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Comparison of marginal fit of lithium disilicate crowns fabricated with CAD-CAM technology using conventional impressions and two intra-oral digital scanners.

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COMPARISON OF MARGINAL FIT OF LITHIUM DISILICATE CROWNS FABRICATED WITH CAD-CAM TECHNOLOGY USING CONVENTIONAL IMPRESSIONS AND TWO INTRA-ORAL DIGITAL SCANNERS

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DEDICATION

This is dedicated to my parents

Albert G. Rogers, Jr.
and
Beth A. Halla

whose sacrifices for my education and constant support have given me courage to pursue my passion.

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I would like to thank my advisor, Dr. Tamer Abdel-Azim for guiding me through the research process and for his patience while teaching me the laboratory and clinical techniques used in this experiment. In addition, I would like to thank Dr. Eiad Elathamna, Dr. Amirali Zandinejad, Dr. Dean Morton, and Dr. Thomas Starr for their assistance, guidance, and feedback. Also, I would like to thank my family in Columbus, OH: Albert Jr., Sheri, Doc, Albert III, Nicole, and Noah Rogers, and Beth and Ben Halla. They have helped me to remain focused during my time completing this degree. Lastly, I would like to thank Ellen, Phares, and Adrienne Steiner who are my “Louisville Family.” They have given me a home away from home, and have been a source of constant support.

ABSTRACT

COMPARISON OF MARGINAL FIT OF LITHIUM DISILICATE CROWNS FABRICATED WITH CAD-CAM TECHNOLOGY USING CONVENTIONAL IMPRESSIONS AND TWO INTRA-ORAL DIGITAL SCANNERS

Kelly E. Rogers

August 13, 2013

The use of digital impression techniques in dental crown fabrication is increasing. It is important these techniques yield prosthesis of equal or better accuracy compared to conventional techniques. This study compared marginal gap size in crowns fabricated by conventional and digital impression methods. One typodont maxillary right central incisor was prepared for an all-ceramic crown. Ten impressions were made with each method: conventional using polyvinyl siloxane impression material, digital impressions using the Lava C.O.S. (3M ESPE), and iTero (Cadent) intraoral scanning devices. Lithium disilicate crowns were fabricated and marginal gap measured for each using an optical microscope. There was no significant difference between average gap size in all groups. However, though not statistically significant, the conventional group average gap size was about 23µm larger compared to the digital groups. Within the limitations of this study, the digital and conventional impressions were found to produce crown crowns with similar marginal accuracy.

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INTRODUCTION

Full coverage crowns are one of the most common fixed prosthodontic treatments in the United States[1], and, for many years elastomeric impression materials have been used in their fabrication with success. Recent technological advancements have introduced alternatives to conventional impression methods through the use of Computer Aided Design-Computer Assisted Manufacturing (CAD-CAM) and intra-oral digital scanners. These new technologies may offer similar or better results compared to conventional methods.[2,3] Some benefits of CAD-CAM production may include a more standardized method of prosthesis fabrication and the use of highly homogenous materials. Additionally, the workflow associated with prosthesis fabrication by digital impression methods may offer benefits such as decreased length and number of appointments, and decreased material cost. For intra-oral scanning devices to be considered an acceptable alternative to conventional impressions methods, it is important that they yield crowns with similar or better clinical success. One factor that can predict clinical success is marginal gap discrepancy, which should be as minimal as possible. This study aims to compare the marginal gap discrepancy of Lithium disilicate single crowns fabricated by CAD-CAM technology using both conventional and digital impression techniques.

Dental Crowns: Conventional Crown Fabrication and IPS e.max CAD (Ivoclar-Vivadent)

A single dental crown is a fixed, full-coverage prosthesis cemented to a prepared tooth. It is made of a rigid, durable material that completely envelopes the visible tooth surface above the gum tissue. It is used to maintain the structural integrity of a weakened tooth, for example, one that may have undergone root canal treatment or received a large restoration, by acting as a coat of armor.[4]

To begin the process of fabricating a crown, the clinician must carefully prepare the tooth by removing parts of the enamel and underlying dentin using a diamond cutting instrument. In the process of removing tooth structure the clinician aims to shape the preparation so it will be able to withstand mechanical load during mastication. The clinician also aims to remove enough structure to make space for the prosthesis but not so much, as to jeopardize pulpal vitality, or the health of the underlying soft tissue that contains vessels and nerves.[4]

After the tooth is prepared an impression, or imprint, is made. The purpose of taking an impression is to obtain an exact negative three-dimensional replica of the prepared tooth, including the surrounding hard and soft tissues of the oral cavity.[5] In a conventional work-flow, the impression is then used to create a stone cast, or working model. The cast acts as an in vitro model of the prepared tooth and surrounding anatomy, and is used in the process of fabricating a crown. Dimensional accuracy, duplication of detail, hard material

surface/resistance to abrasion, and material strength are important aspects of a working cast.[6-17]

A crown is then designed to fit the prepared tooth on the cast. It is important that the cast be an accurate replica of the oral cavity and easy to use in the fabrication process for the final prosthesis to fit properly on the tooth.[18] Conventional impression methods, as described here, present a number of challenges including the time and facilities required to make them, storage, cataloging, and cast retrieval,[19] but this method is familiar to clinicians and easy to use.

After obtaining an accurate cast, the clinician must select a material for the final crown. There are many available materials from which the final prosthesis can be made, and a clinician must consider a number of factors when selecting the appropriate material for each patient. Some factors to consider when selecting a material are esthetics and mechanical reliability.

The desire for tooth-colored, highly esthetic restorations has grown significantly over recent years.[20] Metal-Ceramic crowns have been recorded to have 94% success rate over a ten year period,[24] but despite their high success, porcelains fired on metal frameworks do not provide optimal distribution of reflected light; reducing their esthetics.[22] All-ceramic crowns have been developed in response to the demand for highly esthetic restorations and are considered an esthetic and biocompatible alternative to metal.[23,24] All-ceramic

systems exhibit more potential shade matches,[25] and have been shown to have similar marginal accuracies compared to traditional metal based restorations.[26-28]

There are a number of methods that can be used in all-ceramic crown fabrication, for example, powder condensation, slip casting, hot pressing, and CAD-CAM.[24] One difficulty in using ceramics for crown fabrication is that they are brittle which reduces their mechanical reliability. In addition, they require increased effort and processing time compared to metal alloys and composites.[24] CAD-CAM technology and consequent technological advancements have introduced more mechanically reliable ceramic materials.[24]

CAD-CAM ceramic materials are available as pre-fabricated ingots, or blocks. Ingots are available partially sintered or densely sintered, depending on the material being used. Partially sintered ingots are more porous which enables decreased milling time, reduced risk of bulk fracture, and reduced wear on milling burs.[24] However, partially sintered ingots must be fully sintered after milling. This process may cause a small amount of shrinkage. This shrinkage must be accounted for by the prosthesis designing software.[24] Densely sintered, non-porous ingots are more difficult to mill, but they do not require additional sintering, which eliminates the possibility for error introduced when accounting for shrinkage during sintering.[24]

IPS e.max CAD (Ivoclar Vivadent, Amherst, NY) is an available partially sintered ingot for CAD-CAM crown fabrication, and is the material used in this study. The manufacturer recommends the use of IPS e.max CAD in anterior

restorations. IPS e.max CAD is a Lithium disilicate available as a glass-ceramic block (for use in CAD-CAM) used in fabrication of substructures or full contour restorations. There is a two-stage crystallization process for IPS e.max CAD blocks/restorations. In the first stage, Lithium metasilicate crystals are precipitated leading to a glass ceramic material with a crystal size range of 0.2-1.0 micrometers and about 40 percent Lithium disilicate crystals by volume.[29] The block in this stage has a characteristic blue-violet color and is easily milled; reducing wear on the milling burs and preventing damage to the material during machining. After the restoration has been milled in stage one, it is fired at 850°C in a vaccum during stage two. The metasilicate crystal phase dissolves completely to the resulting lithium disilicate glass ceramic structure with a fine-grained size of about 1.5 micrometers and about 70% crystal volume incorporated in a glass matrix.[30] When fired, the material will take on the selected tooth shade. The resulting flexural strength of the material is 360-400 MPa. In a study by Fasbinder, *et al.* in 2010 it was shown that single crowns fabricated with IPS e.max CAD performed well after 2 years of clinical service.

