. The aim of this study was to compare the accuracy of milled and 3D-printed complete denture bases.

Materials and Methods: The reference edentulous maxillary arch model was scanned to generate virtual denture bases using computer-aided manufacturing (CAD) software that exports as standard tessellation language (STL) files. Denture bases were constructed using a milling and printing technique called digital light processing (DLP) (10 specimens per technique). Denture bases' intaglio surfaces were scanned and superimposed on the reference model. The accuracy was quantified as root mean square error (RMSE) and evaluated statistically using independent T-test comparisons with a significance level of 0.05.

Results: The measurement area was divided into three regions. Milled dentures were significantly more accurate than 3D-printed dentures in the overall intaglio area and primary bearing area of denture bases. Denture bases printed demonstrated significantly greater accuracy than milling dentures in the peripheral/posterior palatal seal area.

Conclusion: According to the study's findings, milled dentures fit better in the overall and primary stress-bearing areas than 3D-printed dentures, while 3D-printed dentures appeared more accurate in the peripheral seal area.

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I would like to express my sincere appreciation to those who have contributed to this project. Associate Professor Dr. . Chaimongkon Peampring, my research supervisor, provided me with patient supervision, passionate support, and informative feedback. His excellent counsel contributed to the success of our research.

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Kanyakorn Charoenphol

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LIST OF ABBREVIATIONS AND SYMBOLS

CAD	= Computer-aided design
CAD/CAM	= Computer Aided Design / Computer Aided
SM	= Subtractive manufacturing
AM	= Additive manufacturing
DLP	= Direct light processing
STL	= Standard tessellation language
PMMA	= Prepolymerized polymethyl methacrylate

CHAPTER 1

INTRODUCTION

Edentulism has been a major public health issue owing to the aging population. Because of edentulism, the life quality and nutritional intake of edentulous individuals are impaired. [1] Complete dentures continue to be the treatment of choice for edentulous people. [2]

According to Jacobson and Krol[3], complete dentures are more efficient in edentulism upon several factors including the availability of sufficient support, retention, and good stability. (Fig. 1) The design of a complete denture which has good retention will involve expanding maximum area without interfering with the function of muscle, denture bases are intimately adapted to the oral tissue and sealing of the adjacent edges. [4] This is accomplished through accurate impressions and the least error denture processing. As a result, different denture bases are distorted during the different fabrication procedures. [5]

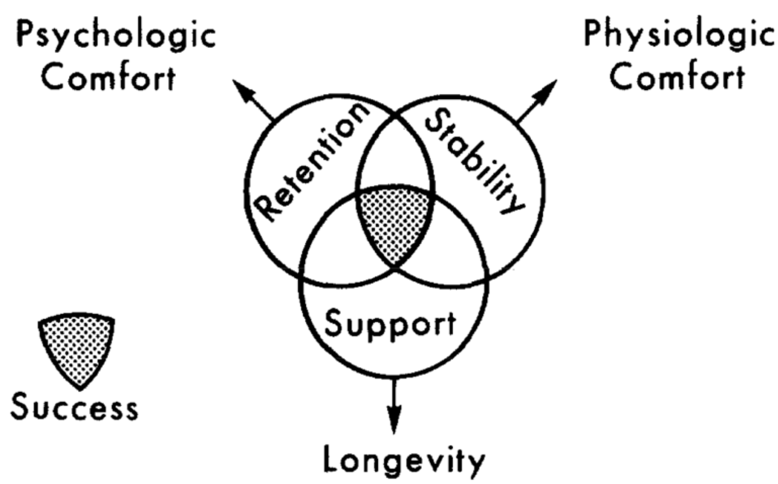

Figure 1 Success requires retention, stability, and support.

Conventionally, complete dentures are produced by compression molding, a process that converts denture wax to heat-cured acrylic resin. Heat-cured acrylic resin deformed due to polymerization shrinkage when processing, cooling, and finishing denture[6] leading to linear deformation of 0.45-0.9 percent.[7] Linear deformation causes tooth movement from its original position, necessitating occlusal spot grinding before the patient wears the prosthesis and denture base to adapt less to oral tissue resulting in decreased retention.[8, 9] Additionally, compression molding involves numerous steps that are prone to error and require considerable time and effort in clinics and laboratories consequently ensuring the quality of a good complete denture requires expertise. Moreover, if the denture is lost, the operation must be repeated. However, issues can be resolved through the use of digital dental technology by implementing a CAD/CAM system (computer-aided design/computer-aided manufacturing), which involves the use of computers to create complete dentures. [10] Goodacre et al. presented the first clinical report of patient treatment using CAD/CAM dentures milled from transparent plastic using a three-axis milling machine in 2012. The denture teeth were manually cemented into the recesses formed by milling.[11] Inokoshi et al. compared conventional try-in dentures to those produced by 3D printing and found that both were precise enough.[12] The advantage of CAD/CAM over conventional complete dentures is simplified laboratory processes, ease of fabricating replacement dentures using patient clinical data stored in the database, and decreased appointment frequency.[13] Soponaro et al. reported an average of 2.39 visits for treated patients, and even though some individuals required the third visit, this represented a significant reduction in the number of five visits. [14]

