CLINICAL MARGINAL FIT AND PATIENT'S PREFERENCES IN IMPRESSION TECHNIQUE USING DIGITAL INTRAORAL SCANNER VERSUS POLYVINYLSILOXANE MATERIAL

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การเปรียบเทียบความแนบบริเวณขอบของครอบฟัน และความพึงพอใจของผู้ป่วยเมื่อพิมพ์ปากด้วย เครื่องพิมพ์ปากดิจิตอล และวัสดุพิมพ์ปากซิลิโคน

นางสาวนวภัทร์ ศากรวิมล

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Thesis Title	CLINICAL MARGINAL FIT AND PATIENT'S PREFERENCES IN IMPRESSION TECHNIQUE USING DIGITAL INTRAORAL SCANNER VERSUS POLYVINYLSILOXANE MATERIAL
By	Miss Nawapat Sakornwimon
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor Chalermpol Leevailoj

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นวภัทร์ ศากรวิมล : การเปรียบเทียบความแนบบริเวณขอบของครอบฟัน และความพึงพอใจของผู้ป่วยเมื่อพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิตอล และวัสดุพิมพ์ปากซิลิโคน (CLINICAL MARGINAL FIT AND PATIENT'S PREFERENCES IN IMPRESSION TECHNIQUE USING DIGITAL INTRAORAL SCANNER VERSUS POLYVINYLSILOXANE MATERIAL) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทพ. เฉลิมพล ลี้ไวโรจน์, 66 หน้า.

วัตถุประสงค์: เพื่อเปรียบเทียบความแนบบริเวณขอบของครอบฟัน และความพึงพอใจของผู้ป่วยเมื่อพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิตอล และวัสดุพิมพ์ปากซิลิโคน

วิธีการศึกษา: ผู้ป่วยที่เข้ารับการรักษาทำครอบฟันฟันหลังจำนวน 16 รายได้รับการกรอเตรียมฟัน จากนั้นได้รับการพิมพ์ปาก 2 วิธี ได้แก่ การพิมพ์ด้วยเครื่องพิมพ์ปากดิจิตอล (3M True Definition Scanner; 3M ESPE) และวัสดุพิมพ์ปากซิลิโคน (Express; 3M ESPE) หลังการพิมพ์ปากผู้ป่วยทำการตอบแบบสอบถามเพื่อให้คะแนนความพึงพอใจต่อวิธีการพิมพ์ปากซึ่งประกอบด้วยหัวข้อต่างๆ รวมถึงความพึงพอใจโดยรวม ผู้วิจัยทำการลองครอบฟันเซอโคเนีย (Lava Plus High Translucency Zirconia; 3M ESPE) ที่ได้จากรอยพิมพ์ทั้งสองวิธี จากนั้นทำการสร้างรอยพิมพ์ลอกเลียนความแนบของครอบฟัน เพื่อนำไปวัดในห้องปฏิบัติการภายใต้กล้องจุลทรรศน์แบบสเตอริโอ จำนวน 3 ครั้ง โดยทำการวัด 4 ด้าน ได้แก่ ด้านประชิดทั้งสอง ด้านแก้ม และด้านลิ้น การวัดทั้งหมดทำโดยผู้ประเมินเพียงคนเดียว การวิเคราะห์ intraclass correlation coefficient (ICC) ถูกใช้เพื่อหาความเที่ยงของผู้ประเมิน ข้อมูลความแนบของครอบฟันและความพึงพอใจของผู้ป่วยนำมาวิเคราะห์ทางสถิติด้วย การวิเคราะห์ Wilcoxon’s signed-rank ที่ระดับนัยสำคัญ 0.05

ผลการศึกษา: คะแนนความพึงพอใจต่อวิธีการพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิตอลสูงกว่าเมื่อพิมพ์ปากด้วยวัสดุพิมพ์ปากซิลิโคนอย่างมีนัยสำคัญในทุกหัวข้อ ผลการวิเคราะห์แสดงให้เห็นถึงความเที่ยงของผู้ประเมินมีค่า ICC .996 ซึ่งอยู่ในระดับดีเยี่ยม ความแนบบริเวณขอบของครอบฟันที่ได้จากการพิมพ์ปากทั้งสองวิธีไม่มีความแตกต่างกันอย่างมีนัยสำคัญ

สรุป: ความแนบบริเวณขอบของครอบฟันเซอโคเนียที่ได้จากการพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิตอลไม่มีความแตกต่างจากความแนบบริเวณขอบของครอบฟันเซอโคเนียที่ได้จากการพิมพ์ปากด้วยวัสดุพิมพ์ปากซิลิโคน อย่างไรก็ตามความพึงพอใจของผู้ป่วยต่อวิธีการพิมพ์ปากด้วยเครื่องพิมพ์ปากดิจิตอลสูงกว่าการพิมพ์ปากด้วยวัสดุพิมพ์ปากซิลิโคนอย่างมีนัยสำคัญ

สาขาวิชา ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม ลายมือชื่อนิสิต .....

ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

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5675831532 : MAJOR ESTHETIC RESTORATIVE AND IMPLANT DENTISTRY
KEYWORDS: DIGITAL IMPRESSION / INTRAORAL SCANNER / CAD/CAM / ZIRCONIA CROWN / MARGINAL GAP / PERCEPTION / PREFERENCE

NAWAPAT SAKORNWIMON: CLINICAL MARGINAL FIT AND PATIENT'S PREFERENCES IN IMPRESSION TECHNIQUE USING DIGITAL INTRAORAL SCANNER VERSUS POLYVINYLSILOXANE MATERIAL. ADVISOR: ASSOC. PROF. CHALERMPOL LEEVAILOJ, 66 pp.

Objective: The purpose of this in vivo study was to compare the clinical marginal fit of monolithic zirconia crowns and patients' preferences using digital impressions versus polyvinyl siloxane (PVS) impressions.

Materials and Methods: Sixteen participants with indications for single molar crowns were included. After crown preparation, digital impressions by intraoral scanner (3M True Definition Scanner; 3M ESPE) and PVS impression (full-arch stock tray, Express; 3M ESPE) were made. The patients were asked to complete a 6-item questionnaire with a visual analog scale (VAS) related to perceptions of each of the following topics: time involved, taste/smell, bite registration, size of impression tray/scanner head, gag reflex, and overall preference. CAD/CAM monolithic zirconia crowns (Lava Plus High Translucency Zirconia; 3M ESPE) were fabricated from both impressions. The crowns were tried, and silicone replicas were made for clinical marginal gap measurements on 4 sides (mesial, buccal, distal, and lingual) under a steromicroscope 3 times by blinded examiner. Intra-examiner reliability was evaluated by calculating the intraclass correlation coefficient (ICC). Data on patients' preferences and marginal gaps were analyzed by Wilcoxon's signed-rank test. All of the analyses were performed using a 95% confidence level.

Results: VAS scores for digital impressions were statistically significant higher than those for PVS impressions in every topic ($P<.05$). The results showed excellent reliability of the examiner with an ICC of .996. There was no significant difference between marginal gap widths between the PVS group and the digital group on all sides ($P>.05$).

Conclusion: There was no difference in the clinical marginal fit of zirconia crowns fabricated from either digital impressions or PVS impressions. Furthermore, patients' satisfaction with digital impressions was significantly higher than with conventional impressions.

Field of Study: Esthetic Restorative and Implant Dentistry Student's Signature .....
Advisor's Signature .....

Academic Year: 2015

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CHAPTER I

INTRODUCTION

Rationale and Significance of the Problem

It cannot be denied that the trends in dental treatment are moving toward digital technology. One significant innovation has been computer-aided design and computer-aided manufacturing or CAD/CAM, which has gained popularity among dentists increasingly over the past 25 years.[1] The invention of CAD/CAM technology made the process of zirconia fabrication became possible due to the ability of CAD/CAM to adjust precisely the shrinkage of zirconia from sintering. Complete digital systems consist of an intraoral scanner, a computer with CAD software, and a milling machine.[2]

Intraoral scanners have improved tremendously since the first one, CEREC 1, was introduced in 1987.[3] Currently, there are many brands of intraoral scanner, such as CEREC Omnicam from Sirona Dental System, iTero from Cadent, Planmeca PlanScan from E4D Technologies, TRIOS from 3Shape, and 3M True Definition Scanner from 3M ESPE. Many previous studies have been performed to evaluate the precision of these devices, and they have found that the scanners could provide similar or even better accuracy than conventional impression materials, either polyvinylsiloxane (PVS) or

polyether.[4-7] However, some scanners have demonstrated less accuracy with digital impressions.[8, 9]

The design of the study as in vivo could imitate clinical situation better than in vitro design. For the direct evaluation of intraoral scanner precision, an in vitro study alone might be sufficient. However, to obtain a good impression, the impression technique should overcome some clinical challenges, including accessibility to the finish line, moisture control, and patient compliance. Therefore, the results from a study conducted clinically might reflect the true performance of the device better.

With better accuracy of impressions, more precise restorations can be fabricated. When the quality of the restoration must be evaluated, the margin is always an area of interest due to its importance. To be called a successful ceramic restoration, three considerable factors must be obtained; marginal fit, fracture resistance, and aesthetics.[10, 11] Of these three, marginal fit can be related directly to the accuracy the impression. Inadequate marginal fit of the restoration was found to cause plaque accumulation, leading to dental caries and periodontal diseases, from which the restoration will eventually fail.[12, 13]

Evaluation of marginal fit can be accomplished by measuring marginal gaps or the absolute marginal discrepancy. The measurement of marginal gaps can be taken as the perpendicular measurement from the internal surface of the restoration to the preparation closest to the finish line.[14] For in vivo studies, due to technical

limitations, only one method could be utilized: a silicone replication technique. In this technique, a light body silicone replica of the marginal gap was created and sectioned, and its thickness was measured under stereomicroscope.[15] Previous studies have found significant differences in marginal gaps measured on die, compared to those made on the abutment teeth.[15, 16] Therefore, to provide better relevance to clinical situations, measuring marginal adaptation on abutment teeth was recommended.[15] The acceptable clinical marginal gap of less than 120 μm was proposed by McLean and Fraunhofer in 1971 and has routinely been used in the studies since then.[17]

Based on the authors' literature review, the studies of the accuracy of these intraoral scanners for crown fabrication in vivo remain very scarce. Moreover, there have still been no publications about the performance of crowns fabricated using the latest device from 3M ESPE, 3M True Definition Scanner, which uses 3-dimensional video-based scanning technology. Thus, the accuracy of this device, which was proposed by the manufacturer to be the replacement of conventional impressions, should be evaluated.