Marginal Gap

After the clinician selects the material that is most appropriate for the restoration, the final prosthesis is fabricated to fit the working cast. The crown is then cemented to the patient's prepared tooth. There is a small space between the surface of the prepared tooth and the internal surface of the crown (cement space). Near the gingiva this space is referred to as the marginal gap. Holmes et al. (1989) defines marginal gap as the measurement between the crown casting

and the prepared tooth at the margin.[31] This measurement does not take into account the possibility that the casting be over or under-extended in regards to the underlying preparation, Holmes et al. defines Absolute Marginal Discrepancy (AMD) as the hypotenuse of the two measures illustrated in **Figure 1.**

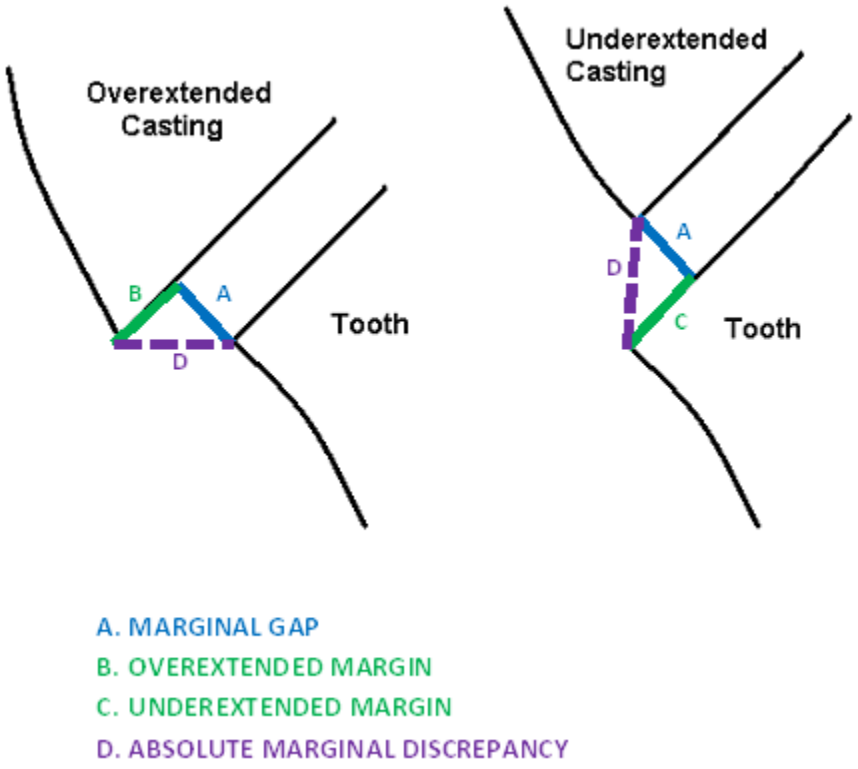


Figure 1. Marginal Discrepancy Measurements (Figure adapted from Holmes et al., 1989)

The marginal gap should be as minimal as possible for clinical success.[32] Poor marginal adaptation in fixed prosthesis leads to increased plaque retention and subsequent changes in the subgingival microflora leading to periodontal disease[33-36] and secondary caries.[37] Additionally, a large marginal gap leads to increased exposure of the luting agent to the oral environment which may cause increased microleakage and cement dissolution. [38,39] It has been shown that a

width of less than 120µm is clinically acceptable.[40,41] For CAD-CAM fabricated crowns the approximate acceptable marginal gap is less than 90µm.[42-44]

CAD-CAM Technology

In this study, a CAD-CAM workflow was used in the fabrication of IPS e.max crowns. CAD-CAM technology was introduced in the early 1980s and has grown to include numerous clinical applications. CAD-CAM milling machines have the capability to fabricate prostheses and working casts from many different types of materials. Currently, there are a number of CAD-CAM systems on the market. The aim of CAD-CAM technology in general is to reduce production cost, standardize restoration-shaping processes, and produce higher quality and more uniform prosthesis from commercially manufactured blocks of material.[45]

Each CAD-CAM system is composed of three basic parts: a digital scanner, computer software, and milling machine. A digital scanner is the device that converts the geometry of the scanned area into data that can be used by a computer. There are two main types of scanners, optical scanners and mechanical scanners. Optical scanners use a “triangulation procedure” where by a light emitting source and sensor are oriented at a defined angle, and are able to detect the geometry of scanned surfaces. There are two ways scanning can occur. In indirect scanning, the clinician takes a conventional impression, fabricates a cast, and then the cast is scanned by a digital scanner in the dental lab. In direct scanning, the clinician uses a chair-side intra-oral scanner to directly

scan the geometry of the patient's oral cavity, eliminating the necessity for conventional impression materials.[46-48]

The digital information obtained by the scanning device is then electronically transferred to the dental laboratory by stereolithographic interface file (STL) and used for computer-aided design. When the digital impression is uploaded, a software program can suggest a prosthesis design for the prepared tooth. The suggested design can be modified by the clinician or dental lab technician to personalize each patient's prosthesis and ensure the functional quality and esthetics of the restoration. This process can take place in a dental lab, centralized milling center, or even in the dental office itself.[46-48]

Next, the information from the software guides the milling machine to fabricate a copy of the digitally designed restoration. The use of commercially produced blanks allows for high homogeneity in the material of the prosthesis. Like the computer aided design process, the milling process can take place in a dental lab, centralized milling center, or dental office. Clinicians are not required to purchase any components of a CAD-CAM system in order to use this technology in prosthesis fabrication. For example, a conventional impression can be sent to a dental lab that will fabricate a stone cast which can be scanned and used to design and mill a restoration. In a chairside CAD-CAM system, a clinician has purchased all three components that allow them to fabricate a crown in a single appointment with the patient present.[45,47]

Intra-Oral Scanners

There are about ten intraoral scanning systems for restorative dentistry. These include: CEREC® by Sirona Dental System GMBH, iTero by CADENT LTD, E4D by D4D TECHNOLOGIES, LLC, LAVA™ C.O.S. by 3M ESPE, IOS FastScan by IOS TECHNOLOGIES, INC., DENSYS 3D by DENSYS LTD., DPI-3D by DIMENSIONAL PHOTONICS INTERNATIONAL, INC., 3D Progress by MHT S.p.A. (IT) and MHT Optic Research AG, directScan by HINT-ELS GMBH, and trios by 3SHAPE A/S.[46] Each scanning system employs a non-contact optical technology for data acquisition, listed in **Table 1**. Only some of these scanners are available commercially.

The CEREC system was the first commercially available CAD-CAM system launched in 1987.[49,50] The latest version CEREC inLab®MCXL operates under the principles of confocal microscopy[50,51] and active triangulation technique.[50,52,53] The intraoral scanner in this system uses blue Light Emitting Diodes (LEDs) as a light source in detecting the surface geometry of the scanned area. It is necessary to coat the scanning area with an optimizing powder to ensure uniformity of the reflective surfaces. This version also contains an image stabilization system to eliminate the need to rest the scanning device on a tooth to achieve stabilization. The CEREC inLab®MCXL scanner can scan half of an arch in under one minute and can be used to fabricate restorations chairside.[46]

The E4D CAD-CAM system became commercially available in early 2008. The intraoral scanner of this system employs Optical Coherence Tomography

(OCT) or confocal sensor. This scanner does not require opportune powder to be used on scanning surfaces and can be used to fabricate restorations chairside.[46]

