Curriculum Vitae

William Maxwell Wahle
Third Year Resident, Post Graduate Prosthodontics
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Education

University of Maryland Baltimore School of Dentistry
Masters & Certificate in Prosthodontics
Expected graduation: June 2016

University of Iowa College of Dentistry
Doctor of Dental Surgery June 2013
GPA 3.72

The George Washington University
Bachelors of Science in Applied Mathematics
Minor in Chemistry May 2009
GPA 3.59

Dental Licenses:

- Iowa:DDS-09045
- Pennsylvania: Pending
- Maryland: Pending

Prosthodontic Residency Program

- Attended July 2013 to June 2016
- Study in the treatment of advanced dental rehabilitation with regards to fixed on natural dentition, fixed on implants, removable with and without implant retention/support
- Study in the treatment of maxillofacial prosthetics
- Study in the placement of implants and minor bone grafting procedures

Professional Goals

- To obtain a full time position that allows me to provide exceptional dental treatment to my community
- To continue advancing my knowledge and experience in a clinical setting
- To provide a comforting environment for my patients and coworkers

Clinical Experiences

- Experience in digital scanning equipment, both intra and extraoral
- Digital designing software employed regularly for surgical guides and restoration planning/milling
- Performed All-on-4® surgery and prosthetic rehabilitation from start to finish
- Placed over 40 implants during residency with guides or freehanded

Masters Research

"Radiographic Evaluation of All Ceramic Crown Margins"

- Determination of correct radiographic marginal adaptation evaluations
- Analysis of the errors in evaluation and their effect upon the practitioner and patient

Presentations

American Academy of Fixed Prosthodontics Meeting, Chicago, IL, February 2016

"Radiographic Evaluation of All Ceramic Crown Margins" - Poster

- Masters research presentation: Clinician radiographic evaluation of marginal adaptation of E.max, ZirPress, and ceramometal crowns

American College of Prosthodontics National Meeting, Orlando, FL, October 2015

"Pros and Cons of the Fixed Detachable Prosthesis" - Poster

- Discussion of the risks and benefits of the fixed detachable prosthesis

Northeastern Implant Symposium, Baltimore, MD, October 2015

"The Longest Day: from old to new in an afternoon" - PowerPoint presentation

- Patient presentation involving extraction, bone reduction, implant placement, and immediate provisionalization on 5 implants

American College of Prosthodontics National Meeting, New Orleans, LA, October 2014

"Broken and Stripped Screw Retrieval" - Poster

- Describing common methods used for broken screw retrieval in implant restorations

American Academy of Fixed Prosthodontics Meeting, Chicago, IL, February 2014

"Laser Tissue Retraction" - Poster

- A comparison of retraction methods and an argument for lasers.

American College of Prosthodontics National Meeting, Las Vegas, NV, October 2013

"Why Removable?" - Poster

- The increasing need for removable prosthetics and expert lab technicians to fabricate removable prostheses.

Lectures

"Restoration of the Class II Fixed Patient" November 2015

- Insight into restoring a dental class II patient with fixed crown and bridge work

"Pantograph vs Cadiax and Facial Analyzers" September 2015

- Comparing the use of the Cadiax and Pantograph in the clinic

"Grafting Materials" March 2015

- Discussion of bone grafting materials and techniques

"Lasers in Dentistry" February 2015

- Describing new laser technology that spans across the dental profession

"Gypsum Products" March 2014

- A review of gypsum products in dentistry and their properties

Related Dental Experiences

Member, Hispanic Dental Association, Fall 2010 – Spring 2013
Treasurer, Fall 2011 – Spring 2012
University of Iowa, Iowa City, IA

- Attended and participated in community outreaches and diversity fairs
- Organized and attended classes to improve dental-related Spanish
- Created, proposed, and implemented budget for 2011-2012 academic year
- Responsible for ordering supplies for officer and member meetings

Participant, Iowa Mission of Mercy
Sioux City, IA, Fall 2011

- Restored severely carious lesions
- Performed root canal therapy on single-rooted teeth
- Assisted numerous dental students in cleanings, root canals and fillings

Cedar Rapids, IA, Fall 2010

- Dental Assistant for local dentist

Newtown, IA, Fall 2009

- Assisted in dental triage
- Acquired dental and other necessary instruments

Registered Dental Assistant, Volunteer at Community Health Free Clinic
Cedar Rapids, IA, Fall 2009 – Summer 2011

- Received in-house assistant training
- Completed jurisprudence, infection control/hazardous materials, and radiography segments of Iowa dental assistant exam
- Performed standard assistant duties

References

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ABSTRACT

William Maxwell Wahle, Master of Science, 2016

Directed by:

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Radiographic Evaluation of All Ceramic Crown Margins

Statement of Problem: Radiographs aid in clinical determination of crown fit, specifically interproximal margins where tactile and visual methods can fail us. With the use of all ceramic materials surpassing ceramometal, it is beneficial to understand what limitations are present with this method to determine the accuracy of marginal fit.

Purpose: The purpose of this study was to assess if we can accurately identify crown margin adaptation via radiographs for all ceramic and ceramometal crown margins.

Materials and Methods: Individual lithium disilicate, fluorapatite, and ceramometal crowns were fabricated using a single prepared maxillary premolar and measured with light microscopy to ensure fit at the margin to below 20μm. The crowns were set up on a margin opening jig, and radiographs were made at 20μm increments starting at 0μm and finishing at 180μm for a total of 10 marginal adaptations. The threshold for closed versus open was >80μm. The 60 radiographs were then randomized and evaluated by prosthodontists and general dentists.

Results: Individual evaluation accuracy of marginal adaptation was 48.8% for ceramometal crowns, 72.1% for lithium disilicate, and 76.9% for fluorapatite. The null hypotheses were rejected. When incorrectly evaluated, ceramometal crowns were significantly more likely to be evaluated acceptable when open margins were present, or as false positives. lithium disilicate and fluorapatite were found to be more likely evaluated unacceptable with closed margins present. No significant difference was seen between general dentists and prosthodontists.

Conclusions: Within the limitations of this in vitro study, accuracy of marginal adaptation evaluations without clinical examination is not as high as would be expected. Ceramometal crowns tend to be incorrectly evaluated closed. Ceramic crowns tend to be incorrectly evaluated open. No difference between prosthodontists and general dentists was evident in this study.

Clinical Implications: The goal of this study was to provide information to aid in radiographic marginal fit determination and guidance when examining crowns of different radiopacities with relation to the common inaccuracies found in the study. This information could be used to reduce adaptation error frequency, understanding the likely assessment errors incurred for each type of crown.

Radiographic Evaluation of All Ceramic Crown Margins

William Maxwell Wahle

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, Baltimore in partial fulfillment
of the requirements for the degree of
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I. Introduction

Full coverage restorations are indicated when insufficient coronal tooth structure exists, teeth have extensive areas of defective axial tooth structure, or there is a need to change contours to refine occlusion or improve esthetics [17, 30, 44]. Depending on the prosthetic, esthetic, and functional demands, full coverage restorations could be cast metal crowns, metal-ceramic crowns, or all ceramic crowns [36].