Furthermore, the ability to eliminate the discomfort that patients can encounter with traditional impressions has also been claimed by the manufacturer. However, there have been only a few reports of patients' preferences comparing impressions made using intraoral scanners versus conventional impressions. A modified visual analog scale (VAS) was utilized in all of the studies, and it seems to be

appropriate tool for assessing patients' preferences. All of the studies demonstrated the advantages of digital impressions over conventional ones.[18-20]

Research Questions

1. Is there any significant difference in clinical marginal fit of zirconia crowns fabricated from digital impression versus PVS impression?
2. Is there any significant difference in patients' perception when making crown impression with intraoral scanner versus PVS impression material?

Objectives of the Study

The main aim of this study was to evaluate and compare the clinical marginal fit of zirconia crowns fabricated from digital impression with those from conventional PVS impression.

Second objective was to investigate and compare patients' perceptions when making crown impression with intraoral scanner and PVS impression material.

Statement of Hypothesis

For primary objective

Null Hypothesis: There is no significant difference in clinical marginal fit of zirconia crowns fabricated from digital impression and PVS impression.

Alternative Hypothesis: There is significant difference in clinical marginal fit of zirconia crowns fabricated from digital impression and PVS impression.

For secondary objective

Null hypothesis: There is no significant difference in patients' perceptions when making crown impression with intraoral scanner and PVS impression material.

Alternative hypothesis: There is significant difference in patients' perceptions when making crown impression with intraoral scanner and PVS impression material.

Conceptual Framework

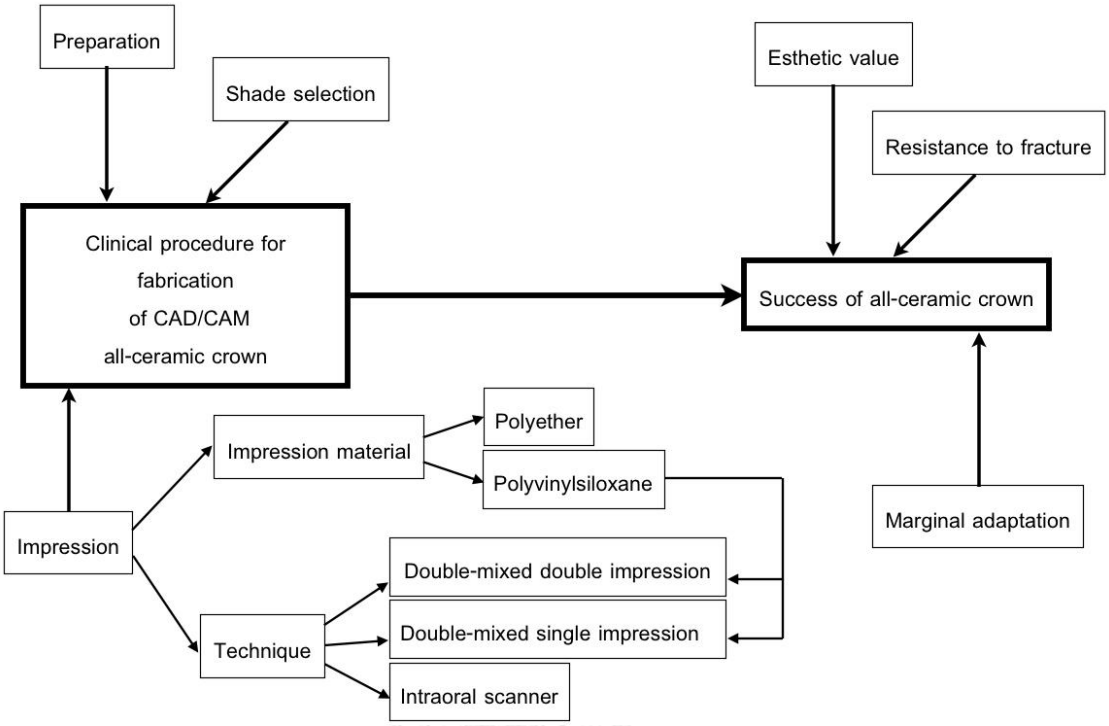


Figure 1 Diagram of conceptual framework

Basis Assumption

Every zirconia crowns were fabricated strictly according to manufacturer's instruction by one technician and had the same quality. Therefore, clinical marginal gap was affected only by the difference in impression technique.

Study Limitation

1. This study focuses only on 3M True Definition scanner, hence the results found here may not be able to infer to other brands of intraoral scanner which using different principle.
2. One brand of PVS impression material was chosen to represent the conventional impression material. So, the results here may not be able to imply with other brands and other types of impression materials.
3. Only Lava Plus High Translucency zirconia crown was evaluated in this study. Therefore, the results may not be able to apply to other brands and types of materials.

Keywords

Digital impression, Intraoral scanner, CAD/CAM, Zirconia crown, Clinical marginal fit, Marginal gap, Perception, Preference

The Expected Benefits

The results from this study might assist the clinician to make a decision whether intraoral scanner should be used clinically, or even replaced the conventional PVS impression material.

CHAPTER II

REVIEW OF LITERATURES

The literatures in these following topics will be reviews.

- Marginal fit of ceramic crown
    - Terminology
    - Methods of measurement
- All-ceramic crown preparation
- CAD/CAM ceramic restoration
- Impression technique
    - Conventional impression technique
    - Digital impression
    - Gingival displacement
- Patients' perceptions on impression techniques

Marginal Fit of Ceramic Crown

Marginal fit is one of the most important factors indicating successful ceramic restoration, besides fracture resistance and esthetic.[10, 11] Inadequate marginal fit of

the restoration was found to cause plaque accumulation, which leads to dental caries and periodontal diseases, then that restoration will fail eventually.[12, 13]

Terminology

The terminology of marginal fit was proposed by Holmes et al. in 1989 as it can be evaluated by measuring either marginal gap or the absolute marginal discrepancy. The measurement of marginal gap can be done as the perpendicular measurement from the internal surface of the restoration to the preparation closet to the finish line.[14] The cut point value of marginal gap was concluded by McLean and Fraunhofer in 1971, after conducting 5-year clinical study of over 1,000 restorations, to be clinical acceptable at less than 120μm.[17] Since then, most of the studies evaluating on the marginal gap of the restorations used this value as a reference.

Methods of Measurement

For *in vitro* studies, various methods of marginal gap measurement can be utilized. The most widely used one was the direct microscopic examination of the marginal area. Second method, the specimens were cemented and cross-sectioned, then measured the marginal gap under a microscope. Other several methods were listed as follows; creating a light body silicone replica, laser videography, profilometry, and x-ray microtomography.[15]

For *in vivo* studies, due to the technical limitation, only one method could be utilized, a silicone replication technique. In this technique, a light body silicone replica

of the marginal gap was created, sectioned, and measured the thickness under stereomicroscope.[15] Previous studies found significant difference of marginal gaps measuring on die compared to those made on the abutment tooth.[15, 16] So, in order to provide better relevant to the clinical situation, measuring marginal adaptation on abutment tooth was recommended.[12] However, in order to conduct the *in vivo* studies, other factors affecting the marginal adaptation of the crowns that have to be concerned were mentioned. Accessibility was absolutely more difficult in the *in vivo* studies.[21] Moreover, there are other factors that might play roles such as location of the finish line, periodontal health, sulcus bleeding, saliva, and patient compliance.[5]

All-ceramic Crown Preparation

It has been known that only two types of finish line configuration indicating for ceramic restorations; chamfer finish lines and rounded shoulders. It was found that when compared between these two types of finish line, in most studies, no significant difference was found.[15], However, in some studies, rounded shoulders resulted in significantly narrower marginal gaps.[21-23] Moreover, Asavapanumas and Leevairoj recommended avoiding the preparation with high degrees of finish line curvature because it could result in an increase in marginal gap.[24]

Angulation of the preparation may also have an impact on the marginal fit as well. One study found that low preparation angulation could create higher hydraulic

pressure, thus obstructed excessive cement discharging.[25] On the other hand, other studies were found no correlation between preparation angulation and marginal adaptation.[26-28] Generally, the recommended total occlusal convergence angle of 10 to 20 degrees proposed by Goodacre in 2001 is used.[29]

CAD/CAM Ceramic Restoration

CAD/CAM was introduced into the dental field since 1970s.[1] Currently, CAD/CAM technology can be used to fabricate many types of works; inlays, onlays, veneers, crowns, fixed partial dentures, or even implant abutments. The invention of this technology allows zirconia crowns fabrication to be feasible due to the ability for precise adjusting the shrinkage from sintering.[2] Many advantages can be gained by using CAD/CAM technology when compared to conventional techniques. These preferences are time saving, ease of use, and better accuracy.