CAD/CAM in complete denture

CAD/CAM is a term that refers to the use of computers to assist in the design and construction of a product. Initially, the CAD/CAM technology has been used for fixed applications. [10] After that, it had been applied in removable work. Maeda et al.[15] developed the first digital complete denture in 1994 using additive manufacturing. They constructed a plastic shell of the dentition and an intaglio surface using photopolymerizable resin and then constructed the denture teeth from tooth-colored composite resin material. Later, in 1997, Kawahata et al. [16] created a complete denture through milling. Fewer patient visits, a simplified laboratory process that results in fewer errors during the denture-making process, and the ability to fabricate replacement prostheses rapidly based on stored data are all advantages of a digitally manufactured complete denture. This is highly helpful for elderly people who have underlying diseases that make going to the dentist inconvenient. [13] Recent reviews have examined the CAD/CAM complete denture technologies accessible to dental professionals.[17, 18] The increased number of publications related to CAD/CAM complete dentures and the rising number of companies using CAD/CAM technology is a strong sign of a growing interest in the use of digital technology for the manufacturing of complete dentures.

There are three processes in CAD/CAM systems. Data collection and computer-aided design (CAD) are the first two steps in the process and then computer-aided manufacturing. Digital dental CAD/CAM systems are classified into two groups based on their manufacturing methods. [19]

1. Subtractive manufacturing (SM) or milling

A milled denture is a method that fabrication dentures by removing materials from pre-polymerized PMMA block to form the desired shape that makes milled dentures superior mechanical qualities over conventional complete dentures [20], absence of polymerized shrinkage causes better retention. [21] (Fig.2) [22] The residual monomer content of PMMA block was lower than that of heat-activated PMMA due to the pressured pre-polymerization of PMMA block. [23] Milled maxillary complete dentures have been reported to be preferred by both dentists and patients.[24] On the other hand, Bidra et al. observed a negative clinical result for CAD/CAM dentures in patients with psychological and physiological complexity. [25] The principal disadvantage of the SM is a waste product, as a large portion of the blank is left unused and wasted during the process. Compared to additive processes, milling techniques have certain limitations: The contour of the restoration relies on the size of the smallest useable tool for each material, and if the diameter of the cutting tool is bigger than the diameter of certain components, the internal fit accuracy will be compromised or the marginal qualities will be degraded. [18]

Figure 2 Milling complete denture

2. Additive manufacturing (AM) or 3D printing

Rapid prototyping is the rapid production of a component assembly utilizing computer-aided design CAD in three dimensions. Typically, additive manufacturing is also known as 3D printing.

A 3D-printed denture is constructed object printing layer by layer. The most extensively used additive manufacturing technique for 3D printing denture bases is direct light processing (DLP).[26] (Fig. 3) It builds up layer-by-layer of photopolymerizable resin using a micro-mirror device and ultraviolet light to solidify. [27]

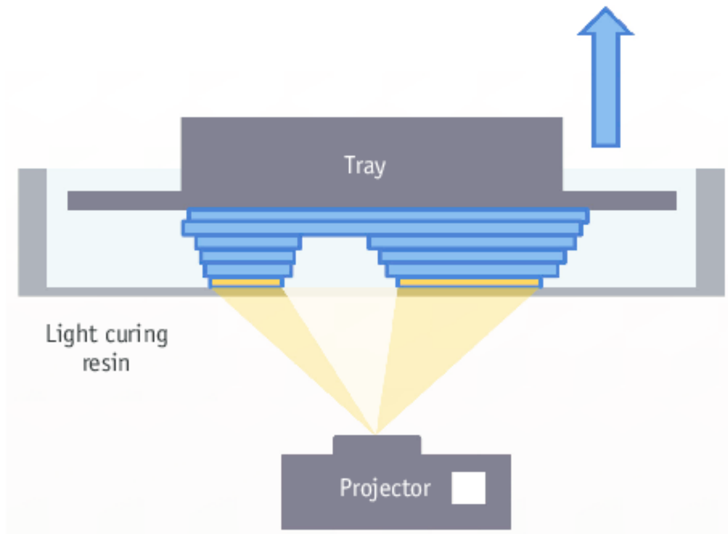

Figure 3 Digital light processing

A quantitative study comparison of 3D printed denture tissue surface adaptation to the conventional approach demonstrated that was no statistically significant difference in adaptation between the 3D printing and conventional fabrication groups. As a result, this study concluded that the use of 3D printing to create complete dentures for try-in visits was clinically acceptable.[28] Prpi et al.[29] found that the flexural strength of the 3D printing resin was statistically significantly low ranging from 60–85 MPa. According to the authors, it was within clinically acceptable limits (65 MPa), as defined by ISO standards.