Cast metal crowns have the advantage of minimal tooth structure reduction, and the material minimally wears the opposing natural dentition. Traditionally, the preparation of a full cast crown is more conservative than the preparation for either metal-ceramic or all-ceramic crowns, tooth reduction being 1 to 1.5 mm compared to ideally 2 mm for all porcelain, or greater than 2 mm for metal-ceramic restorations [36]. Cast metal crowns are typically fabricated from high gold alloys because of their similar physical properties to tooth structure. These crowns provide good wear resistance, flexibility in preparation design, castability, polishability, and excellent biocompatibility [45]. The primary issue with full cast crowns is their color. These crowns are gold or silver and do not match tooth shades like other crown materials.

Since full cast crowns are not always considered esthetic, early attempts at tooth colored restorations involved bone, ivory, and eventually, porcelain and ceramics. [43]. Crowns made completely of feldspathic porcelain are susceptible to fracture, unlike full cast crowns, and were thus limited in their usage. Eventually, an effective method to bond porcelain to a metal core was developed and patented by Dr. Abraham Weinstein [3], allowing strength and esthetics to coexist. These two materials provide high esthetics through the use of porcelain and the necessary strength by the underlying metal [45]. The

lost wax technique is used to fabricate metal frameworks for both full cast and metal-ceramic crowns to ensure accurate fit, optimum marginal adaptation, less porosity, and stronger casting [42]. Tooth reduction required for ideal esthetics in porcelain-metal crowns is 2 mm for the porcelain and 0.3-0.5 mm for the metal framework [36]. The greater amount of required reduction can lead to over-contoured or opaque restorations, if proper reduction is not met. Thus, it is important to understand the pulpal morphology of the patient and that ideal preparations may not be feasible due to the size of the teeth or age of the patient [23].

Increased esthetic demand and improved technology led to the introduction of all-ceramic crowns. Charles Land described one of the first methods for an all porcelain jacket crown. These highly esthetic crowns yielded low strength and were limited to the anterior for placement with frequent failures [29]. McLean and Hughes [20] helped to improve the strength by adding metal oxides as a substructure to the porcelain. More recently, with better bonding techniques and stronger materials, all ceramic restorations have improved sufficiently for posterior occlusion with regard to strength and opposing tooth wear resistance [39]. The first all-ceramic restorations were entirely feldspathic porcelain and presented certain issues with fabrication. Shrinkage, marginal distortion, and inadequate strength were the primary faults of all-porcelain crowns [25]. Innovations have slowly improved these aspects of all-ceramic restorations, the first being the introduction of the platinum foil matrix technique. By layering a thin sheet of platinum over the preparation, porcelain was added more effectively and helped provide these ceramic restorations with a clinically acceptable margin [15].

McLean and Hughes [20] were the first to introduce a higher strength ceramic core material to decrease the fracture potential and crack propagation under low impact stress by reinforcing porcelain restorations using an aluminous ceramic core material. From this initial success, full ceramic crowns have been further developed and modified by employing different materials and cores to improve the overall strength and esthetics. Initially, it was hoped that leucite would improve the strength of all ceramic crowns, but it provided much less than anticipated. Metal oxides, such as zirconia and magnesia, were developed, showing dramatically improved strength, yet creating opaque restorations [14].

Lithium disilicate is a popular new material that has been studied heavily over the last few decades. It is a strong and esthetic material that can be used in the anterior and posterior, be a core for feldspathic porcelain or a full crown. When used as a monolithic crown, it may only require a reduction of 1.0-1.5 mm, similar to cast metal crowns [35]. There have been different developments in the techniques used to make all-ceramic crowns affecting fit on the prep or at the margin. Technology has allowed crowns to be pressed, using a similar method to casting, and be milled out of a block of dense material with the aid of CAD/CAM. These methods have helped increase efficiency and ease of ceramic crown fabrication, as well as reduce the shrinkage of the material during the fabrication process [9].

The most important characteristics for long term success of full coverage restorations, including all-ceramic restorations, are good marginal adaptation and adequate strength [18]. The larger the marginal discrepancy, the more the luting material and dentin are exposed to the oral environment, increasing the risk of seal failure and caries due to bacterial infiltration [1]. Improper fit can impact the fracture strength of the

all-ceramic crown material, reducing the strength and longevity of the restoration [41]. Marginal overhangs facilitate plaque accumulation in difficult to clean areas and can produce gingival inflammation, potentially leading to crestal bone loss [5]. To summarize, marginal defects result in microleakage, increasing risk of dental caries [40], and reduced periodontal bone level due to plaque accumulation [4]. Therefore, marginal fit is an important factor determining short and long term success of a restoration; and if not properly adapted, will likely lead to disease and potential loss of teeth. An additional factor is the location of the margin with respect to the gingival sulcus.

The location of crown margins is typically sub- or supragingival. The advantages of supragingival margins are cleansability, ease of evaluation, minimal effect on the periodontium, ease of accurate impression capture, polishability at the tooth-crown margin, and easily detectable and removable excess cement [32]. The primary disadvantage of this margin location has been esthetic in nature, especially with porcelain-metal crowns with any visible metal support. To understand why subgingival margins are problematic, Larato's [16] work demonstrates that crowns with subgingival margins incurred a higher incidence of gingival inflammation, while crowns with supragingival margins did not. Silness and Newcomb [22, 38] compared sub- and supragingival margins and found that subgingival pathosis is more frequently associated with subgingival margins due to the increased accumulation of plaque.

Possibly the most significant aspect of margin location was addressed through a study performed by Christensen [7], where it was demonstrated that dentists were able to detect marginal discrepancies easier when the location of the margin was supragingival. These same dentists accepted larger marginal discrepancies when the margins became

subgingival. This shows there is a greater likelihood that unacceptable crowns will be cemented and cause problems for the patient in the future. Therefore, the ideal marginal location is supragingival, especially with newer ceramic materials that mask the margins and blend into tooth structure.

Unfortunately, many restorations require subgingival margins, in particular if caries are present below the level of the gingiva or if added preparation height is needed for adequate retention and resistance form. Other indications include extension of the preparation margins on sound tooth structure beyond existing restorative materials, cementum sensitivity, and esthetics [13, 28]. Despite the problems faced by subgingival margins, Richter and Ueno [31] demonstrated that it is more important for the crown margin to have excellent quality and fit rather than the location of the margin on the tooth.

One of the many issues with subgingival margins is the increased difficulty in obtaining accurate impressions and correctly evaluating the margins on the definitive restoration [32]. Christensen [7] examined the ability of dentists to evaluate the marginal fit of gold inlays utilizing direct vision, an explorer, and radiographs. He found that dentists were not able to evaluate consistently the marginal gaps of subgingival areas and observed that using the explorer and visualizing the margin was more reliable than simply using the explorer and radiograph. The result of poor quality impressions is ill-fitting restorations. If inadequately evaluated, unacceptable restorations are cemented and can lead to plaque retention followed by gingival inflammation and caries. Felton [11] studied the effect of crown margin discrepancies on periodontal health. He evaluated 34 single crown restorations and eight fixed partial dentures; 25 were type III gold alloy, and 17 porcelain fused to metal restorations. The restorations had a range of service of four to

18.5 years in the mouth, and the margins were located subgingivally. The increase in marginal discrepancy between the metal and prepared tooth resulted in an increased gingival inflammation.