However, there are still some disadvantages of CAD/CAM technology. First is definitely the high initial cost of the device and software. Another con is the need of training for practitioner who attempts to use this technology.[2]

In addition, many studies showed factors effecting marginal adaptation of restoration fabricated from CAD/CAM technology. Literatures showed that the accuracy of CAD/CAM crowns varied among systems, depended on the optical impression technologies, software technologies and milling accuracy.[30-32] Moreover, the setting

of cement space through the software interface in CAD/CAM system was also shown to affect the marginal and internal fit of the restoration.[26, 27, 32]

Impression Technique

Conventional Impression Technique

Elastomeric impression materials were classified into 4 types; reversible hydrocolloids, polysulfides, polyvinylsiloxanes, and polyethers. Due to their properties, polyvinylsiloxanes and polyethers are currently used as a final impression material.[33] There were several studies attempted to find which one has superior performance. One study found that polyether and addition silicone with one-step/double-mixed impression technique gave more accuracy compared to addition silicone with two-step/double-mixed impression technique and condensation silicone with either technique.[34] The results from this study were corresponded with the results from the study by Johnson GH.[35]

For final impression, using polyvinylsiloxanes with one-step/double-mixed impression technique was proposed by Perakis N, Belser Urs C, and Magne P due to its reliability and simplicity. After superficial cord removal, light body polyvinylsiloxane is injected on the preparation, and blown into the sulcus, follows by applying another layer of impression material. Then, a higher viscosity polyvinylsiloxane is placed in either stock tray or custom tray, and inserted into patient's mouth.[33]

Digital Impression

The first dental system combining intraoral digital scanner with a milling unit was CEREC from Sirona Dental Systems Inc., which was introduced in 1987. At that time, only inlays and onlays could be produced.[3] The successor of CEREC known as CEREC AC was later introduced in 2009, using active triangulation working principle. The procedure of impression making begins with coating the preparation with titanium dioxide powder in order to make the translucent areas opaque. Then use the device to scan the prepared tooth, as well as adjacent and opposing teeth. After the impression is complete, restoration can be fabricated by in-office milling machine or by sending data to the laboratory.[2] The newest one launched from this manufacturer is CEREC Omnicam with additional feature of natural color appearance on the monitor and elimination of powder coating.

Another well-known digital impression system is iTero, introduced by Cadent Inc. (Carlstadt, USA) in 2007 to be the first device for conventionally manufactured crowns and bridges. This device used another working principle called parallel confocal microscopy allowing teeth to be scanned without coating with any powder.

In 2008, 3M ESPE launched Lava Chairside Oral Scanner (Lava COS), using active wavefront sampling principle. In this system, after placing the retraction cord in the gingival sulcus of prepared tooth/teeth, the arch has to be dried and coated with

titanium dioxide powder. This device cannot be combined with in-office design and milling. Therefore, the digital impression file has to be sent to the laboratory.[2]

Numerous studies found the accuracy of these devices to be comparable with the conventional impression technique.[4, 36, 37] Besides, some showed even significant better accuracy obtained from the digital intraoral scanner than from the conventional one.[5, 38] For example, the clinical evaluation of marginal fit of 20 Lava crowns by Syrek A, et al. in 2010. The results showed that the clinical marginal gap of crowns fabricated from Lava COS was significantly lower than crowns fabricated from silicone impression.[5] A study by Henkel found that 68% blinded-dentist examiners have judged that the crown fabricated from digital impression was better than one from conventional impression.[38] On the other hand, few studies showed less accuracy when using digital intraoral scanner compared to conventional impression.[39] Furthermore, digital impression eliminated suffered problems of conventional impression, such as bubbles and tear in the impression material, cords and other debris embedded in the impression material.[40]

The latest launched digital impression device is 3M True Definition Scanner, which was introduced by 3M ESPE in October 2012. The working principle based on "3D-in-motion" video technology. This device is similar to CEREC and iTero in the way that restoration can be fabricated from either chairside milling system or laboratory. Even the manufacturer claimed the device to be the improvement productivity

compared to the traditional process; there was still no published study on the performance of this device yet.

Gingival Displacement

Among all techniques of gingival displacement, using retraction cord procedure is the least traumatic one. The use of "double cord" gingival displacement technique was suggested.[33] By using two different sizes of retraction cords, each of them plays different roles. First, the smaller one is applied deep into the sulcus to prevent any crevicular fluid or blood contaminating the impression material during impression making. The second cord placing superficially over the first one is used to expand the gingival sulcus and will be removed prior to impression making. In addition, rinsing the preparation in order to expand the second cord by water absorption was recommended.

The recommended astringent/hemostatic solutions were aluminum sulfate, potassium sulfate, or aluminum chloride.[41] On the other hand, retraction cord soaking in solution consisted of epinephrine was not recommended because it can result in local tissue necrosis and systemic effects.[42]

Patients' Perceptions on Impression Techniques

There were three studies assessing patients' perception of the difference between conventional impression approach and digital impression approach. Study in

2015 evaluated patient preference and operating time in 15 participants when making impression with Cerec Omnicam versus Impregum. The results showed significant favor in digital impression. In addition, duration in making impression with intraoral scanner was less then conventional impression.[18]

Another study was performed by Wismeijer D, et al., making implant impressions with polyther impression material and Cadent Itero digital impression system in thirty patients. Then patients were asked to answer questions about general opinion, preparing for the impression, time involved, taste, registration of the intraoral relationship, size of the impression tray/scanner, and gag reflex. The results showing overall preference of the patients was significantly toward the use of intraoral scanner.[19]

The other studies done by Yuzbasioglu E, et al. also showed the same patients' preference. The research was done in twenty-four patients using polyether impression material and CEREC Omnicam to make maxillary and mandibular dental arches impression. In this study, Visual Analog Scale (VAS) ranging from 0 to 100 was utilized to evaluate patients' attitudes and perceptions in each topic, such as overall discomfort of impression, smell/voice, taste/heat, discomfort during mouth was opened.[20]

CHAPTER III

MATERIALS AND METHODS

Operational Definition

1. 3M True Definition scanner (3M ESPE) – intraoral scanner
2. Express XT Putty Soft (3M ESPE) – putty silicone
3. Express XT Light Body (3M ESPE) – light body silicone
4. Jeltrate (Dentsply) – reversible hydrocolloid
5. Rely X Temp NE (3M ESPE) – temporary cement
6. Lava Plus High Translucency zirconia (3M ESPE) – zirconia

Research Design

This study was a randomized controlled examiner-blinded clinical trial which molar crowns were used to investigate. Intervention of this study was the type of impression technique, PVS impression and digital impression. Dependent variable was clinical marginal gap, measured in micron under stereomicroscope.

Research Methodology

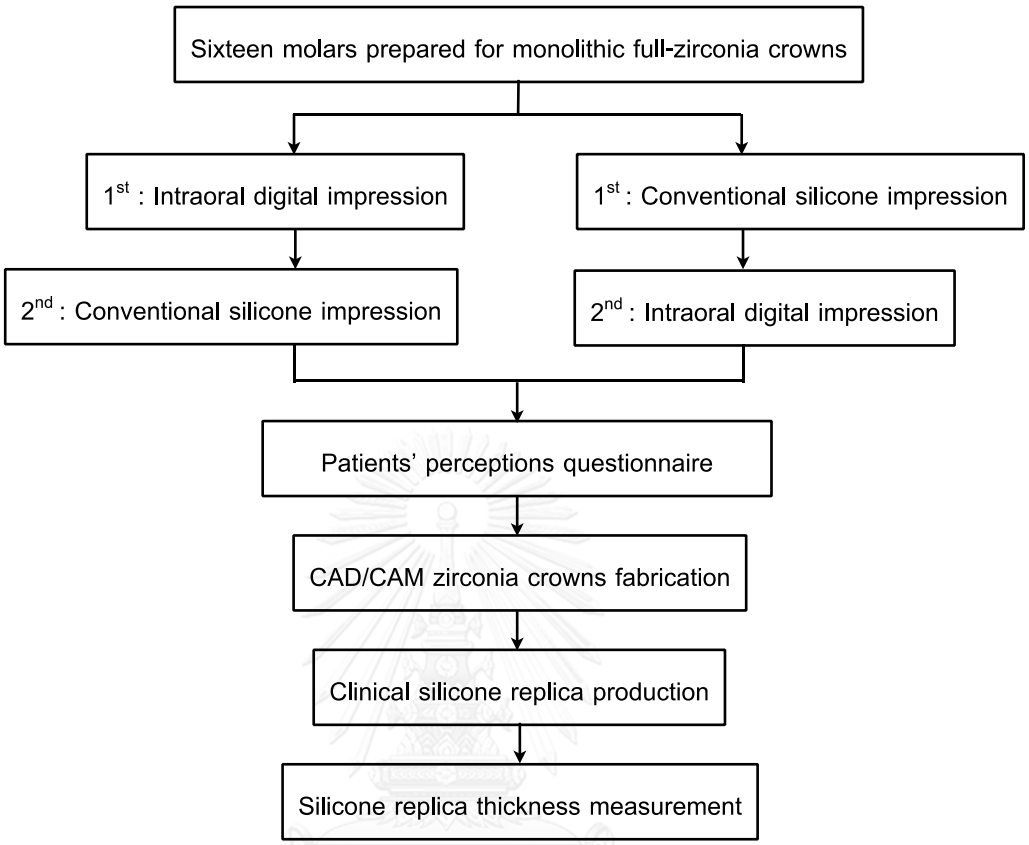


Figure 2 Diagram of study design

Ethical Consideration

This study had been approved by the Ethical committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand. The study reference ID was HREC-DCU 2014-070. (Appendix A)

Subjects

Sixteen patients were randomly selected from patients who came to Esthetic Restorative and Implant Dentistry Clinic, Chulalongkorn University with the indication for single molar crown. Inclusion and exclusion criteria were listed in Table 1.