Denture base adaptation and retention

Complete denture adaptation is essential for its retention, which is impacted by the accuracy of the denture bases. [3] The net volumetric shrinkage of PMMA, resulting in poor denture base adaptability as a consequence of dimension changes, is one of the disadvantages of conventionally fabricated complete dentures.[8]

Many studies have introduced SM to fabricate higher accuracy denture bases compared to a conventional technique. [30, 31] Goodacre et al. [30] evaluated accuracy of the denture base adaptation of pack and press, pour, injection, and milling processes for fabricating complete dentures. When they superimposed each STL file of the master model and STL file of the intaglio surface of denture using Geomagic Control 2014 software. It was concluded that the milling manufacturing procedure was the most accurate and repeatable denture production. Steinmassl et al.[31] compared the adaptation of CAD/CAM dentures made from PMMA provided by four different manufacturers and conventional dentures. they discovered that all CAD/CAM dentures fit better than conventionally fabricated dentures. Clinicians have noted that CAD/CAM dentures have greater retention and a decreased incidence of uncomfortable areas due to their superior fit. Tasaka et al. [32] examined the in vitro accuracy and retention of conventionally and 3D-printed dentures. They discovered that 3D-printed dentures were more accurate and a better fit than conventional dentures.

Comparison between milling and 3D-printing

AM has benefits over SM technology in that it can construct more complicated material geometry since it is not restricted by milling bur accessibility[27], material waste can be reduced, and 3D-printing machined prices are lower than milling machine prices.[33] The use of 3D printing for complete denture fabrication has been documented. Patients' excellent levels of satisfaction with 3D-printed dentures were reported in a follow-up after 18 months in clinical research by Cristache et al.[34]

Only a few studies were evaluated to compare the accuracy of complete dentures made by milling and 3D-printing. In a recent in vitro study, Kalberer et al.[35] examined the accuracy of milled and 3D printed dentures. The results indicated that milled dentures were superior than 3D printed dentures. In contrast, Lee et al.[36] evaluated the accuracy of denture bases manufactured using three different methods: injection molding, milling, and 3D printing using surface matching software. The results indicate that the conventional method showing high deformation because to polymerization shrinkage. However, the mean value of deviations was lowest in the 3D printing procedure, followed by milling and injection molding. However, there is an insufficient study on the accuracy of the base created using the milled complete denture and a 3D-printed complete denture. As a result, the objective of this research was to assess the accuracy of complete denture base fabrication between 3D printing and milling.

The objective of the study

The objective of this research was to compare the accuracy of the overall intaglio surface, peripheral/posterior palatal seal area, and primary bearing area fabricated by milling and 3D-printing complete denture.

Research question

Is there a difference in the accuracy of the overall intaglio surface, peripheral/posterior palatal seal area, and primary bearing area fabricated by milling and 3D-printing complete dentures?

Hypothesis of the study

The accuracy of the overall intaglio surface, peripheral/posterior palatal seal area, and primary bearing area of a complete denture fabricated by milling and 3D-printing would not be different.

CHAPTER 2

RESEARCH DESIGN

Experimental research (Laboratory)

Material and methods

An edentulous maxillary reference model with residual ridge morphology that resembled the Type A classification of the American College of Prosthodontists [37] was created as a reference model. Three metal spheres were put over the reference model, two on the crest of the ridge over each tuberosity and one in the center of the anterior ridge served as reference points for superimposing a virtual reference model and the intaglio surface of the denture base to verify that the measurements were taken at the same position. (Fig.4).

Figure 4 An edentulous maxillary reference model with 3 referent balls

To generate a virtual maxillary model in CAD software (3Shape Software, 3Shape Dental System), the reference model was scanned with an extraoral scanner (E4 scanner, 3Shape Dental System). An exported standard tessellation language (STL) file was created from a scanned file.

A power analysis was investigated to determine the appropriate sample size based on previous research, assuming a large effect size and type I and type II error probability of 0.05 and 0.95 respectively. As a result, ten specimens were required for each group.[38] The denture base was created from the reference CAD maxillary model by designing a virtual denture base with a thickness of 2 mm extended to the vestibule area and saving it as an STL file using the same CAD program used to create a virtual model.