If marginal gaps are one of the primary etiologies leading to gingival inflammation, caries, or eventual non-restorability of a tooth, it is imperative to know which materials can provide accurate fitting to the natural tooth. Christensen[7] showed the marginal fit of cast metal restorations to be closely adapted to natural tooth structure with gaps ranging from 3 - 52 μm (on supragingival margins). Similarly, Chaffee et al [6] showed the marginal fit of porcelain fused to metal crowns average marginal gaps of 40 - 88 μm depending upon the crown margin design and technique used to add porcelain. A systematic review of the marginal fit of all-ceramic crowns was performed by Contrepois et al [8]. They found, for most systems available, that marginal discrepancies were within the realm of acceptability, and marginal gap size should not be the deciding factor when choosing types of all-ceramic crowns. With the materials currently used to fabricate crowns, the above studies, along with others [19, 34, 37], show the materials and techniques are quite able to produce accurately fitting crowns. It simply comes down to whether or not the crown actually does fit the patient's tooth. The evaluating dentist determines this at the time of delivery.

Methods for evaluating marginal fit are threefold: tactile, visual, and radiographic. An impression with the crown temporarily seated can also aid in evaluating fit but is not typically practiced by dentists, even though Assif et al [2] found this procedure to be the best method of evaluating crown margins as compared to using an explorer or radiograph. Assif showed that even in crowns with supragingival margins, there were numerous

misreadings with an explorer crossing over the crown/tooth junction. It was also increasingly more difficult to assess when the margins were subgingival or interproximal. Radiographs of cast restorations were shown not to be significantly more accurate than using the explorer [21]. It was found difficult to detect discrepancies of 120 μm or less by radiographic evaluation, but stated dental radiographs may be the only tool to examine interproximal subgingival margins. In a study performed by Weyns et al [47], it was shown that radiographs alone were not reliable in diagnosing small marginal defects of 100, 50, and 10μm. As the defect increased in size, however, the results improved. In contrast, over a decade later, Opdam et al [26] showed, while determining if adhesive thicknesses could be detected radiographically, radiographs could reliably detect radiolucent gaps greater than 40 μm in interproximal restorations. This demonstrates that radiographs are capable of detecting gaps that would be considered clinically unacceptable along crown margins. Even though radiographs may not be entirely consistent as seen in the Weyns [47] study, for subgingival interproximal margins, they remain the only practical means of proximal and subgingival margin assessment. Improvements in technology, film speeds, and digital radiographs may have improved image readability and quality as seen with the differing results of Opdam et al [26]. However, no research currently exists pertaining to marginal evaluation of crowns, especially ceramic crowns, using digital radiography.

Digital radiography has slowly been replacing traditional film radiography for the last few decades with the ever increasing "need" for new technology and with electronic records becoming the norm. Digital radiographs offer many advantages over analog films: efficiency, potential for lower x-radiation doses, storability and transferability of the data [46]. In terms of accuracy, images captured through conventional film radiography

and digital are at least equivalent; digital potentially becoming better as technology progresses further [12].

Studies by Christensen [7], Chaffee [6], and Contrepois [8] on marginal discrepancies of single restorations using various systems and materials have been reported, but the radiographic evaluation of full coverage restorations has not been reported. Radiographically, there are many factors affecting an individual's perception of porcelain and metal margin fitness. As is seen in the Weyns [47] study, angulation plays a very important role in accurately determining if margins are well adapted. Standard dental radiographs are a two dimensional image of a three dimensional object. These images have overlap, may be over or under exposed, include certain materials that might prevent other structures from being observed, and dentists' interpretations of radiographs vary. Natural physiologic variables, such as quality of eyesight and shade determination, cause limitations in reading radiographs in order to determine the difference between unacceptable margins and well-adapted margins.

As stated above, radiographs are helpful in assessing marginal fit of metal crowns in areas where direct vision is not possible. They are used routinely to detect caries and remaining cement around crown margins. The reliability of radiographs, digital or film, in evaluating marginal adaptation of ceramic crowns has yet to be demonstrated. This is important in clinical situations where subgingival interproximal margins are present. The issue with these newer materials tends to be the differences in radiodensity when compared to full cast and porcelain-metal crowns [14, 24]. Therefore, it is necessary to determine if these new materials can be radiographically evaluated accurately at the time of delivery for the improved longevity of the restoration and oral health of the patient.

Little research has been done concerning the radiopacity of all-ceramic crowns in relation to natural tooth structures or the radiographic assessment of marginal seating of all ceramic crowns.

One study was performed at the University of Maryland School of Dentistry by Ossa[27]. Her results, using conventional radiography, showed that more radiolucent crowns had more false negatives (crown marginal adaptation evaluated to be open or unacceptable when measured closed or acceptable) as compared to metal crowns that had significantly higher rates of false positives (crown marginal adaptation evaluated to be closed when measured open). Table 1 illustrates false negatives and positives.

Table 1: False positive and false negative definitions

Measured Evaluation	Clinician Evaluation	
	Correct	Incorrect
≤ 80 μm (closed margin)	Accurate	False Negative
> 80 μm (open margin)	Accurate	False Positive

Ossa's research showed that all-ceramic crowns may help prevent ill-fitting crowns from being placed more often when compared to porcelain fused to metal. However, her research did not test the new IPS e.max lithium disilicate and IPS e.max ZirPress (fluorapatite) materials. They will be the focus of this study.

II. Purpose

The purpose of this study was to determine if digital radiographic evaluation was an accurate method for assessing the interproximal marginal closure of ceramometal crowns, lithium disilicate, and fluorapatite crowns. The purpose was also to determine if those inaccuracies were random or specific with regards to false positives and false negatives. This study investigated if there was a statistical difference in percentage of correct marginal adaptation evaluations between prosthodontists and general dentists, as well.

III. Power Analysis and Research Hypotheses

A correct radiographic marginal adaptation evaluation of 75% was the predicted result for the power analysis due to numerous potential errors that could occur that would have an impact on the outcome of the radiographs or evaluations being performed. During the radiograph making process, poor quality, difficult patients, or unseating of the crown might have a negative impact upon correct diagnoses. Seventy five percent would be a reasonable expected result.

Testing the ability to radiographically evaluate marginal adaptivity for all dentists, the result of the power analysis of a chi square goodness of fit test, with an n of 23, a one-tailed test, a proportion accuracy of 75%, and a $p \leq 0.05$, power was equal to 81%. The result of the power analysis for the secondary hypothesis, using a chi square test of independence, using an n of 57, a one-tailed test, a proportion accuracy of the prosthodontists at 85% and general dentists at 65% correct evaluation of marginal adaptivity, and a $p \leq 0.05$, power was equal to 80%. This sample size was more than met from 10 general dentists and 11 prosthodontists each individually evaluating 20 radiographs for a total N of 420 per crown.