Table 1 Inclusion and Exclusion Criteria

Inclusion criteria	**Exclusion criteria**
- In need of a single molar crown	- Tooth presented with clinical symptoms
- Aged more than 20 years	- Tooth mobility degree of 2 or higher
- At least one adjacent tooth existed	- Tooth required any periodontal surgery
- At least one opposing tooth existed	before crown preparation
- Crown margin can be located at	- Parafunctional habit
gingival margin level or under not	- In orthodontic treatment process
more than 0.5mm	- Noncompliance patient
- Acceptable good oral hygiene	
- Informed consent obtained	

Sample size calculation was done as the equation shown below;

$$n = \frac{[z_{\frac{\alpha}{2}} + z_{\beta}]^2 \sigma^2}{(\mu - \mu_0)^2}$$

The α and β values utilizing were 0.05 and 0.20 respectively.

The values of μ, μ_0,σ are 48.65, 71 and 29.25 respectively, which obtained from the study of similar design.[5]

$$n = \frac{[1.96+0.84]^2(29.25)^2}{(48.65-71)^2}$$

n = 13.43

From the calculation, the sample size of more than 14 should be adequate to detect the significant difference between groups. Therefore, a randomized group was created consisting of 16 patients.

Materials

Table 2 Materials used in this study

Material	**Manufacturer**
Ultrapak #000	Ultradent
Ultrapak #0	Ultradent
Ultrapak #1	Ultradent
Recestyptine solution	Septodont
Express XT Putty Soft	3M ESPE
Express XT Light Body	3M ESPE
Express XT Regular Body	3M ESPE
Jeltrate	Dentsply

Imprint bite registration material	3M ESPE
Protemp Crown	3M ESPE
Rely X Temp NE	3M ESPE
Lava Plus High Translucency Zirconia ingot	3M ESPE
NX3 Nexus cement	Kerr

Apparatus

Table 3 Apparatus used in this study

Material	**Manufacturer**
3M True Definition scanner	3M ESPE
Stereomicroscope DL 700	OLYMPUS

All patients had at least six appointments. Details of each appointment were described as followed.

First Appointment: Screening

In this appointment, oral examination and periapical radiograph were performed to screen the patients following inclusion and exclusion criteria. Furthermore objective and method of the study, also benefit that patients would

receive, were also explained to the patient in this visit. Patients had a chance to ask for more details and decided whether to join in the study or not.

Second Appointment: Crown Preparation

Prior to the crown preparation procedure, shade selection was done. If the tooth was still vital, patients would receive local anesthesia by infiltration or inferior alveolar nerve block, depended on area of the tooth before tooth preparation for all-ceramic crown. On the other hand, if the tooth was already root canal treated, local anesthesia would be given before retraction cords were placed. Crown preparation finishing on every patient was done by only one clinician with more than 20 years experience. The tooth was prepared for monolithic full-zirconia crown using diamond bur D2, D8, and D16 (Intensiv, Switzerland). Dimensions of preparation were done as follows; occlusal reduction 1.5mm, buccal reduction 1.5mm, and lingual reduction 1.0mm. The preparation had a total occlusal convergence angle of around 10°.

All teeth were prepared with rounded shoulder margin 1.0mm. Margin of the preparation was at the gingival level or under not more than 0.5mm. The preparation was refined using superfine diamond bur (Intensiv, Switzerland).

Third Appointment: Impression Making and Questionnaire

In this appointment, temporary crown was removed and cleaned. Before making the impression either by intraoral digital scanner or additional silicone, retraction cords soaked with topical hemostatic agent (Recestyptine; Septodont, France) were packed into gingival sulcus using double-cord technique. The first cord was retraction cord #00 (Ultrapak; Ultradent, USA), while the second one was retraction cord #0 or #1 (Ultrapak; Ultradent, USA), depended on the sulcus depth. The top cord was removed prior to impression making, while the first cord was left in place. The sequence of impression making either begins with intraoral digital impression or conventional silicone impression was randomized, using randomization program to ensure that there were 8 patients begin with digital impression and 8 patients vice versa

For intraoral digital impression, the procedure was conducted using 3M True Definition Scanner as manufacturer's instructions. Begin with lightly coat the preparation, adjacent teeth, and also opposing teeth with titanium dioxide powder. Then the teeth were scanned from the prepared tooth and adjacent teeth, opposing teeth, and last patient's occlusion record. The procedure was conducted by only one trained dentist who got the accreditation for using 3M True Definition Scanner from 3M ESPE, Thailand. Digital intraoral impression files were automatically sent to the 3M-

connection center where the technician in 3M company did the further investigation if that digital impression was in a good quality, which was a normal protocol.

For conventional impression, the procedure was performed according to the recommensations of Perakis N. et al.: 2 types of PVS (Express XT Putty Soft and Express Light Body; 3M ESPE, USA) were used with a one-step/double-mix impression technique.[33] The tray was inserted into patient's mouth and wait for 5 minutes in order to make the impression. After that, the impression was evaluated for any defect such as void, bubble, and tear. If impression had any of these defects, it will be redone.

The impression on antagonist arch was made using irreversible hydrocolloid (Jeltrate; Dentsply, USA) and bite-registration was done with Imprint bite registration material (3M ESPE, USA). Only one clinician conducted all of the impression procedures.

The prepared tooth was provisionalized using existing temporary crown cemented with temporary cement zinc oxide non-eugenol.

Patients' Perception Questionnaire

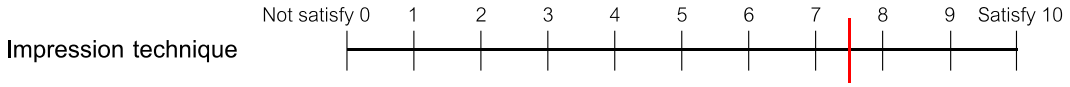
After crown impression making with both techniques was finished, patients were asked to answer 6 questions relating to perception on each topic. VAS scale with line of 10cm in length was utilized for the answer part. The questionnaire format was as follows;

Questionnaire for Patient

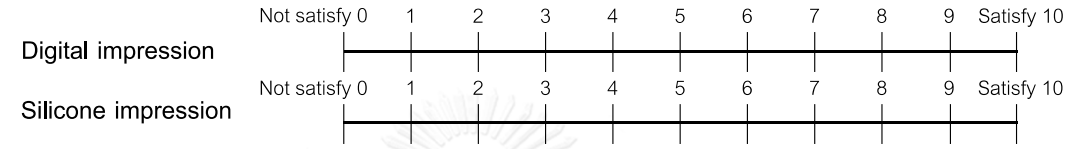
Name _____ Sex _____ Age _____ Time of impression _____

Patients' perception

Example : You satisfy with the impression technique related to that topic, but still not fully satisfy, and want to give a mark of 7.5 from 10. You should give a mark on the line as show below.

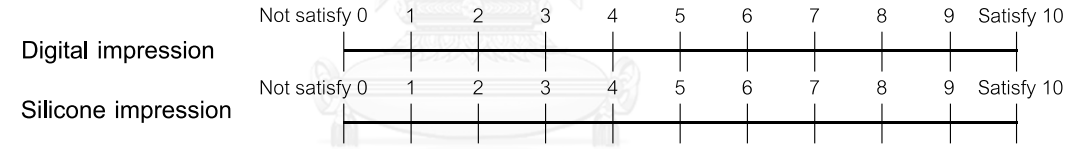


1. Time involved

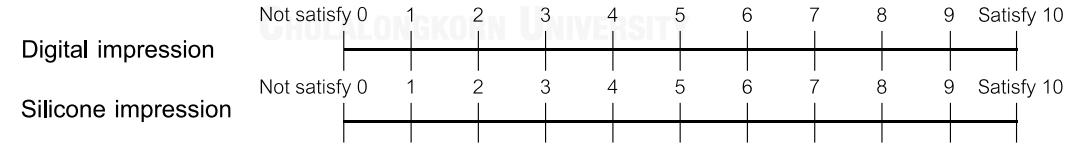


2. Taste/Smell

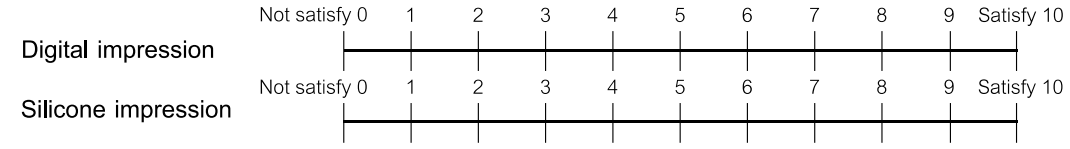
3. Bite registration



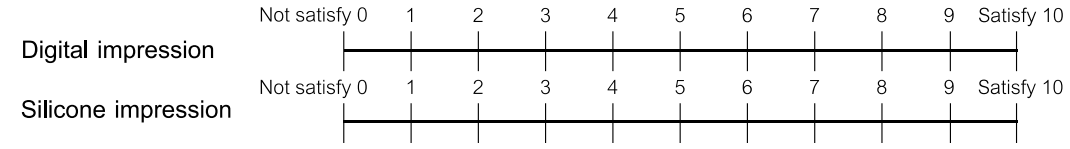
4. Size of impression tray/scanner



5.Gag reflex



6. Overall preference



แบบสอบถามผู้ป่วย

ชื่อ _____ เพศ _____ อายุ _____ ครั้งที่พิมพ์ _____

ความพึงพอใจของผู้ป่วย

ตัวอย่าง : ผู้ป่วยค่อนข้างมีความพึงพอใจต่อวิธีการพิมพ์ปาก แต่ยังไม่ถึงระดับชอบมาก โดยต้องการให้คะแนน 7.5 จากคะแนนเต็ม 10 ขอให้ผู้ป่วยขีดเส้นแสดงคะแนนที่ให้ดังตัวอย่างข้างล่าง

วิธีการพิมพ์ปาก

1. เวลาที่ใช้

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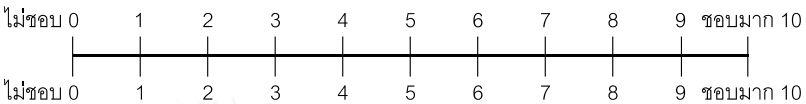