(Fig.5) Twenty denture bases were constructed using two different techniques: milled denture fabrication and 3D-printed denture fabrication.

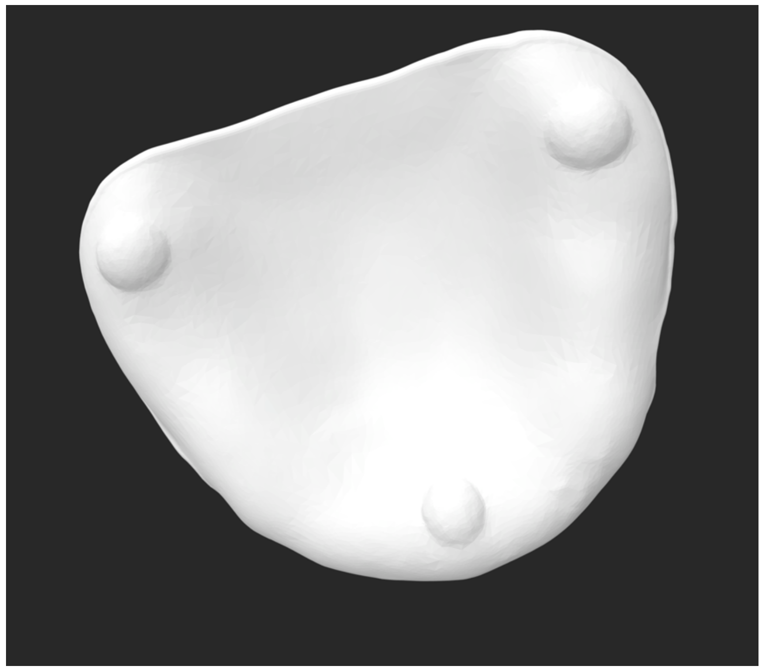

Figure 5 CAD design of denture base

For the milled group (n=10), denture bases were constructed using CAM software (HyperDent, FOLLOW ME! Technology, Munich, Germany) then milled with a five-axis milling machine (Imes-Icore250i, Germany). (Fig.6)

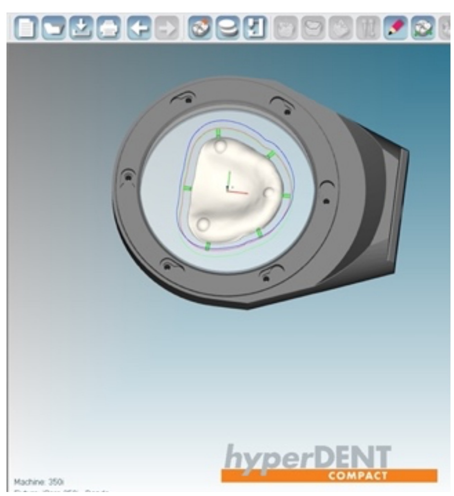

Figure 6 CAM software for milled denture

A prepolymerized polymethyl methacrylate (PMMA) block (Tijiri , China) with a diameter of 98 mm and a height of 25 mm was milled in dry condition. (Fig.7) (Fig.8)

Figure 7 Prepolymerized polymethyl methacrylate block for milling

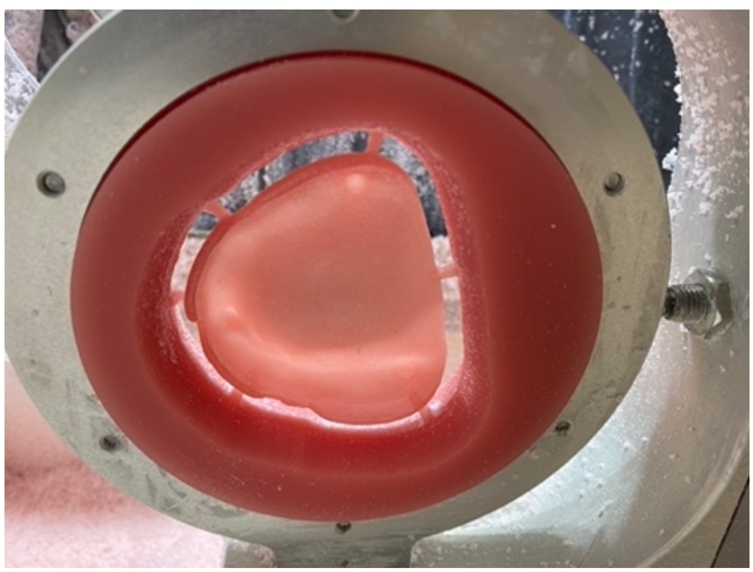

Figure 8 Milling denture

For the 3D-printed group, denture bases were constructed using a 3D printer (Asiga Max, Asiga, Alexandra, NSW, Australia), a digital light processing system. The thickness of the printed layer was fixed to 100 µm and the light source wavelength was 385 nm. Denture bases were printed with a photopolymerized resin material (Optiprint Gingiva, Dentona, Dortmund, Germany) (Fig.9) including aliphatic urethane metacrylate, tetrahydrofurfuryl methacrylate difunctionale methacrylate, and phosphine oxide. (Fig.10)