The LAVA™ C.O.S. scanner was created at Brontes Technologies in Lexington, Massachusetts. In 2006 it was obtained by 3M ESPE, and officially launched in 2008. The LAVA™ C.O.S system consists of a touch screen monitor, a scanning wand, and a mobile cart containing the central processing unit (CPU), illustrated in **Figure 2** and the scanning wand alone is illustrated in **Figure 3**. This system requires that the scanned areas be dusted with a light coat of titanium dioxide powder before image acquisition. This ensures uniformity in the way light reflects off each surface in the mouth. For example, the surface of the gum tissue will reflect light differently than the tooth surface and wet areas will reflect light differently than dry areas. The camera of the LAVA™ C.O.S is located at the tip of the scanning wand and is highly complex; containing 22 lens systems and 192 blue Light Emitting Diode (LED) cells. The scanning wand has a 13.2 mm wide tip and weighs 14 ounces.[49] LAVA™ C.O.S. uses the principle of active wavefront sampling with structured light projection for three dimensional data acquisition, named “3D-in-Motion Technology” by 3M ESPE.[46]

Figure 2. LAVA ™C.O.S. Scanning Unit[46]

Figure 3. **LAVA ™C.O.S. Scanning Wand**[46]

Figure 4 illustrates the basic physical principles employed in this intraoral scanning system. It contains a lens (140), Rotating aperture with off axis exit pupil (160A), image plane (18A), and out of focus point (8A). The single rotating aperture avoids image overlap from different object regions and increases spatial resolution. Images are recorded from multiple aperture locations, for example, as illustrated in **Figure 4** an image is recorded at aperture location '#1 at time t'. Then a second image is recorded at the next aperture location at '#2 at time

t+Δt'. This mechanism is similar to having multiple cameras at different viewpoints and increases measurement sensitivity. During a scan with the LAVA™C.O.S intraoral scanner, up to 2400 data sets may be recorded per arch. To create a three dimensional image, a processor pieces together information from each image obtained and uses cross correlation to reveal image disparities between image frames.[54]

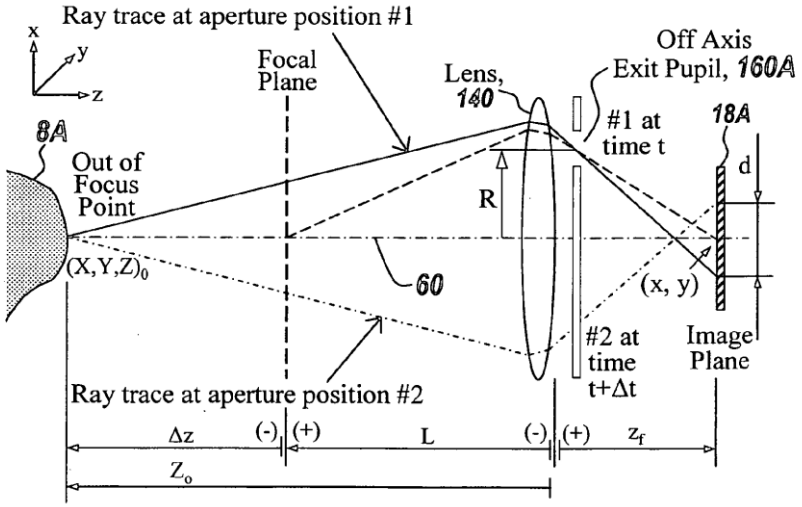


Figure 4. Diagram of Aperture Mechanism[54]

Using these principles, the LAVA C.O.S. system is able to generate three-dimensional images on a touch screen monitor in real time. If the clinician finds that the scanner has not imaged an area of critical importance, re-scanning the area will allow that information to be "filled-in" in real time. After the maxillary and mandibular arches are scanned, the clinician can acquire a virtual bite registration. With this information, the three dimensional maxillary and mandibular arch images can be articulated. The clinician can review the scan with the patient and rotate the three dimensional image for optimal viewing.[46]

The iTero CAD-CAM system became commercially available in early 2007. The iTero system consists of a monitor, a keyboard and mouse, a scanning wand, and a mobile cart containing the CPU, illustrated in **Figure 5**. When using this system, it is not necessary to apply an opportune powder to the scanning surface.

Figure 5. Cadent iTero Scanning Unit. (www.cadent.biz/index.html).

The iTero intraoral scanner employs parallel confocal imaging. In parallel confocal imaging, a beam of light passes through a small opening and various components of the machine and reflects off the scanned object. The beams of light that hit the object at focal length are reflected back through the small hole and read by a sensor that converts the reading into digital data. The iTero scanner expands on the described simplistic model of parallel confocal imaging to include 100,000 beams of parallel red lasers at 300 different focal depths

about 50 microns apart. The scanner captures appoximatley 3-5 million data points for each arch.[55]

To initiate a scan with the iTero scanning system, a laboratory work authorization must be completed. Then the clinician is prompted by both audio and text to capture five different views of the prepared tooth: buccal view, lingual view, occlusal view, and both interproximal views. Then the clinician is prompted to capture angled buccal and occlusal views of the remaining teeth. After the scans are complete, the clinician can view the image on the screen and decide to accept the image, capture additional images, or reject the scan. If an inaccurate scan is taken, the system requires the clinician to retake the scan. After the clinician accepts the scan, a virtual interocclusal record is obtained. Then an articulated image of the scanned arches is rendered.

Table 1. Intraoral Scanning Device Summary Table.

Intraoral Scanner	Company	Functional Principle(s)	In-office Milling
CEREC®AC-Bluecam	Sirona Dental System GMBH	Active Triangulation and confocal microscopy	Yes
iTero	Cadent LTD	Parallel confocal microscopy	No
E4D	D4D Technologies, LLC	Optical coherence tomography and confocal microscopy	Yes
Lava™C.O.S.	3M ESPE	Active wavefront sampling	No
IOS FastScan	IOS Technologies, INC.	Active triangulation and Schleimpflug principle	No
DENSYS 3D	Densys LTD	Active stereophotogrammetry	No
DPI-3D	Dimensional Photonics International, INC.	Accordion fringe interferometry (AFI)	No
3D Progress	MHT S.P.A.-MHT Optic Research AG	Confocal microscopy and Moireé effect	No
directScan	HINT-E:S GMBH	Stereoscopic vision	No
trios	3Shape A/S	Confocal microscopy	No

(Table adapted from Logozzo et al., 2011)

Crown Fabrication- Digital Workflow

Like conventional crown fabrication, digital crown fabrication must begin with the clinician preparing the tooth by removing part of the enamel and underlying dentin. The clinician has the same goals as with conventional crown

fabrication while preparing the tooth: to remove enough structure to make space for the prosthesis and shape the tooth to bare mechanical load during mastication without jeopardizing pulpal vitality, or the health of the underlying soft tissue that contains vessels and nerves.[4]

After the tooth is prepared, an impression is made with an intra-oral digital scanner. The scanner converts the geometry of the prepared tooth and surrounding anatomy into digital information that can be used by the computer to create a three dimensional, digital replica of the area.[2]

The digital impression can be sent as an STL (stereolithographic) file to a dental laboratory where a technician will review the impression for accuracy. The technician will then use computer software to digitally design a crown to fit the prepared tooth on the three dimensional digital impression. The software can suggest a prosthesis design, and then the technician can manipulate the design to customize the prosthesis for the patient.[2]

As with conventional crown fabrication, a clinician must select the material they wish to use for each prosthesis. They can select from a variety of available materials. When the dental lab sends the digital prosthesis design to the fabrication center, the material to be used is specified. The crown can be milled from a blank or block of material or printed by rapid prototyping. Milling is a subtractive process whereby a computer controlled machine uses a sharp power-driven tool to cut a block of material to a desired geometry, one disadvantage to this method is that the excess material cut away is wasted. Conversely, rapid

prototyping is an additive method. In this method a computer makes virtual cross sections of the three dimensional data obtained in the digital scan and uses a machine to print each layer one on top of the other. An advantage to this method is there is no waste, and highly complex objects can be printed.[2]

MATERIALS AND METHODS

In this experiment, a typodont was used as an *in* vitro model (Dentoform M-860, Columbia Dentoform Corporation, Long Island City, NY). Before preparation of the tooth, a cast of the maxillary arch of the typodont was made using Jeltrate Regular Set Alginate impression material (Dentsply Caulk, Milford, DE), and Type IV dental stone (Jade stone, WhipMix Corp., Louisville, KY). A clear reduction guide was fabricated with the cast using Clear Temporary Splint material (Buffalo Dental Mfg Co Inc., Syosset, NY).