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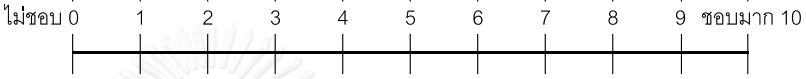
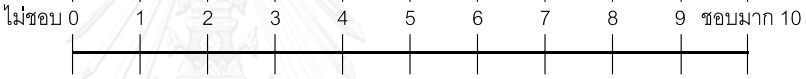


2. รสชาติ/กลิ่น

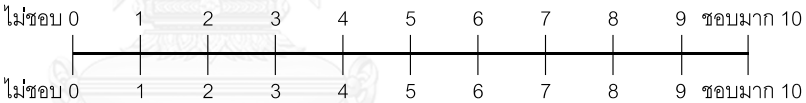
เครื่องพิมพ์ปากดิจิตอล

วัสดุพิมพ์ปากซิลิโคน



3. การบันทึกการสบฟัน

เครื่องพิมพ์ปากดิจิตอล



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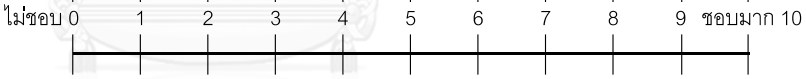
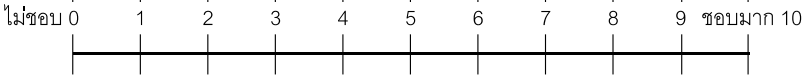


4. ขนาดของถาดพิมพ์ปาก/หัวอ่านเครื่องพิมพ์ปากดิจิตอล

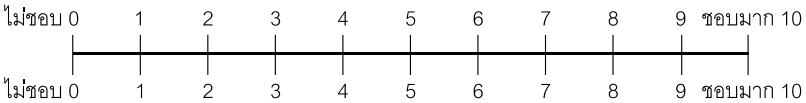
เครื่องพิมพ์ปากดิจิตอล

วัสดุพิมพ์ปากซิลิโคน



5. กระตุ้นให้รู้สึกอาเจียน

เครื่องพิมพ์ปากดิจิตอล



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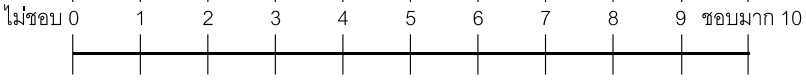
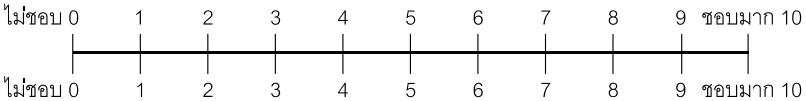


6. ความพึงพอใจโดยรวม

เครื่องพิมพ์ปากดิจิตอล



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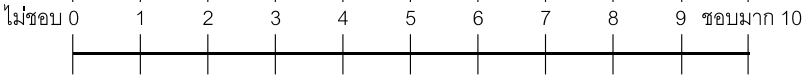

Zirconia Crown Fabrication

Each patient's digital impression files, PVS impression, impression of antagonist arch, bite registration, and prescription were sent to the dental laboratory for fabrication of a zirconia crown (Lava Plus High Translucency Zirconia; 3M ESPE, USA). Only one technician was assigned to fabricate all of the crowns used in this study.

The cast poured from PVS impression was scanned using laboratory scanner (3Shape's D900L Scanner; 3Shape, Denmark). Digital files from both groups were utilized to design crowns by 3Shape Dental System program. All crowns were milled as full monolithic zirconia crowns using hiCut milling machine (Hint-ELs, Germany).

Fourth Appointment: Clinical Crown Evaluation and Silicone Replica Production

At the crown try-in appointment, the provisional crown was removed and the prepared tooth was cleaned using rubber cup with pumice. Standard clinical crown try-in procedure was conducted as follows; proximal contact(s), followed with occlusal contact checked and adjusted if needed prior to the production of silicone replica. The need of adjustment was also recorded. Periapical radiographs of each crown were made with parallel technique to ensure quality of the crown. If the crown was clinically acceptable, the silicone replica would be created, if not, impression would be redone followed by patients' perceptions questionnaire.

To create the silicone replica, light body silicone (Express Light Body Quick; 3M ESPE, USA) was mixed and loaded into the crown, which would be seated on the prepared tooth, then patient would be told to occlude the teeth on the gauze for three and a half minutes. Then, thin silicone layer adjacent to the crown was removed from the mouth (Fig.3A). In order to stabilize the thin silicone layer, light body silicone (Express Regular Body; 3M ESPE, USA) was mixed and lightly injected into the crown, waited to set for 5 minutes (Fig.3B), and was removed with the thin light body silicone layer from the crown as one piece (Fig.3C).

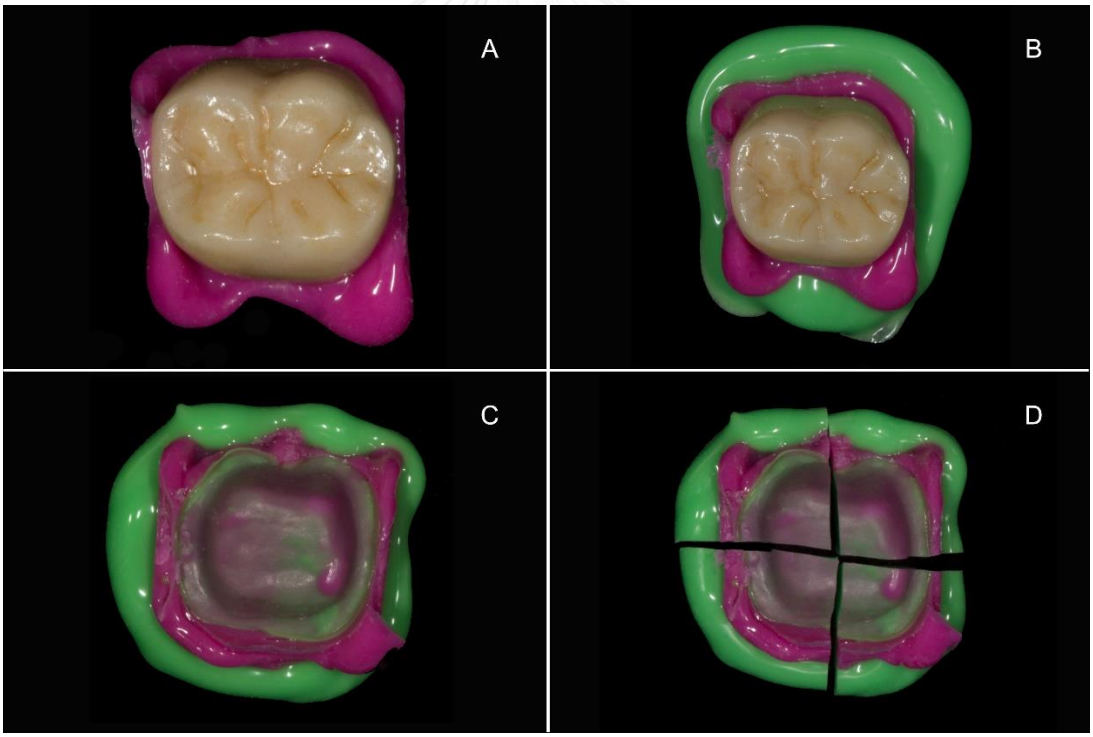

Figure 3 Process of creating silicone replica

Figure 3A Thin silicone layer in crown,

Figure 3B Stabilized thin silicone layer with another silicone layer,

Figure 3C Finished silicone replica, and Figure 3D Four sections of silicone replica

Silicone Replica Thickness Measurement

The factor focused in this study was silicone replica thickness at the margin represented clinical marginal gap. Silicone replica was hold and cut perpendicularly to the occlusal surface by surgical blade no.15 into four sections, mesiodistally and buccolingually as shown in fig.3D. Each section was measured for two sides of margin (buccal, mesial, lingual, distal, depended on the section) under stereomicroscope (Olympus DL 700; Olympus, Japan) at 40x magnification, 3 times within 8-16 hours interval between each measurement, by one blinded examiner. Figure 4 showed area of marginal gap in silicone replica as seen under stereomicroscope.

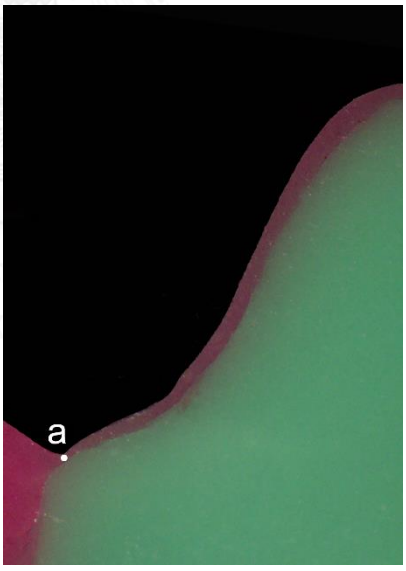

Figure 4 Silicone replica viewed under stereomicroscope

with area of marginal gap width measurement (a)

There were two groups with 16 specimens each, resulting in 128 sections and 768 marginal measurements of silicone replicas as shown in Table 4.

Table 4 Specimen groups and details

Group	**Detail**	**Numbers of measurement**			
		Buccal	**Mesial**	**Lingual**	**Distal**
Group 1 (n = 16)	Silicone replicas from CAD/CAM zirconia crowns fabricated from intraoral digital impression	16x2x3 = 96	16x2x3 = 96	16x2x3 = 96	16x2x3 = 96
Group 2 (n = 16)	Silicone replicas from CAD/CAM zirconia crowns fabricated from silicone impression	16x2x3 = 96	16x2x3 = 96	16x2x3 = 96	16x2x3 = 96

Fifth Appointment: Crown Cementation

After silicone replica thickness measurement from both impression techniques was performed, crown with less average marginal gap was cemented to the prepared tooth using resin cement (NX3 Nexus cement; Kerr, USA).