Figure 9 Photopolymerized resin material

Figure 10 3D-printing denture

After the printing process was completed, the denture bases were removed from the platform and cleaned twice with 99 percent isopropyl alcohol for 3 minutes each, followed by 30 minutes of post-polymerization using UV polymerization equipment (Asiga Flush, Asiga, Alexandria, NSW, Australia) (Fig.11) according to manufacture's recommendation.

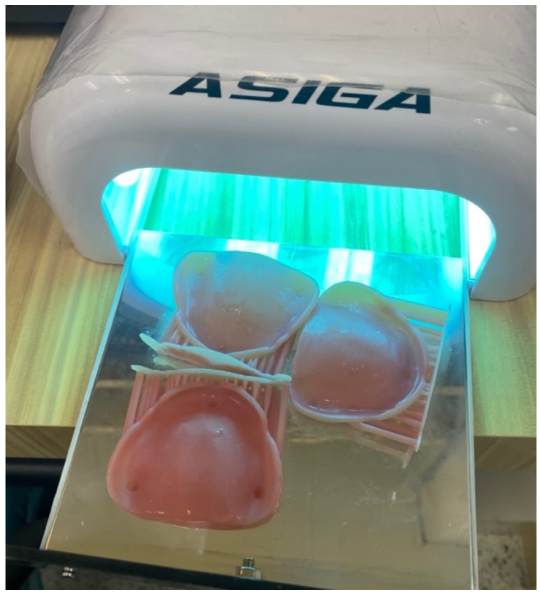

Figure 11 light cured 3D-printind denture for final polymerization

Using the previously mentioned extraoral scanner, the intaglio surfaces of all denture bases were scanned and saved as STL files. For accuracy measurement, each STL file of the intaglio surface of the denture was superimposed with the STL file of the reference model using first initial alignment and then best-fit alignment in a 3D measuring tool (Geomagic Control X, 3D Systems, Rockhill, SC, USA). (Fig.12)

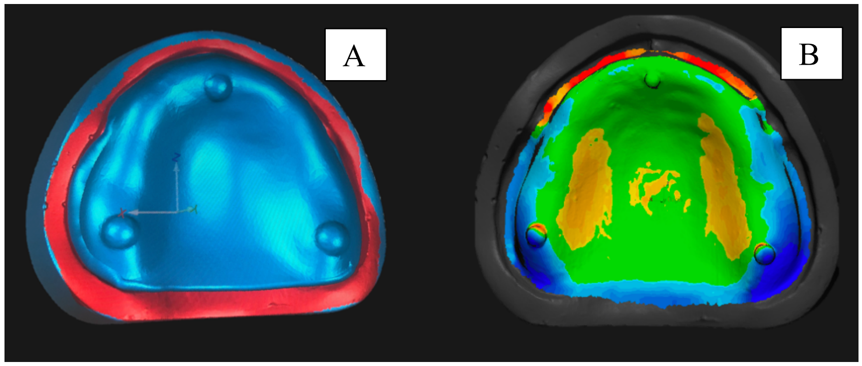

Figure 12 Measurement of accuracy by surface matching software. (A) initial alignment (B) best-fit alignment

Since each point's measurements included both positive and negative values, the root means square error (RMSE) (mm) was calculated to close to zero measure accuracy. A RMSE score demonstrated the denture base as well accuracy. Accuracy was determined as the distance between the reference model's point clouds and the denture's intaglio surface. The accuracy evaluation was conducted in three locations, as indicated in Figure 1: 1) total intaglio surface with 105 measurement points, 2) peripheral/posterior palatal seal area with 72 measuring points, and 3) primary bearing area with 140 measuring points. (Fig.13) Following that, a color map for qualitative expression was established. The normal variation was set to +50 µm and the critical deviation to +300 µm. [30]