1) Individual Crowns

a. Ceramco 3 - Ceramometal crown

i. Null – No significant difference will exist for ceramometal crowns between correct and incorrect evaluations for measured closed or open margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

ii. Specific Research Hypothesis – For ceramometal crowns, clinicians will be significantly more likely to correctly evaluate closed margins as opposed to open margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

b. Monolithic lithium disilicate crown

i. Null – No significant difference will exist, for lithium disilicate crowns, between correct and incorrect clinician evaluations for measured closed or open margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

ii. Specific Research Hypothesis – For lithium disilicate crowns, clinicians will be significantly more likely to correctly evaluate open margins as opposed to closed margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

c. Monolithic fluorapatite crown

i. Null – No significant difference will exist, for fluorapatite crowns, between correct and incorrect clinician evaluations for measured closed or open margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

ii. Specific Research Hypothesis – For fluorapatite crowns, clinicians will be significantly more likely to correctly evaluate open margins as opposed to closed margins for

1. All Clinicians.

2. Prosthodontists.

3. General Dentists.

2) General Dentists and Prosthodontists

a. Null – No significant difference will exist between general dentists and prosthodontists evaluation correctness of measured crown marginal adaptation for

i. All Crowns

ii. Ceramco 3 - Porcelain fused to metal crown

iii. Monolithic lithium disilicate all-ceramic crown

iv. Monolithic fluorapatite all-ceramic crown

b. Specific Research Hypothesis – Prosthodontists will be significantly better at correctly evaluating measured crown marginal adaptation than general dentists for

i. All Crowns

ii. Ceramco 3 - Porcelain fused to metal crown

iii. Monolithic lithium disilicate all-ceramic crown

iv. Monolithic fluorapatite all-ceramic crown

IV. Materials and Methods

One recently extracted, intact tooth (a mandibular second premolar) was embedded in a clear autopolymerizing acrylic resin block (2 1/2" x 3" x 2"; Caulk Orthodontic Resin). The tooth was free of any restorations. The block was fabricated by making a rectangular shaped matrix from boxing wax (Heraeus Kulzer Inc., Armonk, NY). The acrylic resin was mixed according to the manufacturer instructions and poured into the matrix. The tooth was lubricated and placed, utilizing a surveyor, with the long axis perpendicular to the surface of the table. The tooth was prepared using a milling machine (PFG 100, Dental Cendres and Metaux SA, Biel-Bienne, Switzerland) with a preparation design of a 360° chamfer,1.5 mm in width, 2 mm occlusal reduction, and a total occlusal convergence of 20°. An effort was made to simulate in vivo preparations where the margin was scalloped (higher mesial and distal than buccal and lingual). A preliminary impression was made for the tooth using a stock tray and an irreversible hydrocolloid impression material (Fast Set Jeltrate, Dentsply Caulk; Burlington, NJ), and poured in a type III dental stone (Microstone; Whip-Mix Corp, Louisville, KY). Two sheets of baseplate wax (Modeling wax, PemacoInc, St. Louis, MO) were used as a spacer, and three custom trays were fabricated using autopolymerizing acrylic resin. Final impressions were made for the tooth with medium and light body vinyl polysiloxane (Aquasil LV, Caulk), and poured with type IV die stone material (ResinRock, Whip-Mix Corp., Louisville, KY). The dies were separated from the impressions and trimmed. The margins were marked with a red pencil and cyanoacrylate (Eastman 910, Rochester, NY) was applied on the margins. Two coats of die spacer material (Tanaka Die spacer, Tanaka Dental Products, Skokie, IL) were then applied approximately 1mm away from the

margin. The tooth was removed from the block and stored in saline at room temperature, except during the period of crown preparation, impression making, and radiograph exposure. To fabricate the E.max Press, ZirPress, and metal framework for the ceramometal crown, a wax pattern with adequate proximal surfaces, that was well adapted to the margins of the die when examined under stereomicroscopy, was fabricated using margin wax and green wax (Pro-Art. Williams Premium, Amherst, NY).

Three crowns were fabricated for the prepared mandibular premolar. All crowns were fabricated by the principal investigator. To fabricate the PG-200 framework for the ceramometal crown, the wax was invested (Beauty Cast, Whip-Mix Corp., Louisville, KY) in a casting ring with a liner (Kaoliner liner, Dentsply International, Burlington, NJ). Induction heating was used, and the crown was cast with a centrifugal casting machine (BEGO, Lincoln, RI). The casting was divested after it cooled for 45 minutes, sandblasted with aluminum oxide, cleaned in an ultrasonic cleaner with distilled water for five minutes, and examined for nodules under a microscope (Light microscope Nikon Corp., Zentrum, Zurich) and Scion imaging software (Scion corp., Frederick, MD). Any nodules on the internal surfaces of the casting were removed with a No. 1/4 carbide bur. The IPS e.max lithium disilicate and IPS e.max ZirPress (fluorapatite) crowns were invested (IPS PressVEST Speed, Ivoclar) and pressed in the Programat EP 5000 and divested as per the ceramometal crown protocol.

After the crowns were fabricated and polished using the appropriate polishing discs and wheels (Brasseler polishing kits for porcelain, lithium disilicate), the accuracy of fit on the prepared tooth was evaluated with visual examination and by using a sharp explorer. The crowns were then examined with a stereomicroscope (SZX10

Stereomicroscope, Olympus). Marginal adaptation of each crown, when it was fully seated on the tooth, was measured at four locations: mid-mesial, mid-distal, mid-buccal, and mid-lingual marginal areas of the crown. Only crowns with less than 20 μm mean marginal openings were accepted for this study and were further evaluated using radiographs.

A rectangular block of pressure treated wood (12" X 4" X 2") was used to accommodate the acrylic resin block containing the tooth, the radiographic sensor holder, and the electronic digital caliper (Model: 62379-531, VWR Digital Calipers, Radnor, PA). The acrylic block was placed in the caliper and was fixed with sticky wax (Whip-Mix Corp., Louisville, KY). Each crown was attached to the opposing end of the caliper with sticky wax during measurements. An initial reading for each crown was made at complete closure and incremental increases were calculated from there. The digital caliper was attached to the wood block using a Tee Plate (3”x 3”, zinc, Ace Hardware) screwed to the block and zip ties (4” long, nylon, Ace Hardware) were used to hold the caliper in the desired position. The digital caliper was used to increase the marginal opening of the tested crowns in increments of 20 μm. The radiographic sensor was attached to the holder which was attached to the wood block using zip ties and an additional Tee Plate. Another segment of wood was placed on the block to elevate the collimation tube and be a position indicator for 80° and 90° angles using a protractor (Fiskars 12” Protractor, Ace Hardware) to measure the angle. This block of wood was attached with a hinge (1-1/2”, zinc, Ace Hardware) to align the collimation tube of the x-ray unit correctly with the crowns. A bubble gauge (level line 3”, Ace Hardware) was

used to ensure the collimation tube was 90° to the crowns when radiographs were made (Figure 1).

Figure 1: Radiographic Sensor Alignment and Crown Measurement Jig

A twelve-inch collimation cone was used to make radiographs at two different angles (perpendicular and 80°) to the long axis of the tooth. The cone was placed 1" in front and perpendicular to the long axis of the tooth in the horizontal plane. Radiographs were made at marginal discrepancies of <21; 21-40; 41-60; 61-80; 81-100; 101-120; 121-140; 141-160; 161-180; 181-200 μm. A total of 10 radiographs are made. Each film was exposed at 63 kVp for 0.1 seconds and 8 mA. This procedure was repeated for all the crowns tested in this study and finished the same day. The procedure was repeated with an 80° angle to the tooth. These increments and angles were obtained from research performed by Dr. Ossa and the limitations of the calipers (resolution of 10 μm). In Ossa's research, she used 11 general dentists total, each evaluating 60 radiographs, and showed sufficient N for the results to have significance[27].