In addition, 10 custom trays were fabricated with the cast using clear Triad® TruTray™ Custom Tray Material (Dentsply, York, PA). To fabricate the custom tray, TruWax baseplate wax (Dentsply, York, PA) was used to block out undercuts in the jade stone cast. Then, a thin layer of foil and petroleum jelly were placed over the wax, and Triad® TruTray™ material draped over the entire arch. The tray material was then reduced using a scalpel blade number 20 (Miltex, York, PA) and set in a light curing unit (Triad 2000 Dental, Dentsply, York, PA) for five minutes. The edges of the tray were then smoothed using a carbide acrylic bur (Faskut Carbide Cutter, 216C, Dentsply, York, PA) and polishing brushes (Polishing Brushes-Coarse, Medium, and Fine, Dentsply, York, PA). Then the trays were polished using pumice and a pumice wheel (CL-85 Pumice, Whip Mix, Louisville, KY).

One typodont maxillary right central incisor (Dentoform M-860, 860 Ivorine Tooth #8, Columbia Dentoform Corporation, Long Island City, NY) was prepared for an all-ceramic IPS e.max CAD crown. The marginal shoulder was prepared supragingivally, to facilitate impression making, with rounded inner angles using a round-ended diamond cutting instrument and reduction guide (Braessler USA, Savannah, GA). Preparation depth was 1 mm axially and 2 mm incisally, as recommended by the manufacturer **Figure 6**.[4,56,57]

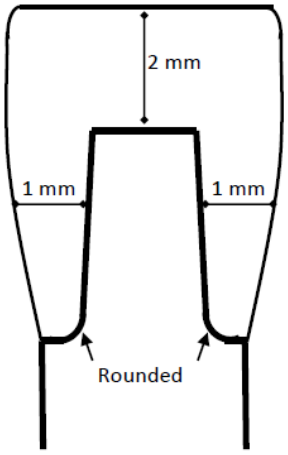


Figure 6. Tooth Preparation Diagram

Impressions and Lab Workflow

Ten conventional impressions were taken of the prepared tooth, including the entire maxillary arch of the typodont using polyvinyl siloxane (PVS) impression material. Both light and heavy body PVS materials were used with a custom tray for each conventional impression (Dentsply, Aquasil Ultra York, PA).

A Type IV stone cast was fabricated for each at a commercial dental laboratory. All the impressions for each group were taken by a prosthodontist (**Figure 8).**

Ten digital impressions were taken of the prepared tooth using an iTero (Software Version 4.5.1.61, Cadent Inc, Carlstadt, NJ) scanner and ten digital impressions were taken using a LAVA C.O.S. (Software Version 3.0.2, 3M EPSE, St. Paul, MN) scanner according to the manufacturer's recommendations. Before Lava C.O.S. scanning, the typodont was lightly powdered with titanium dioxide, ESPE Lava scanpowder (3m ESPE, St. Paul, MN); iTero scans do not require optimizing powder. The iTero scans were performed before the Lava C.O.S. scans so no residual powder would affect the scans. The sterolithographic interface (STL) files were then sent electronically to a commercial dental lab for review. A technician ensured margins were properly marked and selected section locations so casts would have removable dies **(Figure 7)**.

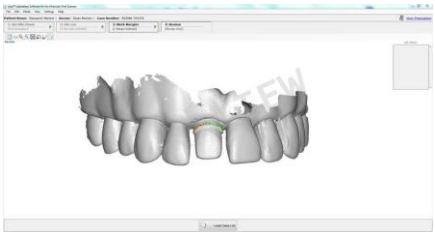
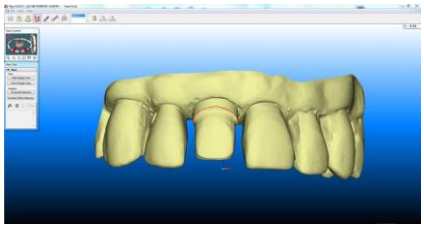
a)  **b)** 

Figure 7. Margin Marking on STL Files. a) Lava C.O.S. scan margins marked on STL file, and b) iTero scan margins marked on STL file

When the scans were approved, they were sent to their respective centralized milling centers for post-processing and cast fabrication. Lava C.O.S. epoxy resin stereolithographic casts were fabricated by rapid prototyping (InTech Industries Incorporated, Ramsey, Minnesota). iTero polyurethane casts were fabricated by 5-Axis CAD-CAM milling (Cadent iTero, Align Technology, Inc., Mexico) (**Figure 8).**

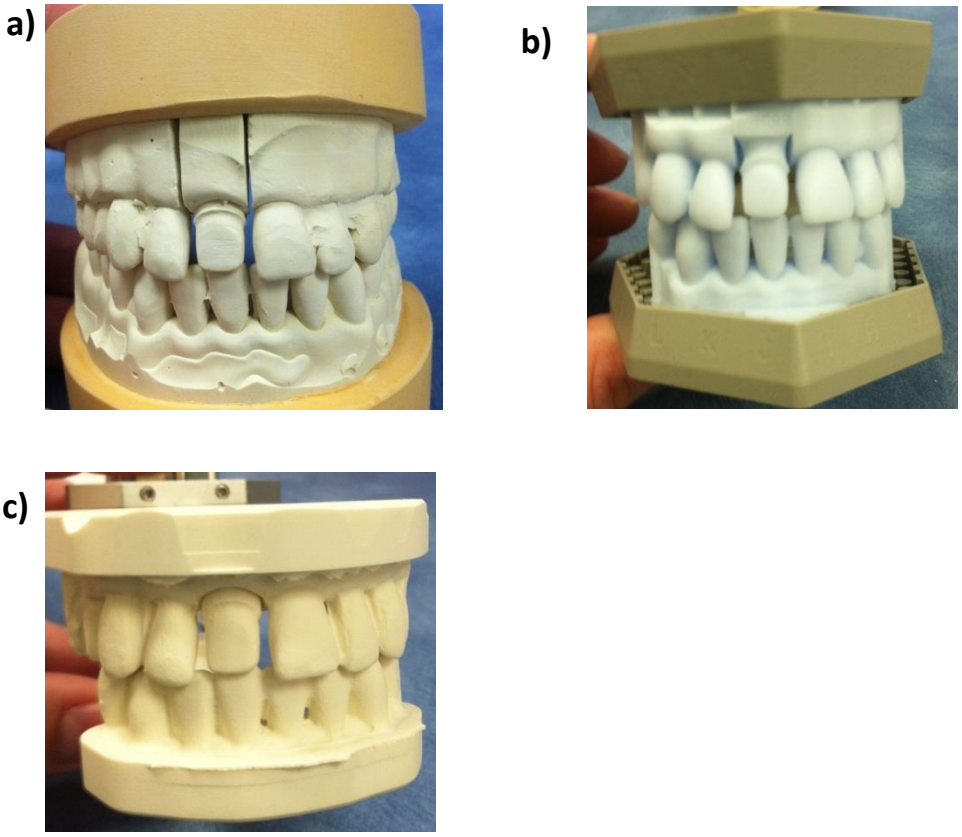


Figure 8. Working Casts. a) Conventional impression type IV dental stone cast, b) Lava C.O.S. epoxy resin stereolithographic cast, and c) iTero polyurethane cast

All conventional and digital casts were then scanned by Straumann® CARES® Scan CS2. A commercial dental lab technician used the same crown

design for all the impressions in each group using the Straumann® CARES® 8.0 Validated Dental Wings Software Program (**Figure 9).**