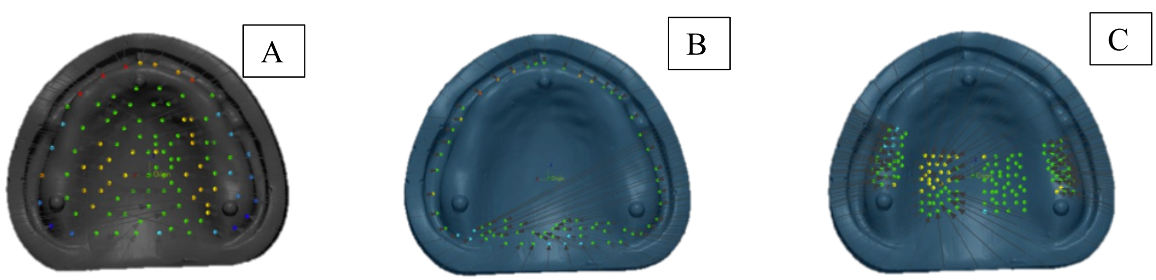

Figure 13 The adaptation evaluation performed in three areas; A) overall intaglio surface with 105 measuring points, B) peripheral/posterior palatal seal area with 72 measuring points, and C) primary bearing area with 140 measuring points

Data were statistically analyzed using SPSS 24.0 for Windows (SPSS, Chicago, IL, USA). The Shapiro-Wilk test was used to verify the normal distribution and the Levene's test was used to verify the homogeneity of variance. Thus, using independent T-tests with a significance level of = 0.05, the accuracy determined from the averages of the RMSE values was statistically compared.

CHAPTER 3

RESULTS

The root mean square values of the absolute surface deviation were determined to measure accuracy. The average RMSE values and standard deviations for three evaluation areas were presented in Table 1 and Fig.14. Independent T-tests demonstrated a significant difference in the total intaglio and primary stress-bearing region surface adaptation of denture bases manufactured using different methods ($P < 0.001$), indicating that milled dentures are more accurate than 3D-printed dentures. While the peripheral/posterior palatal seal region was evaluated, 3D-printed denture bases showed lesser deviation from the reference model, implying superior adaptation, when compared to milled denture bases (P=0.09).

Group	**Mean ± SD**		**P-value**
	Milling	**3D printing**	
Overall surface area	.0964 ± .0014	.1219 ± .0036	<0.001
Peripheral and posterior palatal seal area	.1839 ± .0057	.1635 ± .0040	0.009
Primary bearing area	.0207 ± .0014	.0498 ± .0032	<0.001

Table 1 Descriptive statistics showing RMSE values (mean ± standard deviation in mm) of three different area of measurement

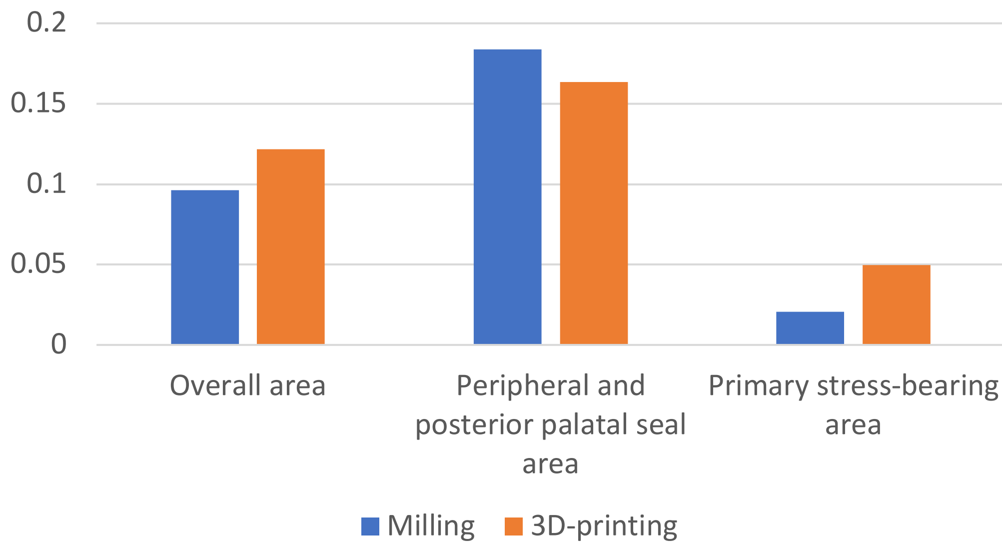

Figure 14 Graphical data showing RMSE values (mean ± standard deviation in mm) of three different area of measurement

The results of the study showed that there were statistically significant differences in overall intaglio, peripheral/posterior palatal seal area and primary bearing area surface adaptation of denture bases fabricated from milling and 3D-print. The milled denture base provides better adaptability in the overall intaglio and primary bearing area while the 3D-printed denture showed better adaptability than the milled denture in the peripheral/posterior palatal seal area. As a result, the null hypothesis is rejected.