Sixth Appointment: Recheck

Two weeks after crown cementation, patients were appointed to come back for recheck. Gingival health, proximal contact(s) and occlusal contact should be in good condition. If not, the problem would be corrected and recheck again in 2 weeks.

Statistical Analysis

Data were analyzed with statistical software (SPSS 23.0; SPSS). Intra-examiner reliability was evaluated by calculating intraclass correlation coefficient (ICC) from data of marginal gap of the same site measured 3 times. Data of patients' preferences and marginal gap were analyzed by Wilcoxon signed-rank test. Results with *P*-value < .05 were considered statistically significant difference.

CHAPTER IV

RESULTS

Subjects

Sixteen patients were included in this study, 13 female and 3 male. Average age of subjects was 39 years. In this group, 9 patients had the indication for crown in maxillary arch and 7 in mandibular arch, 13 for first molar and 3 for second molar.

Patients' Preferences

Regarding overall preference, 15 of 16 patients preferred digital impressions to PVS impressions. The highest VAS score (8.64 $\pm$ 1.51) of patients' perception was found in the topic of gag reflex, followed by taste/smell (8.42 $\pm$ 1.48) for digital impression. On the other hand, the lowest VAS score (6.26 $\pm$ 1.51) was presented in the topic of size of impression tray, followed by gag reflex (6.32 $\pm$ 2.74) for PVS impression.

The data of patients' perception were not normally distributed using Kolmogorov-Smirnov analysis. Therefore, Wilcoxon signed-rank test was utilized to compare patients' preference on each topic. The patients' preference for digital impressions was statistically significantly greater than for PVS impressions at a 95% confidence level in every aspect ($P<.05$). The means and standard deviations of the

patients' perceptions in VAS scores, as well as P-values for each topic are shown in Table 5 and Figure 5.

Table 5 Patients' perception (mean ± standard deviation, VAS score and P-value)

Topic	**Impression technique**		***P*-value**
	PVS	**Digital**	**(2-tailed)**
Time involved	6.94 ± 0.99	7.91 ± 1.43	.015
Taste/Smell	6.84 ± 1.84	8.42 ± 1.48	.002
Bite registration	7.73 ± 1.53	8.27 ± 1.99	.026
Size of impression tray/ Scanner head	6.26 ± 1.51	7.56 ± 2.12	.014
Gag reflex	6.32 ± 2.74	8.64 ± 1.51	.004
Overall preference	6.78 ± 1.42	8.27 ± 1.92	.007

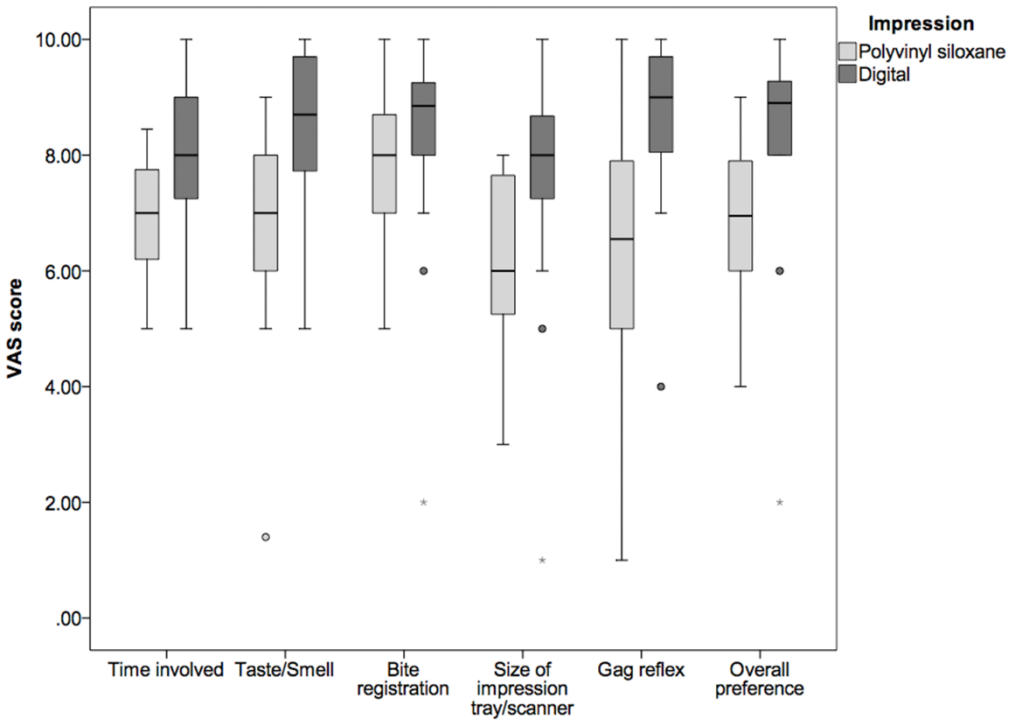

Figure 5 Patients' perception boxplot

Clinical Crown Evaluation

For both proximal and occlusal contacts, only good or too heavy contact was found. The data on adjustment were collected with an adjustment duration in minute. In situations that required no adjustment, the time was recorded as 0 minute (Table 6).

Table 6 Clinical crown evaluation: Number of crowns needed adjustment and average adjustment duration (minute)

Impression technique	Proximal contact(s)		Occlusal contact	
	Adjustment needed	Adjustment duration	Adjustment needed	Adjustment duration
PVS	12	3.6	12	8.7
Digital	8	2.3	5	3.6

Clinical Marginal Gap

The analysis using data of marginal gap of the same site measured 3 times showed an ICC of .996, which is considered to indicate excellent intra-examiner reliability. The highest marginal gap (71.67 $\pm$ 38.57) was found in lingual side of crowns from PVS impression, while the lowest marginal gap (38.99 $\pm$ 36.82) was found in mesial side of crowns also from PVS impression.

The data on marginal gap width were not normally distributed by Kolmogorov-Smirnov analysis. Thus, Wilcoxon's signed-rank test with a confidence level of 95% was utilized. No significant differences in marginal gap widths between the PVS impression group and digital impression groups were found in all 4 sides measured. The results of means, standard deviations and P-values are shown in Table 7 and Figure 6.

Table 7 Marginal gap width (mean ± standard deviation, μm and P-value)

Sides	Marginal gap width		*P*-value
	PVS	Digital	(2-tailed)
buccal	61.96 ± 41.82	66.81 ± 26.28	.569
mesial	38.99 ± 36.82	42.66 ± 28.94	.363
lingual	71.67 ± 38.57	59.99 ± 39.70	.379
distal	52.55 ± 34.78	76.62 ± 32.16	.056

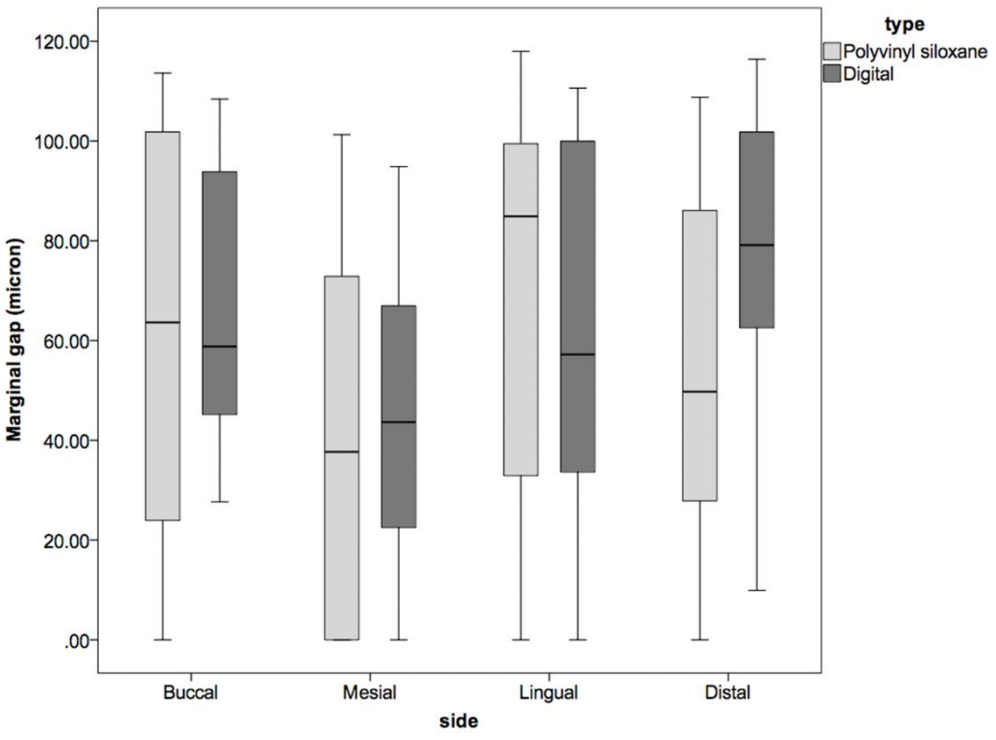

Figure 6 Marginal gap boxplot

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion

There was no significant difference in the clinical marginal fit of zirconia crowns between the digital and conventional groups; therefore, the first null hypothesis was accepted. However, the second null hypothesis was rejected because the VAS scores of patients' perceptions of digital impressions were significantly higher than those with PVS impressions.

Conclusions regarding the precision of intraoral scanners still could not be drawn due to the differences in the results from each study.[4-9] This diversity might arise from the dissimilarity of the scanners from each brand, for example, working principles, light sources, imaging types, and the necessity of coating. Furthermore, the research design and technique utilized might also influence the results.