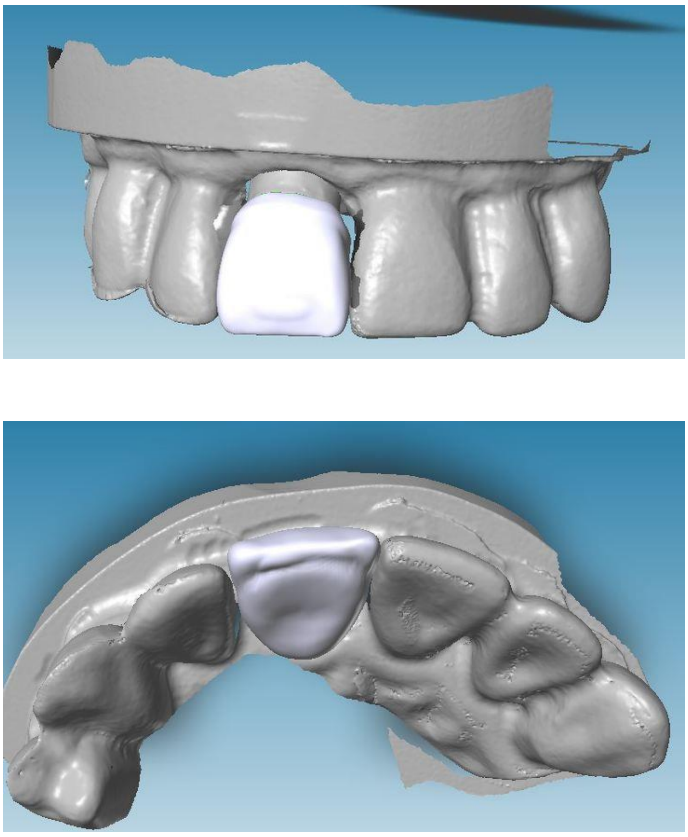


Figure 9.Prosthesis Design. Crown design created by technician using Straumann® CARES® 8.0 Validated Dental Wings Software Program

Each was sent to the Straumann® Centralized milling center (Straumann Milling Center, Arlington, TX) and IPS e.Max crowns were milled by Straumann® CARES ® Milling. Crowns were milled using IPS e.max CAD LT blocks in shade A1. The crowns were shipped in the blue block, or pre-sintered state, to the dental lab. The technician adjusted the blue block externally where necessary to ensure the crown was properly seated. Then the technician packed the blue block with IPS Object Fix (Ivoclar Vivadent, Amherst, NY) to prevent internal

distortion during sintering. Crowns were sintered at 850°C (EP 600 Combi, Ivoclar-Vivadent, Amherst, NY) **(Figure 10).**

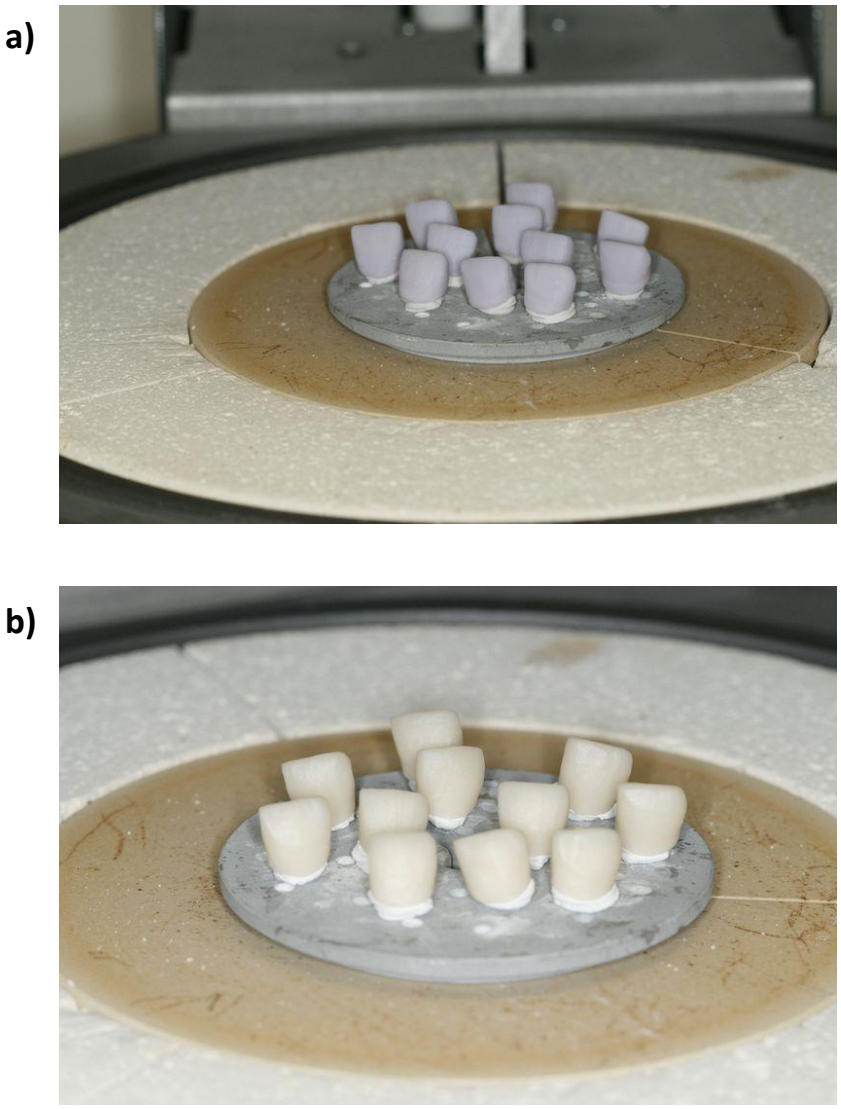


Figure 10. IPS E.max CAD Sintering. a) Crowns in blue-block state packed with IPS Object Fix, and b) Crowns post-sintering

Marginal Gap Measurement

Ten samples were fabricated for each group. However, one crown in the conventional group fractured during measurement, reducing the conventional sample size to nine. Marginal gap was measured for each crown under 45X magnification using a stereomiscroscope (Olympus SZX12, Olympus, America, Inc. Center Valley, PA) with a microscope camera (Spot Insight 4MP Mosaic, Spot Imaging Solutions, Sterling Heights, MI) and a computer program (Image-Pro Plus Version 6.2.1.491, Media Cyrbermetrics, Inc. Rockville, MD). The prepared typodont tooth was used as the reference for comparison (**Figure 11)**. The crowns were placed on the typodont and measurements taken at four points: mid-facial, mid-lingual, mid-distal and mid-mesial. Each measurement location was marked on the prepared tooth, to standardize measurement location for each crown. Specimens were not cemented for measurement. The mean was calculated for each location by group, and overall mean gap size by group.

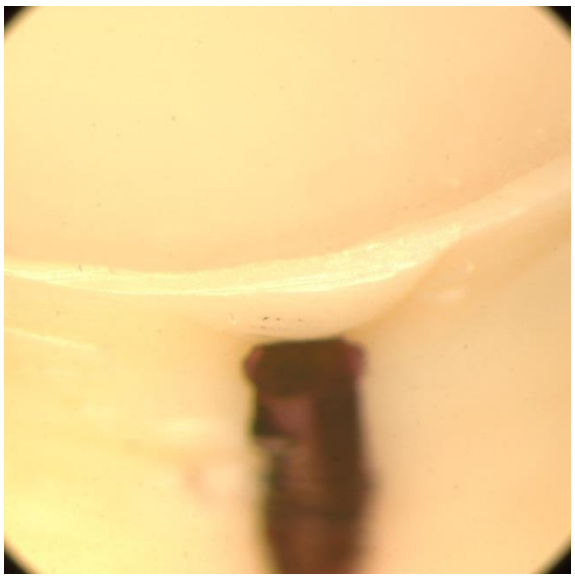


Figure 11. Microscope Image of a Lava Crown

Statistical Analysis

Initially, summary statistics (mean, standard deviation, median, minimum, maximum, and n) were generated for gap (µm) stratified by impression technique and location for each framework. Then, a repeated measures mixed-effects (RMME) model with *location* and *impression technique* as a fixed effects, *subject/sample* as random effect, and an additional covariance term for the repeated measure (*location*) was fit to assess the differences between the impression techniques. The RMME model can be defined in the following form: $y_{ijk} = \mu + \alpha_j + \beta_k + u_i + \epsilon_{ij}$ *, where* y_{ijk} *is the response for subject i at location j = 1,2,… assessed using impression technique k = 1,2,3, with* $u_i \sim N(0, \sigma_u^2)$ *the random effect accounting for subject-level variability and* $\epsilon_{ij} \sim N(0, \sigma_\epsilon^2)$ *the residual error term. The terms* α_j *and* β_k *are fixed effects for location and impression technique, respectively, with* $\alpha_1 = \beta_1 = 0$ *for identifiability purposes. Statistically significant differences between the impression techniques were tested by* $H_0: \beta_k = 0$ *vs.* $H_1: \beta_k \neq 0$*, using F and t tests. To test whether there is a location effect on impression technique differences, an interaction term between location and impression technique was included in the model and tested for significance. If significant, impression technique effect were analyzed separately by location, by testing appropriate contrasts within the interaction model.* Residual plots were used to assess the normality assumption.