Ten general dentists and eleven prosthodontists (full or part-time faculty at the University of Maryland, School of Dentistry) individually viewed the radiographs on a standardized computer monitor (NEC EA221WM 22 inch monitor) using Romexis (Planmecca) radiographic software. They viewed the radiographs in a single dark room and had no ability to adjust the contrast or brightness. A survey was given with the images and for each radiograph they were asked to grade them as clinically acceptable or unacceptable. The 10 general dentists and eleven prosthodontists selected were all licensed to practice, actively treating patients, routinely using ceramic crowns in their practices, and were blinded to the experimental conditions. Clinical acceptance is determined at or below 80 μm marginal opening.

Statistical analysis: Chi square (χ_2) goodness of fit test and test independence were used to analyze the categorical data comparing clinician evaluation to actual measured marginal seating and compare prosthodontist to general dentist with relation to percentage of correct evaluations (No comparison of angulation differences were statistically analyzed). IBM SPSS® software was used for the data input and computation. A *p* of .05 was considered significant.

V. Results

This study investigated the ability of clinicians to radiographically assess crown margin adaptation, specifically for ceramometal, IPS e.max lithium disilicate, and IPS e.max ZirPress (fluorapatite). The study also compared results between prosthodontists and general dentists.

The percentage of correct radiographic marginal assessments, across all crowns and clinicians, was measured to be 66.0%. Individually, the percentage of correct evaluations was 48.8%, 72.1%, and 76.9%, for the ceramometal, lithium disilicate, and fluorapatite crown respectively. (Table 2)

Hypothesis 1: Evaluations of Individual Crowns

The section looks into the ability to correctly identify marginal adaptation of a crown. Statistical analysis of the data revealed there were significant differences in the types of incorrect evaluations for each crown. For each table, under the "measured marginal adaptivity" the adaptation is listed as "≤ 80 μm" or "> 80 μm" for acceptable/closed margin and unacceptable/open margin crowns, respectively. Under the second column of evaluations, correct or incorrect radiographic evaluations of marginal adaptivity are listed.

Table 2: Correct Evaluations for All Clinicians

	Correct Evaluations
All crowns	66.0%
Ceramometal	48.8%
Lithium Disilicate	72.1%
Fluorapatite	76.9%

Hypothesis 1.a.1: All clinicians, ceramometal crown

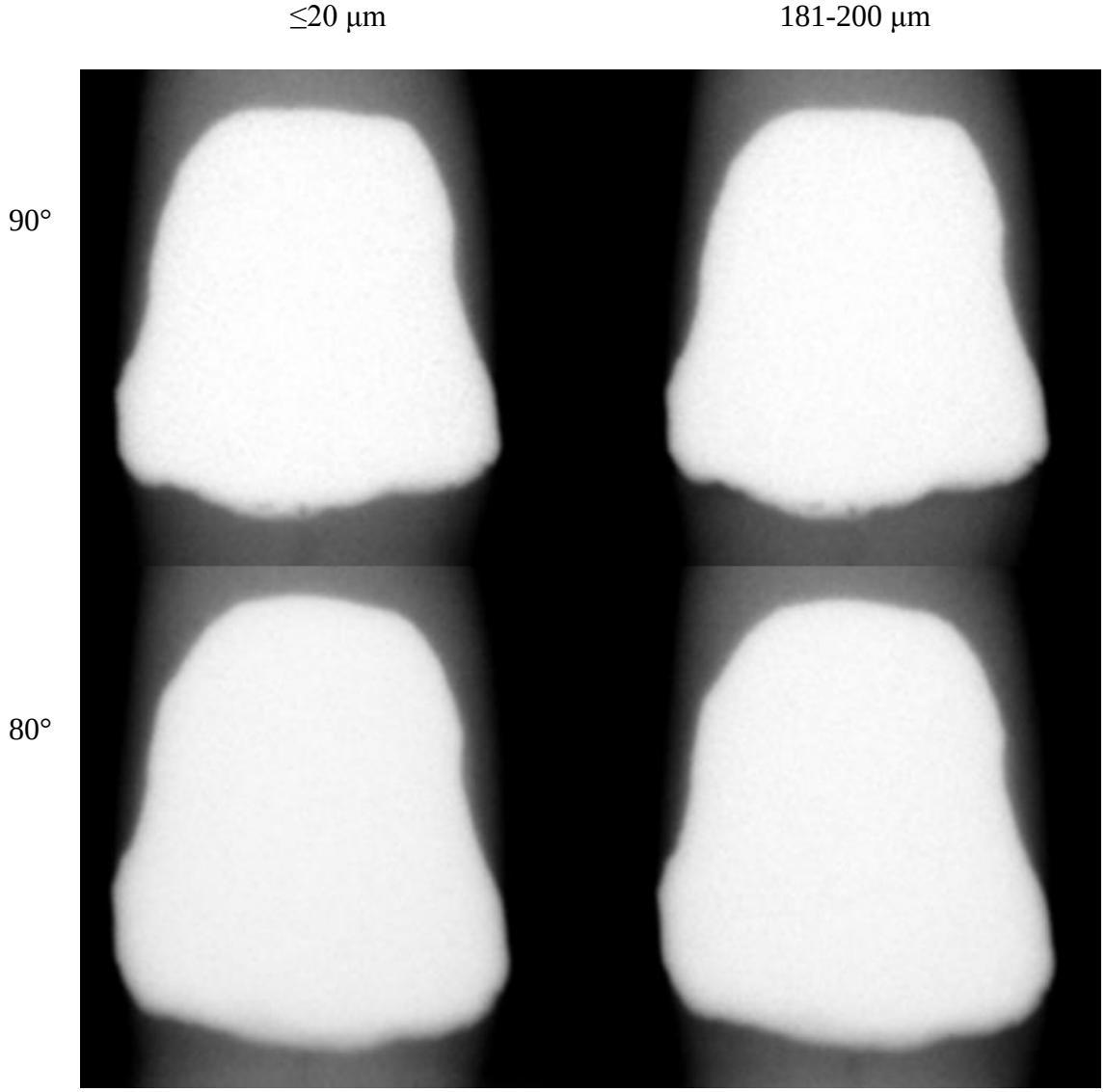
For the ceramometal crown, combining all clinician evaluations, the percentage of correct evaluations of measured acceptable crown margins was 89.9%. The percentage of correct evaluations of measured unacceptable crown margins was 21.4% (Table 3). The radiographs evaluated include the sample images in Figure 2.

Table 3: Ceramometal crown, evaluated by all clinicians ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Ceramometal Crown Evaluation	
	Correct	Incorrect
≤ 80 μm (closed margin)	151 (89.9%)	17 (10.1%)[a]
> 80 μm (open margin)	54 (21.4%)	198 (78.6%)[b]

a = false negative (closed margin evaluated open), b = false positive (open margin evaluated closed)

Figure 2: Ceramometal Sample Radiographs



Hypothesis 1.b.1: All clinicians, lithium disilicate crown

For the Lithium disilicate crown, combining all clinician evaluations, the percentage of correct evaluations of measured acceptable crown margins was 33.9%. The percentage of correct evaluations of measured unacceptable crown margins was 97.6% (Table 4). The radiographs evaluated include the sample images in Figure 3.