The scanner used in this study requires that the teeth and gingiva be powdered before scanning. Some researchers have hypothesized that the thickness of the powder could reduce the accuracy of the impression. However, a recent study demonstrated that the powder did not reduce the precision or adds any value.[43] Moreover, an in vivo study comparing the marginal fit of lithium disilicate crowns fabricated using a Cerec 3D Bluecam scanner with titanium dioxide powder and an E4D

Laser scanner without powder found a significantly smaller vertical misfit in crowns fabricated by using the Cerec 3D Bluecam scanner.[23] Therefore, other factors might play more important roles in the accuracy of intraoral scanners, rather than the coating powder.

In accordance with the results of the present study, a recent in vitro study found similar marginal accuracy of CAD/CAM lithium disilicate crowns fabricated by using PVS impressions and two intraoral scanners: the Lava COS and iTero.[6] However, an in vivo study with a similar design to the present study, conducted in 20 patients, found a better marginal fit of zirconia copings fabricated from digital impressions (Lava COS) than from PVS impressions.[5] The findings might have differed due to the differences in the expertise of the operators and/or lab technicians for each impression technique. Moreover, the study reported a median marginal gap of 71μm, ranging from 0μm up to 170μm for the conventional group and 49μm, ranging from 0μm up to 110μm for the digital group. Compared with the results of the present study, not much difference was seen. Therefore, the contrast in the conclusions might also have arisen from the differences in the selection of statistics.

The cut-off value of the marginal gap was determined by McLean and Fraunofer to be clinically acceptable at less than 120 μm.[17] The zirconia crowns in this study, in both the digital and conventional groups, demonstrated clinical marginal gaps of less than 120 μm. Therefore, it could be concluded that both intraoral scans and PVS

impressions could be used effectively. This conclusion was in agreement with many previous studies that found the marginal gaps of zirconia copings/crowns fabricated from both techniques to be clinically acceptable.[4, 5, 7, 9]

In this study, making the prostheses crowns, not just copings, could provide extended benefit from the research. Not only could the margin be evaluated but also the proximal contacts and the occlusal contacts. The results demonstrated fewer crowns that needed adjustment for both proximal and occlusal contacts in the digital group. Moreover, the average time used for occlusal adjustment was much less in the digital group. Thus, this study showed a trend toward better proximal and occlusal contact precision obtained from digital impressions. This advantage might be the result of eliminating the process from the lab. To create the occlusion, the lab technician would use the bite registration silicone to guide the occlusion, which might have led to some error, either from the lab technician or from the registration material itself. While, intraoral scanner records the occlusion when the patient actually occludes in maximum intercuspation. It might nevertheless have been the results of normal lab processes here that tended to overestimate the occlusion when checking the crown on the cast. Compared to a previous study with the same design using Lava COS and PVS impressions, the results here were partly not in accordance. The previous study found that crowns from intraoral scans showed better interproximal contact but were equal with regard to occlusion.[5]

Every manufacturer claims that its digital impressions are more comfortable for patients; nevertheless, only a few studies have been conducted to evaluate this subject. The results here were in accordance with other studies that found digital impressions to be the technique preferred by patients.[18-20] However only one detail was not in agreement in a study conducted in 2013 that compared patients' preferences for polyether impressions versus digital impressions.[19] In this study, a 7-item questionnaire was developed, consisting of the preparation, time involved, taste, bite registration, impression tray/scan head, gag reflex, and overall preference. The results demonstrated that the patients significantly preferred digital impressions over polyether impressions in every subject except for the time involved.[13] However, in the present study, the patients significantly preferred digital impressions over PVS impressions in every topic, including the time involved. In fact, the time involved in both impression techniques was approximately the same. The reason that patients perceived digital impressions to be quicker might be because it was their first experience with the intraoral scanner. In addition, using PVS impression material, there was a waiting time for the material to set, and patients might perceive that time to be troublesome.

One limitation was the sample size. Increasing the sample size will also increase the statistical power. Another limitation was that only a silicone replication technique could be utilized for the marginal gap measurement technique due to the in vivo

design. With this technique, only a few marginal gap points can be measured, which was weaker than the direct measurement technique.15 Moreover, this study evaluated only one type of prosthesis. Studies assessing partial fixed dental prostheses fabricated from digital impressions should be conducted.

Conclusions

Within the limitations of this study, it could be concluded that the clinical marginal fit of CAD/CAM zirconia crowns fabricated from digital impressions and PVS impressions were not different and were both clinically acceptable. In this study, the patients considerably preferred digital impressions.

Clinical Implications

Both digital impressions and PVS impressions provided clinical acceptable crown marginal fit. Moreover, the patients significantly preferred digital impressions to the conventional technique.

Declaration of Conflicting Interest

The authors declare that there is no conflict of interest.

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APPENDIX

Appendix A. Study Protocol and Consent Form Approval

No. 081/2014

Study Protocol and Consent Form Approval

The Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand has approved the following study to be carried out according to the protocol and patient/participant information sheet dated and/or amended as follows in compliance with the **ICH/GCP.**

Study Title	: CLINICAL MARGINAL FIT AND PATIENT'S PREFERENCES IN IMPRESSION TECHNIQUES USING DIGITAL INTRAORAL SCANNER VERSUS POLYVINYLSILOXANE MATERIAL
Study Code	: HREC-DCU **2014-070**
Study Center	: Chulalongkorn University
Principle Investigator	: Dr. Nawapat Sakornwimon
Protocol Date	: October 2, 2014
Date of Approval	: December 2, 2014
Date of Expiration	: December 1, 2016

V. Lertchirakarn.

(Associate Professor Dr. Veera Lertchirakarn)
Chairman of Ethics Committee

K. Bhalang

(Assistant Professor Dr. Kanokporn Bhalang)
Associate Dean for Research

*A list of the Ethics Committee members (names and positions) present at the Ethics Committee meeting on the date of approval of this study has been attached (upon requested). This Study Protocol Approval Form will be forwarded to the Principal Investigator.

Approval is granted subject to the following conditions (see back of this approval)

Appendix B. Patients' Perception on Time Involved

Patient	VAS score	
	PVS impression	Digital impression
1	5.5	9.5
2	8	10
3	6	8.45
4	7.4	9
5	8	9
6	8	5
7	8.45	8.15
8	7	8
9	6	7
10	7.5	8
11	6.4	7.5
12	5	5
13	7	8
14	7	7
15	7.45	9.4
16	8	8.7
mean	6.94	7.91

Appendix C. Patients' Perception on Bite Registration

Patient	VAS score	
	PVS impression	Digital impression
1	9.5	9.5
2	10	10
3	9	10
4	8.4	8
5	8	9
6	8	2
7	7.45	9
8	7	8
9	6	7
10	5	9
11	8	8.7
12	5	6
13	7	9
14	10	10
15	8	8.7
16	7.4	8,4
mean	7.73	8.27

Appendix D. Patients' Perception on Size of Impression Tray/Scanner head

Patient	VAS score	
	PVS impression	Digital impression
1	7.5	9.5
2	8	8
3	6	8
4	6	9
5	6	9
6	8	1
7	7.1	8.7
8	5	7
9	4	5
10	5.5	8
11	7.8	8.65
12	7	8
13	5	6
14	6	8
15	3	10
16	8.25	7.1
mean	6.26	7.56

Appendix E. Patients' Perception on Gag Reflex

Patient	VAS score	
	PVS impression	Digital impression
1	10	10
2	10	10
3	8	10
4	6	9.3
5	5	9
6	5	4
7	7.1	8.1
8	5	8
9	3	8
10	1	9
11	7.8	8.7
12	6	7
13	2	9
14	10	10
15	7.4	9.1
16	7.8	9
mean	6.32	8.64

Appendix F. Patients' Overall Preference

Patient	VAS score	
	PVS impression	Digital impression
1	6.6	9.5
2	9	10
3	8.5	9.6
4	7.3	9
5	6	9
6	8	2
7	8.1	9.15
8	6	8
9	5	8
10	4	8
11	7.5	8.5
12	5	6
13	6	8
14	6	9
15	7.4	9.4
16	8.1	9.2
mean	6.78	8.27

Appendix G. Proximal Contact Adjustment Duration (minute)

Crown	Adjustment duration (minute)	
	PVS impression	Digital impression
1	6	3
2	5	5
3	7	2
4	5	0
5	2	0
6	2	0
7	2	0
8	8	8
9	8	5
10	8	10
11	3	3
12	0	2
13	0	0
14	0	0
15	0	0
16	2	0
mean	3.6	2.3

Appendix H. Occlusal Contact Adjustment Duration (minute)

Crown	Adjustment duration (minute)	
	PVS impression	Digital impression
1	10	0
2	0	0
3	10	0
4	0	0
5	15	0
6	0	0
7	0	0
8	8	0
9	5	0
10	15	8
11	10	10
12	10	10
13	15	10
14	20	0
15	2	0
16	20	20
mean	8.7	3.6

Appendix I. Buccal Marginal Gap (micron)