RESULTS

A summary of average gap measure (µm) by impression technique is depicted in **Table 2** and graphically in **Figure 12**. One of the specimens in the conventional group was fractured during measurement; consequently, the n (number of samples) for this group was reduced to 9 (*n=9*). Average gap in microns for the conventional group was about 23µm greater than the digital groups at 112.3 µm (±35.3). The digital groups had similar average gap sizes, the Lava group was 89.8 µm (±25.4), and the iTero group was 89.6 µm (±30.1). Average gap size by location for each group is presented in **Table 3** and graphically in **Figure 13**. The average gap size in microns for the facial, lingual, mesial, and distal measuring locations were 117.5 (±60.5), 114.5 (±79.0), 127.2 (±50.4) and 90.2 (±59.0), respectively for the conventional group. The average gap size in microns for the facial, lingual, mesial, and distal measuring locations were 88.5 (±45.2), 105.4 (±20.1), 82.4 (±48.1), and 83.0 (±37.8), respectively for the Lava group. The average gap size in microns for the facial, lingual, mesial, and distal measuring locations were 96.2 (±37.6), 63.8 (±17.7), 89.3 (±53.1), and 109.2 (±71.2), respectively for the iTero group. The RMME model, **Table 4**, shows no significance in the effects between impression technique (p=0.185). Moreover, it shows that the main effects, location (p=0.929) and impression technique (p=0.198) were also not significant at an alpha of 0.05 (level of

significance). Though not statistically significant, measures in the conventional group were on average 23µm greater compared to either the Lava or iTero methods. Additionally, there was no signficant difference between iTero and Lava methods (**Table 5)**.

Table 2. Summary statistics of gap (µm) measures by impression technique.

Impression Technique	N	Average Gap (microns)	SD	Median	Min	Max
Conventional	9	112.3	35.3	115.3	67.0	161.6
LAVA	10	89.8	25.4	100.1	50.8	120.5
iTero	10	89.6	30.1	90.2	41.7	139.7

Figure 12. Average gap (µm) measures by impression technique.

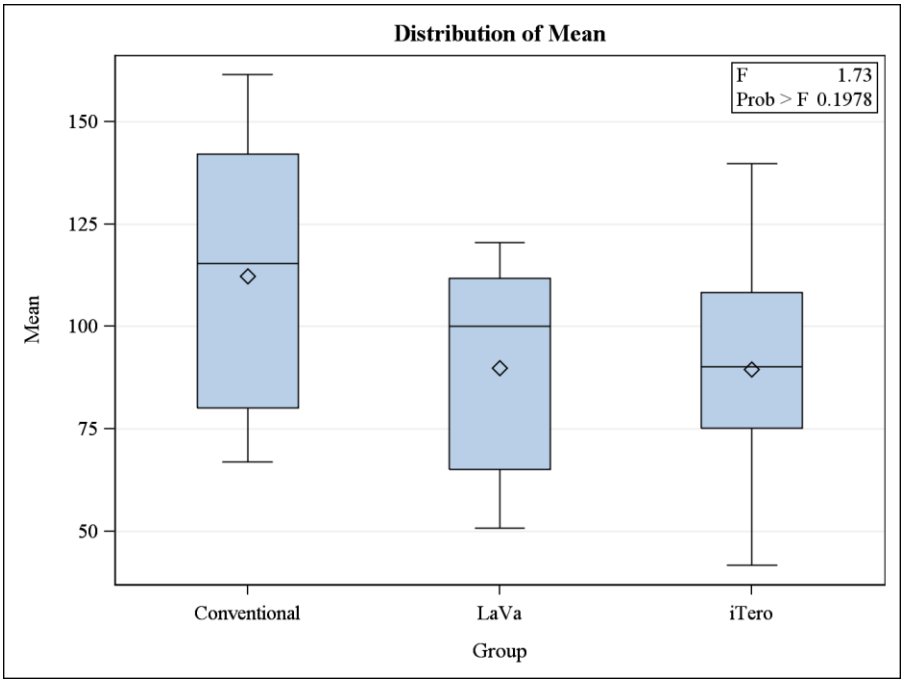


Table 3. Summary statistics of gap (µm) measures by impression technique and location.

Impression Technique	Location	N	Average Gap (microns)	SD	Median	Min	Max
Conventional	Facial	9	117.5	60.5	90.9	51.2	217.4
	Lingual	9	114.5	79.0	102.4	38.4	292.3
	Mesial	9	127.2	50.4	122.9	64.0	214.3
	Distal	9	90.2	59.0	63.0	36.9	217.4
LAVA	Facial	10	88.5	45.2	80.0	19.4	172.8
	Lingual	10	105.4	20.1	103.3	71.0	137.6
	Mesial	10	82.4	48.1	81.0	25.6	155.7
	Distal	10	83.0	37.8	86.7	38.4	158.8
iTero	Facial	10	96.2	37.6	115.9	44.8	140.8
	Lingual	10	63.8	17.7	60.8	38.4	91.4
	Mesial	10	89.3	53.1	65.0	44.8	199.2
	Distal	10	109.2	71.2	85.2	19.2	246.6

Figure 13. Average gap (µm) measures ± 2*SE bars by impression technique and location

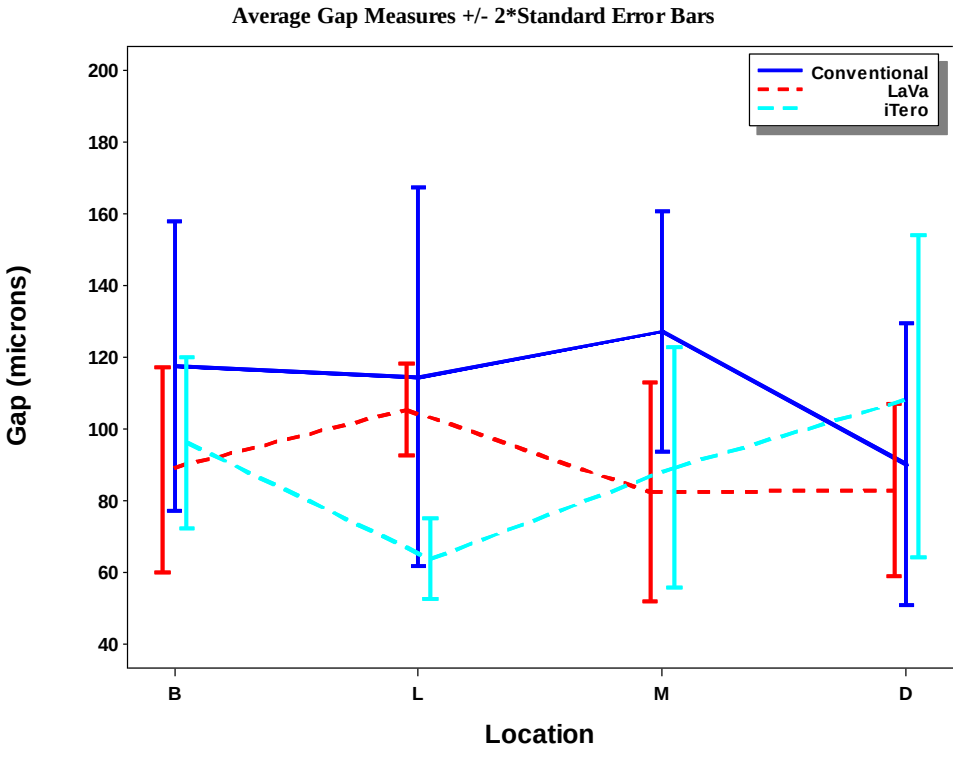


Table 4: RMME model results of gap (µm) measure, Type 3 tests of model effects.