The color mapping demonstrated a positive deviation in either yellow or red, indicating that there were spaces between the denture base and the reference model. On the other hand, color mapping in cyan or blue indicated a negative deviation, indicating that the denture base was compressed relative to the reference model. The green color represents perfect intimacy between the denture base and the reference model, with an RMSE of less than 50 µm. Color mapping revealed a predominance of green color in the milled denture group, except at the periphery and posterior palatal showed red or yellow color whereas in the 3D-printed denture groups revealed a variety of color mapping results, as illustrated in Fig 15.

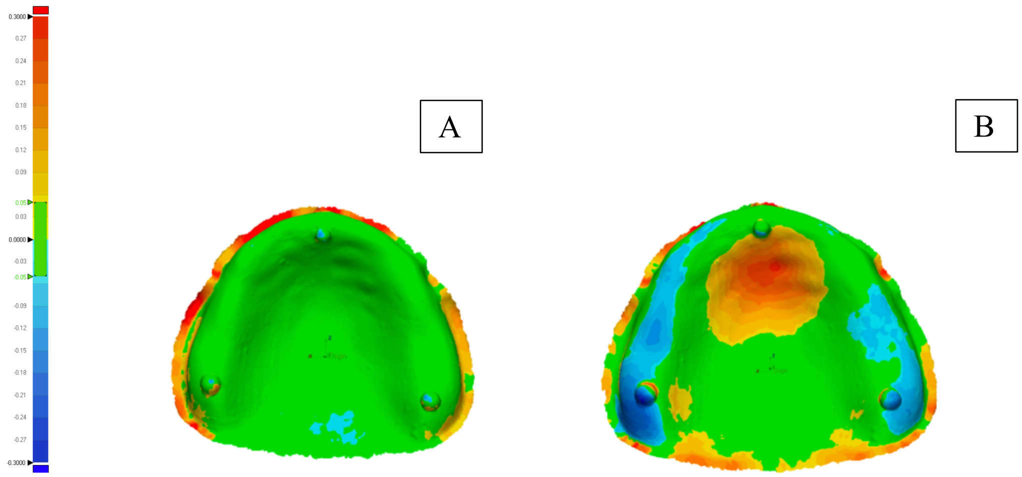

Figure 15 The color mapping demonstrated deviation from the reference model of denture bases; A) milling, B) 3D-printing

CHAPTER 4

DISCUSSIONS

Mucosal tissues covering the maxilla and mandible provide support and retention for complete dentures in edentulous jaws. Certain mucosal regions can withstand pressure while others cannot due to the diversity of soft tissues and bone structure. [39] Generally, the primary stress-bearing area has a thick keratinized mucosa and dense cortical bone that undergoes less resorption during function. The peripheral seal is the principal factor by which the maxillary denture is retained. To maintain the peripheral seal, the periphery denture bases must maintain intimate contact with the mucosa during functions that are closely suited to the primary stress-bearing area and peripheral seal to improve support, retention and stability. [3]

Several techniques have been applied to assess the degree and location of dimension change that occurs during denture processing. These have included sophisticated 2-dimensional and 3-dimensional measurements. Recently, extraoral scanners combined with surface matching software have gained popularity as a method for measuring denture base adaptation. [40] The adaptation of this study was obtained by RMSE by dividing the sum of all the absolute values of the deviations which are the distance between the reference model's point clouds and the surface of the scanned model. Adaptation analysis by these techniques has previously been. [40, 41]

Several studies have recently compared the accuracy of CAD/CAM milling to that of conventional methods. According to Goodacre et al.[30] the CAD/CAM milling technique demonstrated more accuracy and repeatability than other conventional methods in the maxillary complete denture. Additionally, Steinmassl et al.[31] revealed that CAD/CAM milling procedures had a higher degree of accuracy than compression molding methods. The findings of this study support Yoon et al. [42] examined the accuracy and adaptability of milled and 3D-printed mandibular denture bases. They concluded that milled bases were more accurate than printed bases. In comparison to 3D printing, milled bases resulted in homogeneous tissue adaption in color surface mapping. However, there was no substantial difference in adaptation between milled and printed denture bases. and Kalberer et al. [35] examined the adaptation of milled and 3D-printed complete dentures throughout wet, dry, and wet-dry cycles. In the regions of the posterior crest, palatal vault, posterior palatal seal, tuberosity, and anterior ridge, the fit of CAD/CAM dentures was significantly better than that of 3D-printed dentures. Both studies' experimental measurement procedures will be labeled as an area in contrast to this research used measuring point to measurement and the accuracy was estimated using the median, which was replaced in this research by the root mean squared. This contrasts with a study published by Hwang et al.[43] examined the accuracy and tissue adaptation of milled and 3D-printed maxillary bases. They reported that 3D-printed maxillary dentures demonstrated superior tissue adaption compared to milled maxillary dentures. However, caution should be taken when interpreting the results, since their conclusions do not match the color mapping of the Intaglio surface of the scanned dentures which indicated that 3D printed upper prostheses were more accurate than milled prostheses.