Site	PVS impression				Digital impression			
	Measurement number				Measurement number			
	1	2	3	mean	1	2	3	mean
1	0.00	0.00	0.00	0.00	70.00	64.30	68.44	44.25
2	0.00	0.00	0.00	0.00	72.92	76.62	74.34	74.63
3	125.90	119.60	115.20	120.23	99.00	99.40	94.60	97.67
4	109.00	102.40	102.20	104.53	96.60	92.60	97.80	95.67
5	60.72	57.07	52.48	56.76	107.6	98.27	95.36	100.41
6	58.31	62.32	56.22	58.95	95.83	73.50	74.99	81.44
7	73.37	84.75	79.81	79.31	48.40	35.59	36.34	40.11
8	85.59	92.05	88.98	88.87	47.02	39.79	39.79	42.20
9	101.10	113.40	99.15	104.55	106.10	110.00	111.20	109.10
10	104.60	99.15	102.70	102.15	92.89	96.45	102.70	97.35
11	110.30	95.83	95.83	100.65	53.67	51.80	52.77	52.75
12	103.90	98.54	97.35	99.93	52.26	47.21	54.66	51.38
13	75.90	76.72	81.00	77.87	42.20	38.65	39.79	40.21
14	78.83	67.26	77.18	74.42	31.78	29.33	34.22	31.78
15	53.67	58.87	57.69	56.74	109.90	116.00	107.20	111.03
16	62.32	61.11	63.08	62.17	103.00	107.60	106.80	105.8
17	29.84	39.49	35.25	34.86	96.30	82.46	83.61	87.46
18	40.46	40.46	43.32	41.41	116.70	107.20	107.50	110.47
19	109.20	112.40	118.80	113.47	35.59	38.65	40.68	38.31
20	117.70	112.70	110.80	113.73	78.11	71.27	73.54	74.31
21	56.86	57.95	57.54	57.45	45.47	39.42	37.31	40.73
22	61.31	62.85	56.43	60.20	38.03	38.03	42.76	39.61
23	74.34	65.82	75.30	71.82	80.41	76.52	78.11	81.11

24	57.01	69.23	65.09	63.78	74.83	82.97	81.26	79.69
25	17.28	22.54	18.62	19.48	59.53	58.10	61.11	58.58
26	0.00	0.00	0.00	0.00	56.70	62.85	60.47	60.01
27	107.80	103.20	111.20	107.40	35.00	27.00	29.44	30.48
28	113.20	112.80	109.90	111.97	22.54	27.33	24.57	24.81
29	0.00	0.00	0.00	0.00	57.01	58.28	57.01	57.43
30	0.00	0.00	0.00	0.00	59.12	60.37	54.93	58.14
31	0.00	0.00	0.00	0.00	44.61	44.00	41.84	43.48
32	0.00	0.00	0.00	0.00	57.54	51.80	55.15	54.83

Appendix J. Mesial Marginal Gap (micron)

Site	PVS impression				Digital impression			
	Measurement number				Measurement number			
	1	2	3	mean	1	2	3	mean
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	120.40	102.30	94.07	105.59
3	24.44	22.00	24.57	23.67	36.34	39.49	38.26	38.03
4	0.00	0.00	0.00	0.00	29.44	21.03	24.07	24.85
5	59.00	59.20	51.50	56.57	56.22	54.28	53.83	54.78
6	59.50	52.90	58.10	56.83	55.85	57.22	63.41	58.83
7	57.07	51.57	48.21	52.28	66.72	69.57	56.18	64.16
8	44.07	43.73	30.49	39.43	64.72	68.49	66.00	66.39
9	77.60	75.00	72.30	74.97	78.22	114.8	96.21	96.41
10	78.50	75.70	70.90	75.03	99.61	66.91	113.4	93.31
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	72.39	67.12	77.18	72.23	72.39	71.27	70.93	71.53
14	72.39	67.12	68.18	69.23	73.33	73.37	75.82	74.17
15	0.00	0.00	0.00	0.00	34.74	29.84	35.25	33.28
16	0.00	0.00	0.00	0.00	46.12	52.88	43.52	47.51
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	53.61	51.97	60.52	55.37	33.25	31.11	29.44	31.27
20	55.74	55.74	58.87	56.78	38.03	43.52	41.63	41.06
21	77.30	76.37	76.76	76.81	0.00	0.00	0.00	0.00
22	91.85	96.21	89.75	92.60	0.00	0.00	0.00	0.00
23	19.56	14.67	14.67	16.30	29.44	24.93	29.44	27.94

24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	36.34	30.24	30.92	32.50
26	0.00	0.00	0.00	0.00	28.51	30.63	29.54	29.56
27	81.95	77.69	84.29	81.31	73.90	70.89	66.05	70.28
28	89.65	87.46	86.42	87.84	74.34	71.00	72.68	72.67
29	26.33	28.57	28.51	27.80	49.19	40.46	44.94	44.86
30	32.89	31.30	29.44	31.21	48.89	46.96	50.87	48.91
31	104.40	100.80	97.84	101.01	60.72	67.92	71.39	66.68
32	104.00	101.10	99.53	101.54	74.51	64.54	72.56	70.54

Appendix K. Lingual Marginal Gap (micron)

Site	PVS impression				Digital impression			
	Measurement number				Measurement number			
	1	2	3	mean	1	2	3	mean
1	28.51	32.80	32.80	31.37	49.50	45.67	45.07	46.75
2	42.76	36.34	37.39	38.83	36.34	30.92	33.25	33.50
3	55.67	54.32	57.13	55.71	59.07	65.23	64.16	62.82
4	72.39	66.18	57.54	65.37	111.80	116.70	116.70	115.07
5	113.20	115.10	114.50	114.27	114.00	119.10	105.20	112.77
6	110.10	114.90	115.10	113.37	109.30	107.20	108.70	108.40
7	59.68	67.12	67.12	64.64	49.50	50.87	55.42	51.93
8	88.98	87.63	84.29	86.97	60.52	66.72	66.05	64.43
9	107.60	110.70	113.80	110.7	51.33	54.11	55.00	53.48
10	123.90	123.00	128.90	125.27	55.74	55.74	47.31	52.93
11	118.70	119.10	119.50	119.1	115.10	110.00	100.20	108.43
12	118.70	113.80	113.80	115.43	102.70	100.30	107.60	103.53
13	0.00	0.00	0.00	0.00	51.33	53.78	53.83	52.98
14	0.00	0.00	0.00	0.00	63.60	56.22	58.67	59.50
15	96.21	104.00	112.60	104.27	90.18	86.42	90.74	89.11
16	106.90	93.08	101.70	100.56	57.07	60.52	60.52	59.37
17	98.99	97.35	94.36	96.90	96.86	96.86	98.66	97.46
18	90.18	88.98	89.51	89.56	105.90	101.40	105.00	104.10
19	101.10	99.74	101.90	100.91	29.84	26.44	25.17	27.15
20	92.92	86.49	96.86	92.09	31.30	29.44	29.84	30.19
21	95.11	92.76	101.40	96.42	0.00	0.00	0.00	0.00
22	87.76	89.65	85.03	87.51	0.00	0.00	0.00	0.00
23	88.17	84.75	83.04	85.32	0.00	0.00	0.00	0.00

24	85.38	80.70	81.26	82.45	0.00	0.00	0.00	0.00
25	82.13	80.18	84.11	82.14	100.30	96.86	97.04	98.07
26	97.04	85.56	86.49	89.70	97.78	102.00	100.80	100.19
27	0.00	0.00	0.00	0.00	26.44	22.54	22.54	23.84
28	28.51	30.92	33.25	30.89	53.67	56.28	50.39	53.45
29	24.44	32.89	33.96	30.43	0.00	0.00	0.00	0.00
30	29.54	32.80	30.63	30.99	0.00	0.00	0.00	0.00
31	22.54	25.17	24.07	23.93	107.50	102.10	104.40	104.67
32	28.51	27.33	29.44	28.43	102.10	111.00	103.70	105.60

Appendix L. Distal Marginal Gap (micron)

Site	PVS impression				Digital impression			
	Measurement number				Measurement number			
	1	2	3	mean	1	2	3	mean
1	24.20	20.74	17.28	20.74	71.27	62.32	61.11	64.90
2	41.56	31.87	33.96	35.79	62.32	60.37	60.37	61.02
3	36.34	35.00	28.51	33.28	0.00	0.00	0.00	0.00
4	36.67	30.63	28.61	31.97	19.53	18.88	21.03	19.81
5	96.05	101.30	95.08	97.48	64.54	72.39	69.53	68.82
6	75.50	82.71	80.93	79.71	80.07	77.18	76.52	77.92
7	69.53	63.98	67.61	67.04	113.80	116.20	115.10	115.03
8	48.52	49.19	51.85	49.85	105.00	112.20	117.00	111.40
9	78.26	73.38	77.20	76.28	119.40	118.50	119.00	118.97
10	85.38	93.50	93.50	90.79	38.18	66.77	64.14	56.36
11	38.65	41.84	46.70	42.39	110.00	110.20	119.80	113.33
12	44.00	39.19	34.22	39.13	115.00	120.40	118.00	117.8
13	100.20	82.46	93.08	91.91	102.70	110.00	105.10	105.93
14	100.50	102.10	99.26	100.62	97.81	97.78	105.10	100.23
15	0.00	0.00	0.00	0.00	56.86	53.67	57.95	56.16
16	0.00	0.00	0.00	0.00	90.18	93.08	90.97	91.41
17	0.00	0.00	0.00	0.00	103.90	116.40	108.20	109.5
18	0.00	0.00	0.00	0.00	92.76	91.33	90.71	91.60
19	19.56	15.46	16.40	17.14	65.23	67.61	66.77	66.54
20	10.93	15.46	14.25	13.55	63.98	64.16	71.06	66.40
21	90.44	97.32	90.44	92.73	121.40	113.40	117.60	117.47
22	100.30	98.54	102.70	100.51	114.00	120.80	111.20	115.33
23	43.32	44.07	42.69	43.36	60.37	67.79	63.56	63.91

24	61.26	57.22	61.26	59.91	59.12	60.13	61.69	60.31
25	65.68	66.50	67.92	66.70	43.73	42.69	49.19	45.20
26	61.69	57.95	67.92	62.52	53.67	59.68	52.31	55.22
27	114.40	107.60	111.30	111.10	13.16	17.80	14.87	15.28
28	106.50	102.40	110.40	106.43	17.80	15.46	13.16	15.47
29	24.44	22.00	27.00	24.48	83.43	81.37	75.30	80.03
30	34.31	27.33	29.44	30.36	88.58	88.58	89.65	88.94
31	47.02	48.89	48.21	48.04	90.94	91.89	92.92	91.92
32	50.87	44.87	47.21	47.65	92.92	87.52	88.14	89.53

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