Effect	Num DF	Den DF	F Value	P value
Group	2	26	1.73	0.198
Location	3	78	0.15	0.929
Group*Location	6	78	1.51	0.185

Table 5: Pairwise comparisons of gap (µ) measures between impression techniques with Tukey adjustment for multiple comparisons.

Effect	Group	_Group	Estimate	SE	DF	t Value	P value	Adj P	Adj Lower	Adj Upper
Group	Conventional	LaVa	22.5	13.9	26	1.62	0.118	0.257	-12.1	57.2
Group	Conventional	iTero	22.7	13.9	26	1.63	0.115	0.251	-11.9	57.4
Group	LaVa	iTero	0.22	13.6	26	0.02	0.987	0.999	-33.5	33.9

DISCUSSION

The use of CAD-CAM technology and intra-oral digital scanners has gained popularity among clinicians in the dental field. CAD-CAM workflows may offer an array of benefits including a more standardized method of prosthesis fabrication, the use of highly homogenous materials, decreased material cost, and a workflow with decreased length and number of appointments. For intra-oral digital scanners to be considered an alternative to conventional impression methods, it is important that they result in crowns with similar or better clinical success.

One aspect of critical importance for the clinical success of a crown is marginal fit.[32] Poor marginal adaptation can increase exposure of the luting agent to the oral environment, which may cause microleakage and cement dissolution.[38,39] Poor marginal adaptation can also lead to increased plaque retention and changes in the subgingival microflora, which may result in periodontal disease,[33-36] and secondary caries.[37] Additionally, it has been shown that marginal fit of crown is a good indicator of overall crown fit.[39,58] Because marginal adaptation is an important factor in clinical success and a good indicator of over-all crown fit, it was used as a parameter for comparison in this study.

While marginal adaptation is an important element when predicting the clinical success of a crown, there is a lack of consensus regarding what the

maximum gap size can be before the clinical success of a crown is compromised. A wide range of values have been reported in the literature from 50-200µm.[59-61] However, a number of studies have shown that clinically acceptable marginal gap size is less than 120µm.[40,41] This difference in values may be attributed to lack of standardization in measurement methodology.

Holme et al. discusses the lack of consensus on measurement reference points and terminology used among investigators in assessing marginal fit. There are multiple ways marginal gap can be measured, making comparison between studies difficult.[31,62-65] Two common techniques are measurement of embedded and sectioned specimens[66-68] and measurement by direct visualization.[69,70]

This *in vitro* study aimed to compare the marginal fit of IPS e.max crowns fabricated by conventional and digital impression methods. A standardized *in vitro* model was chosen in order to assess best possible accuracy under ideal conditions. For this study, direct visualization was used to measure marginal gap, as defined by Holmes et al. and 120µm was considered the maximum clinically acceptable marginal gap width.

Within the limitations of this experiment, it was found that the digital groups (Lava and iTero) did not have a statistically significant difference in marginal gap size compared to the conventional group. The large standard error bars in Figure 12 and Figure 13, indicate the lack of a significant difference between average measure between each group and between each location per group. The average gap size for each group was found to be within clinically

acceptable limits. These results are in agreement with those found in a study by Seelbach, Brueckel and Wostmann (2012) where a simplified tooth model was used to compare the internal and marginal fit of crowns fabricated by conventional and digital impression methods using Lava C.O.S., Cerec, and iTero scanning systems.[71] They also found that crowns fabricated by conventional and digital impression techniques have similar marginal fit.

In addition, in a study by Ender and Mehl (2011), the precision and trueness of conventional and digital impression scanners were compared.[72] Precision refers to the variability of measurements by location and trueness refers to the deviation of the measurements from the master model. Cerec AC Bluecam and Lava C.O.S. scanners were used. The data models were superimposed and compared. It was found that the precision and trueness of the digital scans were similar to those of the conventional.

Likewise, in a study by Phark and Oliviera (2010) a typodont first maxillary molar was prepared for an all-ceramic full coverage crown, and conventional PVS impressions and digital impressions using the iTero scanner were made.[73] There was no statistical difference between the iTero and conventional group.

While not statistically significant, the average marginal gap size of the conventional group in this study was found to be about 23µm larger than the digital groups. Perhaps this would have been revealed as a statistically significant difference if the power of the study had been increased, by increasing the sample size. Also, more locations of measurement per crown could have

increased the power of the study and provided a more accurate average measurement. Additional studies should be conducted with increased sample size and number of measurement locations.

In a study by Syrek *et al.* (2010) where crowns fabricated with Lava C.O.S. and conventional impressions were compared, it was found that Lava crowns had a smaller marginal gap size compared to the conventional group.[74] In addition to the increased sample size of this study, these findings may be due to difference in marginal gap measurement technique, previously discussed as a factor to consider when comparing study results. Syrek et al. employed an indirect measuring method in which an A-silicone was injected into the crown, and crown was fully seated. After the material set, the crown was removed and a light-bodied silicone was injected into the crown to stabilize the film for removal. This was repeated three times per crown. The silicone films were sectioned buccolingually and mesiodistally with a sharp razor blade, and measured by a stereomicroscope at 66x magnification. Marginal gap was recorded as the shortest distance between the internal surface of the crown and the prepared tooth close to the finish line.

In addition, Syrek et al. recorded the shortest marginal gap for each anatomic location, whereas standardized mid-facial, lingual, mesial and distal measurement locations were used in this study. In the study by Syrek et al., a statistically smaller average gap size for the Lava group may have resulted from recording the smallest measure at each location. An additional factor to consider is that gap size can vary by measurement location.[75] Without standardized

measurement location, a smaller average gap size may have resulted. Additional studies should be conducted to evaluate the effects of the location of measurement and measurement technique on assessing marginal fit.

In addition to the measuring technique and sample size of the Syrek study, there are a number of factors that have been shown to influence the accuracy of conventional impression methods generally. For example, the type of tray used can have an impact on the quality of the resulting impression. Plastic or metal stock trays have been shown to have increased dimensional inaccuracies when compared to custom trays. A custom tray offers an advantage by providing a uniform thickness of impression material which improves the accuracy of the resulting cast.[76-86] In this study, custom trays were used to reduce the effect of bulk material on the impression accuracy. However, the impression is susceptible to dimensional changes over time due to possible instabilities in the tray itself and the impression material.[81,87,88] In addition, studies have revealed that dental stone can expand slightly while setting.[10,15,89] These effects could have influenced the accuracy of the impression and casts in the conventional group.

In this study, it was found that the conventional and iTero groups had larger variance in average gap size by location, then the Lava group as can be seen in Table 3. The iTero group had the largest range of measures between average gap size at each location with a difference of 45.5µm. The Lava group had the smallest range of measures with a difference of 23µm. A factor affecting the range of marginal gap size in the digital crowns could be the technology each device employs to capture data. The iTero scanner employs parallel confocal

imaging in a point-and-click system. The Lava scanner gathers data continuously by active wavefront sampling in a video system. Both the accuracy of data acquisition and the accuracy of the algorithims used in each scanning system have an effect on the overall accuracy of the resulting impression. Algorithims register the images as they are acquired and piece them together by overlapping data points. Errors may occur in this registration process each time image overlap is matched. This may cause an additive error effect as additional image overlap is assessed while scanning the arch.[74,90]