Table 4: Lithium disilicate crown evaluated by all clinicians ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Lithium Disilicate Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	57 (33.9%)	111 (66.1%)[a]
> 80 μm	246 (97.6%)	6 (2.4%)[b]

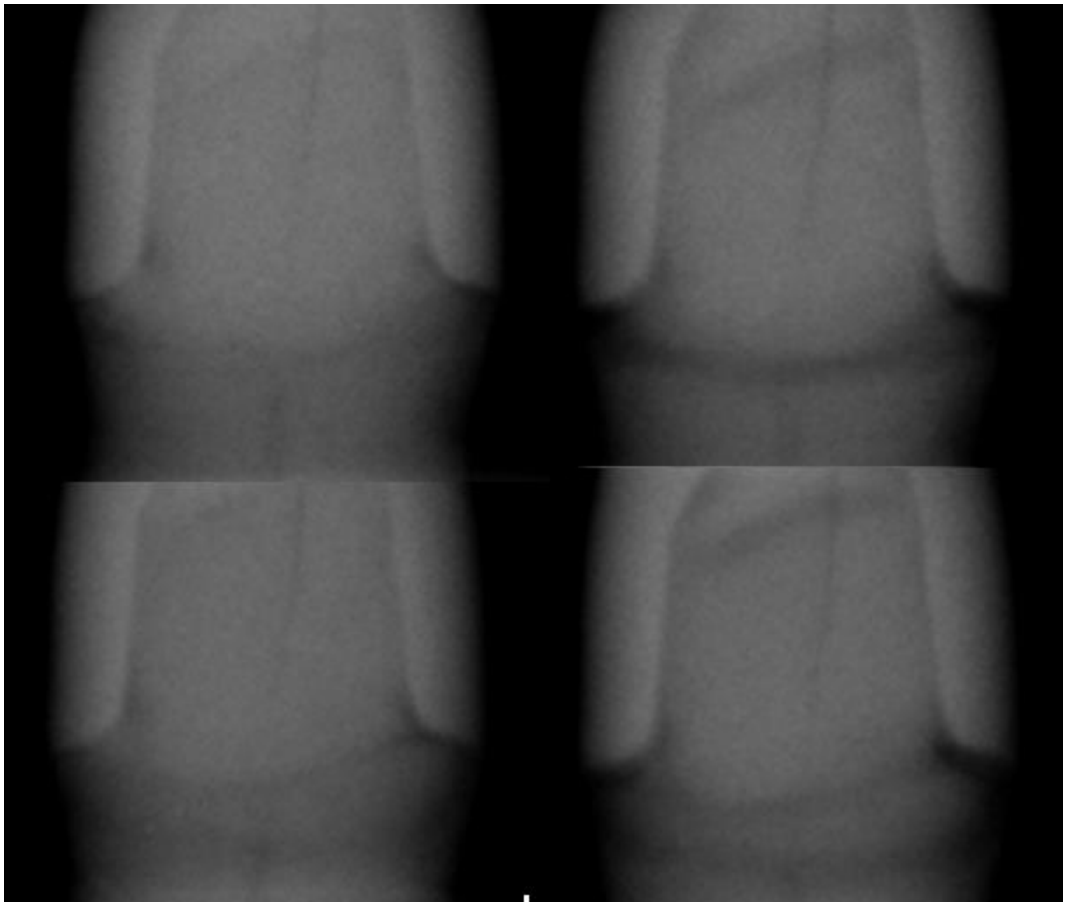
a = false negative, b = false positive

Figure 3: Lithium Disilicate Sample Radiographs

≤20 μm 181-200 μm

90°

80°



Hypothesis 1) c.1: All clinicians, fluorapatite crown

For the Fluorapatite crown, combining all clinician evaluations, the percentage of correct clinician evaluations of measured acceptable crown margins was 54.2%. The percentage of correct evaluations of measured unacceptable crown margins was 92.1% (Table 5). The radiographs evaluated include the images in Figure 4.

Table 5 Fluorapatite crown evaluated by all clinicians ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Fluorapatite Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	91 (54.2%)	77 (45.8%)[a]
> 80 μm	232 (92.1%)	20 (7.9%)[b]

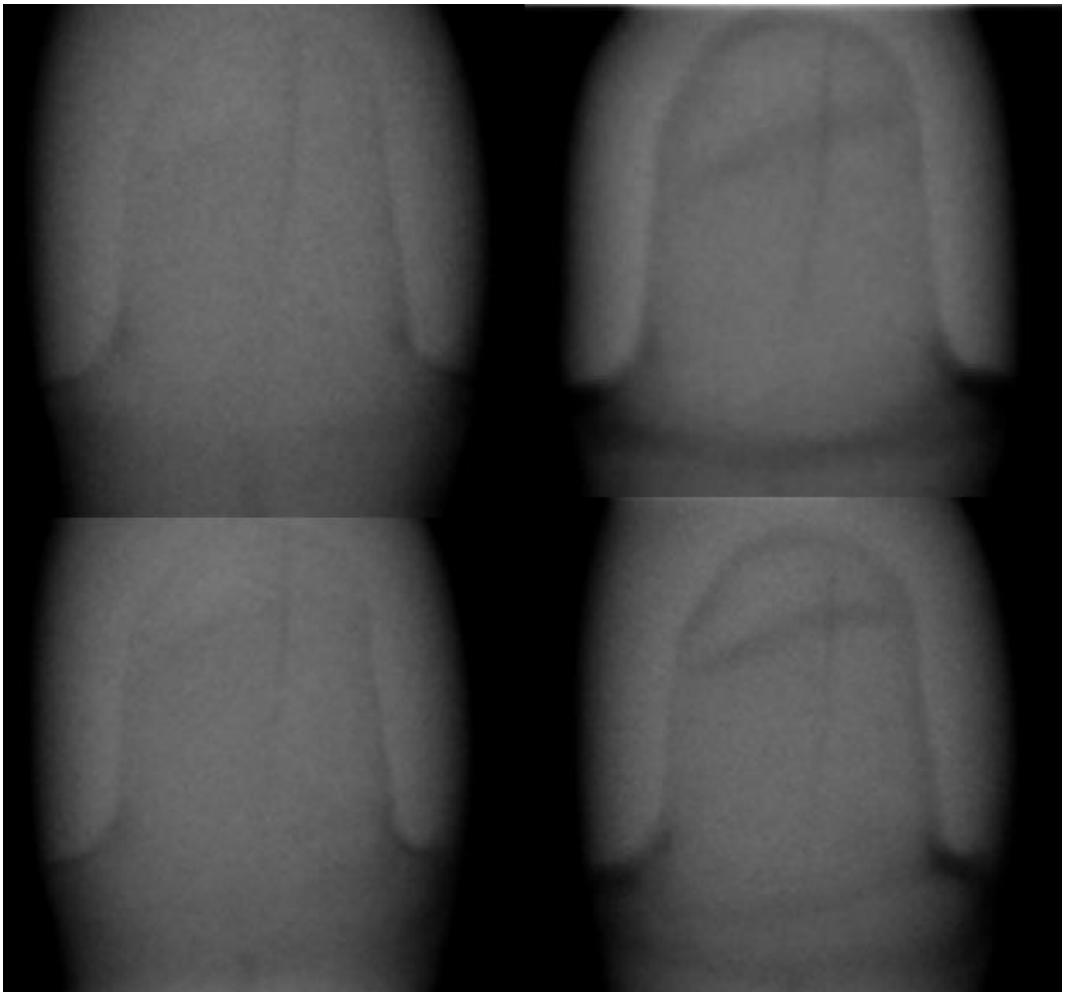
a = false negative, b = false positive

Figure 4: Fluorapatite Sample Radiographs

≤20 μm 181-200 μm

90°

80°



Hypothesis 1.a.2: Prosthodontists, ceramometal crown

For the ceramometal crown, the percentage of correct prosthodontist evaluations of measured acceptable crown margins was 95.5%. The percentage of correct evaluations of measured unacceptable crown margins was 5.8% (Table 6)