Constructing complete dentures using milling or 3D printing is a relatively new trend. Although both methods require a digital 3D-image file generated by CAD software, the fabrication methods are completely different. Milling denture exhibits more accuracy owing to fabrication by subtracting a PMMA block that has been industrially pre-polymerized. Theoretically, the denture base does not distort in any dimension. [19] While 3D printing involves photosensitive liquid resins that are continuously placed onto a support structure layer by layer and polymerized by UV light, it also needs a final light-cured to ensure the polymerization is complete as dentures are not completely polymerized, deformation may occur during printing. [44] The result of this study demonstrated that milled dentures were statistically better in accuracy than 3D-printed dentures except for peripheral areas the greatest amount of milled denture mismatch was found in peripheral regions due to the reference model's minor undercut in the vestibule area although using 5-axis milling machine. Despite the lower accuracy discovered, 3D printing outperformed milled dentures. Milling units are expensive and may be appropriate for commercial centers but not for small dentistry offices. Milled dentures generated a greater quantity of material waste because of the fabrication process. Additionally, when comparing time requirements, milled dentures took approximately 5 hours to produce, whereas 3D printing took approximately 1.30 hours, and when comparing material costs, milled dentures were considerably more expensive than 3D printing. Both techniques were satisfactory to both the patient and the dentist. [24, 34, 45, 46] Due to the dynamic movement of the mucosa in a complete denture, the tolerance of soft tissue displacement may be large. [47]Macaque monkeys using continuous or dynamic loading on the maxillary denture found a compressive mucosal displacement of 375 -500 µm. [47] This range of values is about 2-3 times that seen in this study. Thus, the tissue surface adaptation of the 3D-printed denture base may be clinically acceptable.

The limitation of this study was that the intaglio surface adaptation of denture base was determined in an extraoral condition. The oral mucosa has dynamic characteristics of compressed soft tissue which is not simulated in this study. Other factors such as saliva immersion and morphology of ridge were not considered in this study and needed to be investigated in the future.

CHAPTER 5

CONCLUSIONS

Within the limitation of this in vitro study, the following conclusions could be drawn. milled dentures fit better in the overall and primary stress-bearing areas than 3D-printed dentures, while 3D-printed dentures appeared more accurate in the peripheral seal area. However, the accuracy of milled and 3D printed denture bases in this study was a clinical acceptable level.

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APPENDIX

APPENDIX A

Accuracy at overall area (μm)

No.	**Milling**	**3D-printing**
1	**0.098**	**0.1228**
2	**0.0965**	**0.1274**
3	**0.0992**	**0.1293**
4	**0.0943**	**0.1392**
5	**0.0989**	**0.1349**
6	**0.0987**	**0.112**
7	**0.1042**	**0.1092**
8	**0.092**	**0.1072**
9	**0.0921**	**0.1111**
10	**0.0901**	**0.1262**
Mean	**0.0964**	**0.1219**
SD	**0.0014**	**0.0036**

Accuracy at peripheral area (μm)

No.	**Milling**	**3D-printing**
1	**0.2037**	**0.1692**
2	**0.2010**	**0.1516**
3	**0.1606**	**0.1739**
4	**0.1722**	**0.1693**
5	**0.1794**	**0.1811**
6	**0.1823**	**0.1471**
7	**0.1965**	**0.1719**
8	**0.2079**	**0.1516**
9	**0.1808**	**0.1716**
10	**0.1550**	**0.1477**
Mean	**0.1839**	**0.1635**
SD	**0.0057**	**0.0040**

Accuracy at primary stress-bearing area (μm)

No.	**Milling**	**3D-printing**
1	**0.0259**	**0.0427**
2	**0.0222**	**0.0551**
3	**0.0196**	**0.0515**
4	**0.0197**	**0.066**
5	**0.0254**	**0.0519**
6	**0.0251**	**0.0311**
7	**0.0132**	**0.0407**
8	**0.0204**	**0.0529**
9	**0.0221**	**0.0456**
10	**0.0132**	**0.0602**
Mean	**0.0207**	**0.0498**
SD	**0.0014**	**0.0032**

APPENDIX B

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