In a study by Hwang et al. the iTero scanning system was examined.[18] They compared a stone cast to the virtual cast created by scanning with the iTero digital scanner, and two working models: polyurethane milled cast and rapid prototyping (RP) cast. They compared the original scanned stone cast to the virtual cast to examine the accuracy of the scanning device, and found that little discrepancy existed between them which was in agreement with previous studies.[91,92] This indicates that the virtual casts were accurate and highly reproducible. The RP and polyurethane casts were compared to the virtual cast, to determine the accuracy of each fabrication process. There were more inaccuracies in the polyurethane cast indicating less accuracy in the milling process, compared to rapid prototyping. Milling of the iTero polyurethane model is a subtractive process whereby a computer controlled machine uses a sharp power-driven tool to cut a block of material to a desired geometry, one disadvantage to this method is that the excess material cut away is wasted. Conversley, rapid prototyping is an additive method. In this method a computer

makes virtual cross sections of the three dimensional data obtained in the digital scan and uses a machine to print each layer one on top of the other. An advantage to this method is there is no waste, and highly complex objects can be printed.[93]

As well as difference in cast fabrication methods between the iTero and Lava groups, another factor that has contributed to the marginal gap size for each crown is the workflow used. In this study, ten digital impressions were made using each intra-oral scanner. The digital impressions were then used to fabricate casts. Casts milled for the digital groups, and the Type IV dental stone casts of the conventional group were scanned with Straumann® CARES ® CS2 and crowns designed using Straumann ® CARES ® 8.0 Validated Dental Wings Software Program. This workflow was used to standardize the crown fabrication method used. Crowns from each group were able to be designed, and milled by the same software and milling center. While this has standardized the fabrication process, it has also introduced the possibility for additional error with the digital groups. An additive error effect could have resulted from this process because errors would have occurred in the impression taking process, cast fabrication, scanning with the Straumann ® CARES CS2, and then final prosthesis milling. Less error would have been introduced with the use of an all-digital pathway, in which the digital impression would have been directly used to create a digital crown design.

This *in vitro* study aimed to compare the marginal fit of IPS e.max crowns fabricated by conventional and digital impression methods. A standardized *in*

vitro model was chosen in order to assess best possible accuracy under ideal conditions. Further *in vivo* studies are needed to evaluate the effects of the clinical factors eliminated in this experiment. Challenges such as salivary flow, humidity, patient movement, and lack of space in the mouth could contribute to the overall accuracy of each impression technique.[94,95]

Moreover, this study takes into account the effects of the entire workflow for each method. The effects of milling parameters, shrinkage during sintering, and experience level of the laboratory technician for example, are not eliminated in this study. However, similar production processes were selected where applicable. To assess the accuracy of the scanning devices alone, a direct comparison of the digital data would be necessary.[95]

CONCLUSIONS

Within the limitations of this experiment, it was found that crowns fabricated by Lava C.O.S. and iTero impression methods had similar marginal gap size compared to those fabricated by conventional impression methods. Therefore, the null hypothesis cannot be rejected.

CLINICAL APPLICATIONS

This *in vitro* study does not take into account the challenges faced in the *in vivo* environment, such as salivary flow, humidity, and patient compliance, but within the conditions of the experiment, the digital intraoral impression methods can be considered an alternative to the conventional method. *In vivo* studies should be conducted to evaluate the results of this study in a clinical application.

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CURRICULUM VITAE

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PROFESSIONAL EXPERIENCE

The Ohio State University College of Medicine, Columbus, Ohio
Clinical Research Assistant, October 2012-present

- Assist with recruiting research subjects and evaluate clinical tests to identify potential patients for studies in the area of endocrinology and the diabetes clinic
- Explain and answer patient questions about the study
- Collect and process biological specimens
- Collect, log-in, and track patient vital signs
- Learn, update, and maintain patient database
- Write Informed Consent forms and prepare submissions for the Institutional Review Board
- Organize data spreadsheets with Microsoft Excel for data summary and analysis

Norton Cancer Institute Research Program, Louisville, Kentucky
Post-Graduate Intern, January 2012-present

- Served as Clinical Research Coordinator on over 25 studies
- Worked closely with Clinical Research Nurse to organize care of research patients and data submission
- Followed- up with research patients by phone and medical records
- Maintained records of research employee's certifications and trainings

Case Western Comprehensive Cancer Center, Cleveland, Ohio
Research Assistant, Academic year 2009-2010

- Quickly learned new information and laboratory techniques including flow cytometry, cell line maintenance, and cell staining
- Performed various laboratory tasks associated with operating flow cytometers

The Ohio State University College of Dentistry Dental Implant Clinic, Columbus, Ohio

Undergraduate Assistant, Summers 2009, 2010

- Worked closely with dentists, hygienists, dental assistants, office staff, and patients to learn many aspects of dentistry including chart writing, bookkeeping, space organization, and WinDent operation
- Gained knowledge of dental instrument names and uses by assisting in patient care and instrument sterilization
- Took and poured alginate impressions, fabricated surgical guides, mouth guards, and night guards

Case Western Reserve University School of Dental Medicine, Cleveland, Ohio
Data Entry, Academic years 2009-2010, 2010-2011

- Demonstrated proficiency with Microsoft Excel and Access programs for quality assurance, HIPPA, patient satisfaction surveys, lab forms, and treatment completion, transfer, and exit forms
- Worked closely with dental professionals, faculty, and staff

Emeritus at Lakeview Senior Living, Groveport, Ohio
Resident Assistant, 2006-2007, Summers 2008, 2010

- Assisted patients with activities of daily life such as bathing, feeding, and restroom assistance
- Checked blood pressures; recorded weights and heart rates; and maintained weight, meal, and behavior logs
- Directed patient daily activities
- Worked as a team in a health care setting with health professionals, patients, and their family members

EDUCATION

Case Western Reserve University, Cleveland, Ohio
Bachelor of Arts, Biology and Spanish, Minor: Chemistry, May 2011
Provost's Scholarship
Senior Project: The occipitofrontal fasciculus is essential for memory recall in Multiple Sclerosis patients: a proposal

University of Louisville, Louisville, Kentucky
Masters of Science, Oral Biology, expected graduation date: August 2013
Thesis: Comparison of Marginal Fit of Lithium Disilicate Crowns Fabricated with CAD-CAM Technology Using Conventional Impressions and Two Intra-Oral Scanners

SPECIAL TRAINING

- **Collaborative Institutional Training Initiative (CITI Training):** Biomedical Responsible Conduct of Research, Good Clinical Practice and ICH, and Biomedical Research Investigators and Key Personnel; Modules Completed October 8, 2012

- **Mayo Medical Laboratories, International Air Transport Association (IATA Training):** For the shipping of Category A, Infectious Substance Affecting Humans Category B, Biological Substance; Completed January 6, 2012
- **American Heart Association Basic Life Support for Healthcare Providers;** Completed April 2013
- **The Ohio State University College of Medicine Clinical Research Orientation:** December 11, 2012
- **Phlebotomy Venipuncture Skills**, November 13, 2012
- **Basic ECG Course**, October 29, 2012
- **Microsoft Office Proficiency**, including Microsoft Word, Microsoft Excel, and Microsoft PowerPoint

RELEVANT TRIAL TITLES

Endocrinology, Diabetes, and Metabolism

- Effect of Glycemic Variability on Autonomic Tone in Hospitalized Patients with Type 2 Diabetes
- Diabetes Control, Compliance, and Continuity Outpatient Program (DC3)
- Prandial Insulin Dosing Using the Carbohydrate Counting Technique in Hospitalized Patients with Diabetes
- Glycemic Control and Variability in Congestive Heart Failure Exacerbation
- Intensive Glycemic Control for Congestive Heart Failure Exacerbation
- Randomized Controlled Trial on the Safety and Efficacy of Sitagliptin Therapy for the Inpatient Management of General Medicine and Surgery Patients with Type 2 Diabetes

ACTIVITIES, HONORS, AND LEADERSHIP

- **Founder and President:** The Labre Project 2009-2011; homeless outreach program in which we provide a hot meal, donated items, and conversation to people experiencing homelessness in Cleveland
- Civic Engagement Scholar 2010-2011
- Eucharistic Minister for Norton Healthcare Downtown Hospital: March 2012-September 2012
- **Guest Speaker:** Students Who Make A Difference 2011
- **Member***:* Alpha Phi Omega National Service Fraternity 2010, Operation Smile 2009-2010, Newman Campus Ministry 2009-2011
- **Nominee:** Dorothy M. Pijan Student Leadership Award 2011
- **Columbus Young Professionals Club**, May 2013-present