Table 6: Ceramometal crown, prosthodontist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Ceramometal Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	84 (95.5%)	4 (4.5%)[a]
> 80 μm	19 (5.8%)	113 (94.2%)[b]

a = false negative, b = false positive

Hypothesis 1.b.2: Prosthodontists, lithium disilicate crown

For the lithium disilicate crown, the percentage of correct prosthodontist evaluations of measured acceptable crown margins was 43.2%. The percentage of correct evaluations of measured unacceptable crown margins was 96.2% (Table 7).

Table 7: Lithium disilicate crown, prosthodontist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Lithium Disilicate Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	38 (43.2%)	50 (56.8%)[a]
> 80 μm	127 (96.2%)	5 (3.8%)[b]

a = false negative, b = false positive

Hypothesis 1.c.2: Prosthodontists, fluorapatite crown

For the fluorapatite crown, the percentage of correct prosthodontist evaluations of measured acceptable crown margins was 63.6%. The percentage of correct evaluations of measured unacceptable crown margins was 90.9% (Table 8).

Table 8: Fluorapatite crown, prosthodontist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Fluorapatite Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	56 (63.6%)	32 (36.4%)[a]
> 80 μm	120 (90.9%)	12 (9.1%)[b]

a = false negative, b = false positive

Hypothesis 1.a.3: General dentists, ceramometal crown

For the ceramometal crown, the percentage of correct general dentist evaluations of measured acceptable crown margins was 83.8%. The percentage of correct evaluations of measured unacceptable crown margins was 29.2% (Table 9).

Table 9: Ceramometal crown, general dentist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Ceramometal Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	67 (83.8%)	13 (16.2%)[a]
> 80 μm	35 (29.2%)	85 (70.8%)[b]

a = false negative, b = false positive

Hypothesis 1.b.3: General dentists, lithium disilicate crown

For the lithium disilicate crown, the percentage of correct general dentist evaluations of measured acceptable crown margins was 23.8%. The percentage of correct evaluations of measured unacceptable crown margins was 99.2% (Table 10).

Table 10: Lithium disilicate crown, general dentist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Lithium Disilicate Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	19 (23.8%)	61 (76.2%)[a]
> 80 μm	119 (99.2%)	1 (0.8%)[b]

a = false negative, b = false positive

Hypothesis 1.c.3: General dentists, Fluorapatite crown

For the Fluorapatite crown, the percentage of correct general dentist evaluations of measured acceptable crown margins was 43.8%. The percentage of correct evaluations of measured unacceptable crown margins was 93.3% (Table 11).

Table 11: Fluorapatite crown, general dentist evaluated ($p \leq .001$)

Measured Marginal Adaptivity	Radiographic Fluorapatite Crown Evaluation	
	Correct	Incorrect
≤ 80 μm	35 (43.8%)	45 (56.2%)[a]
> 80 μm	112 (93.3%)	8 (6.7%)[b]

a = false negative, b = false positive

Summary of Hypothesis 1:

The null hypothesis was rejected for all crowns regardless of clinician type. A significant difference existed between correctness of closed versus open marginal adaptation evaluations. For ceramometal crowns, there were significantly more correct evaluations for measured closed (≤ 80 μm) marginal adaptations compared to open (> 80 μm). However, for lithium disilicate and fluorapatite crowns, there were significantly more correct evaluations for measured open marginal adaptations compared to closed.

Hypothesis 2: Comparison of Prosthodontists to General Dentists

This section studied the percentage of correct evaluations for prosthodontists and general dentists. For each table, under the "Clinician" column, the different types of clinicians are listed. Under the second column "Evaluation," the samples correctly evaluated and incorrectly evaluated are listed.

Hypothesis 2.i: Prosthodontists compared to general dentists, all crown

Prosthodontists had a correct evaluation percentage of 67.2% and general dentists 64.5% when evaluating all crown marginal adaptivity. No significant difference was found between the groups (p = .164) (Table 12)

Table 12: Prosthodontists compared to general dentists, all crowns (p = .164)

Clinician	All Crown Evaluation	
	Correct	Incorrect
Prosthodontist	444 (67.2%)	216 (32.8%)
General Dentist	387 (64.5%)	213 (35.5%)

Hypothesis 2.ii: Prosthodontists compared to general dentists, ceramometal crown

Prosthodontists had a correct evaluation percentage of 46.8% and general dentists 51.0% when evaluating ceramometal crown marginal adaptivity. No significant difference was found between the groups (p = .224) (Table 13).

Table 13: Prosthodontists compared to general dentists, ceramometal crown

(p = .224)

Clinician	Ceramometal Crown Evaluation	
	Correct	Incorrect
Prosthodontist	103 (46.8%)	117 (53.2%)
General Dentist	102 (51.0%)	98 (49.0%)

Hypothesis 2.iii: Prosthodontists compared to general dentists, lithium disilicate crown

Prosthodontists had a correct evaluation percentage of 75.0% and general dentists 69% when evaluating lithium disilicate crown margin adaptivity. No significant difference was found between the groups (p = 0.104) (Table 14).

Table 14: Prosthodontists compared to general dentists, lithium disilicate crown

(p = .104)

Clinician	Lithium Disilicate Crown Evaluation	
	Correct	Incorrect
Prosthodontist	165 (75.0%)	55 (25.0%)
General Dentist	138 (69.0%)	62 (31.0%)

Hypothesis 2.iv: Prosthodontists compared to general dentists, fluorapatite

Prosthodontists had a correct evaluation percentage of 80.0% and general dentists 73.5% when evaluating fluorapatite crown marginal adaptivity. No significant difference was found between the groups (p = 0.072) (Table 15).

Table 15: Prosthodontists compared to general dentists, Fluorapatite crown

($p = .072$)

Clinician	Fluorapatite Crown Evaluation	
	Correct	Incorrect
Prosthodontist	176 (88.0%)	44 (22.0%)
General Dentist	147 (73.5%)	53 (26.5%)

Hypothesis 2 Summary:

The null hypothesis was accepted for all crown types with relation to general dentist and prosthodontic comparisons in correctness of evaluation of marginal adaptivity. Statistical analysis of prosthodontists compared to general dentists in ability to determine crown margin adaptivity yielded no significant difference for all categories tested.

VI. Discussion

This study looked at the ability of a general dentist or a prosthodontist to radiographically evaluate the marginal adaptation of a crown. It focused on three types of crowns, a ceramometal crown with a metal margin, an IPS e.max lithium disilicate crown, and an IPS e.max ZirPress (fluorapatite) crown. The study also investigated if a difference in evaluation ability between prosthodontists and general dentists existed.

Hypothesis 1:

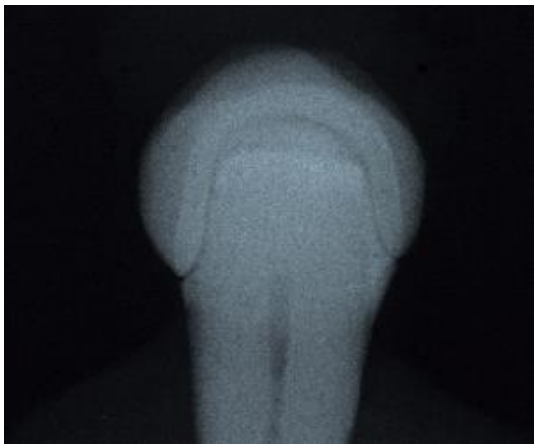
The study rejected the null hypothesis for clinician marginal adaptation evaluation correctness for every crown type and every clinician type. There were significantly different abilities to determine marginal adaptation ≤ 80 as acceptable and > 80 as unacceptable for each crown type. For Ossa's investigation, the most radiolucent crown (Procera Alumina with veneering porcelain, Figure 5) found a significant difference in percentage correctly evaluated as open (percentage correct ≤ 80 = 33.3%) and closed (> 80 = 80.3%). The radiolucent crowns tested in this study (lithium disilicate and fluorapatite) similarly had a significantly higher percentage of correct evaluations for the open marginal adaptations. The full cast crown in Ossa's study was found to be significantly more correct for closed (≤ 80) than for open (> 80) with 97.0% and 16.7% correct respectively. The correspondingly radiopaque crown in the current study was found to also have significantly more correct evaluations for closed marginal adaptations compared to open (89.9% and 21.4% for the ≤ 80 and > 80). The other crowns studied in Ossa's research had differing results, however, and did not necessarily relate to any crown in the current study, possibly because of the marginal designs of the crowns. Different marginal increments were used in Ossa's research and might have had an

impact on whether her results were significant or not (a smaller sample size in general and fewer ≤ 80 increments than the current study). Ossa studied 80° and 90° angulations but did not compare them to one another, similar to this study, but she did keep the angulations separated, whereas all angles were grouped to maintain sufficient sample sizes and account for variations in radiographic technique in the current investigation.

The results showed that the assumption of a 75% correct marginal adaptation evaluation was not present for all crowns. With the ceramometal crown being the worst in regards to correctness (48.8%) and the lithium disilicate and fluorapatite being closer to and slightly surpassing the initial assumption of 75% (72.1%, 76.9% respectively). Relating back to Ossa's study, the full cast crown was 43.4% correct in marginal closure evaluation, the Procera Alumina (most radiolucent crown) was 64.6% correct. The other crowns were Procera Zirconia (79.3%), Ceramometal with porcelain butt-margin (65.7%), and In-Ceram Zirconia (77.8%).

For an in vitro study, one would assume results to be better than a clinical study because sources of error are better controlled. Due to the reliance of the general dentists' and prosthodontists' interpretations of the radiographs, however, it is likely that this would more closely relate to clinical results if the same study was performed with patient radiographs, as opposed to artificially mounted single tooth radiographs.

Figure 5: Procera Porcelain Fused to Alumina Crown Radiograph from Dr. Ossa's Research



When reviewing the protocol for Ossa's crown/radiograph jig design, a problem was encountered with the micrometer that was used. The measuring table rotated when adjusted. This meant the crowns had to have been disconnected from the jig each time a new measurement was made. She reported using sticky wax to fix the crowns to the jig and there was likely sufficient error incorporated into the opening when this was re-glued every increment change. Comparing the radiographs visually, the openings she presented to the dentists appear much larger than the openings encountered in the current study. This problem may have had a significant impact on the outcome of Ossa's research and makes it difficult to compare the results of the two studies. Numerous other design aspects were different in the two studies: digital radiology, different crowns, different tooth, different jig, different dentists, prosthodontists used, and different marginal increments (including 4 acceptable marginal adaptations as opposed to 3).

Continuing the discussion of marginal adaptation evaluation, studies showing tactile sensitivity for marginal discrepancies when margins are subgingival have also found a range in the size of marginal openings that were able to be detected. Christensen's study [28] tested both tactile and visual, and tactile and radiographic marginal assessment post cementation of gold inlays. The range for proximal margins was 34-119 μm while the range for occlusal margins of the gold inlay was 2-51 μm. This corresponds with the greater percentage of correct evaluations of closed ceramometal marginal adaptations in the current study.

This might mean there is a larger amount of ill-fitting crowns that are being cemented due to clinician inability to determine proper fit when placing ceramometal or full cast crowns. Some authors argue that poor marginal adaptation no longer poses a

problem with the use of newer resin and resin-modified glass ionomer cements[10]. This becomes a slippery slope, however, and could be the foundation for lower quality dentistry in the future. Similarly, with resin cements being more widely used, the film thickness is becoming an issue. Studies have shown that resin-modified glass ionomer cements and resin cements are better at initially sealing margins, but no long term studies are present[10, 33]. These same studies are also showing larger vertical cement gaps in the 75-80 μm range. A good study might examine the fit of crowns on extracted teeth compared to the dies they were created on. A diagnosis for the tooth to be extracted and comparison of fit (and longevity) might provide insight to a range of acceptable marginal adaptation of a crown for improved long-term success. Unfortunately, this would be a lengthy endeavor with many variables to control and is likely unrealistic at the current time.

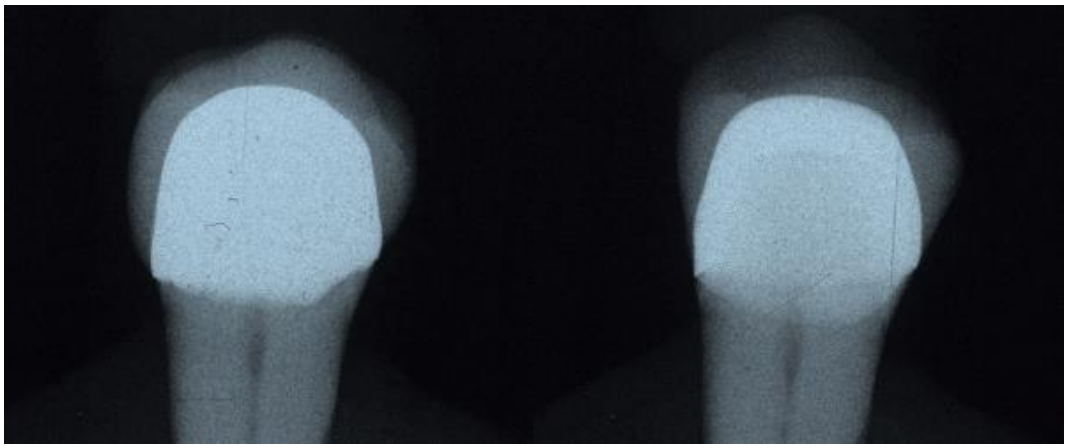
The results from the first hypotheses were further broken down into the categories of false positives and false negatives. A false negative (measured closed or margins ≤ 80 μm, but determined unacceptable by the clinician) results in a new crown being fabricated. A false positive (measured open or >80 μm, but determined acceptable by the clinician) results in an ill-fitting crown cemented in the patient's mouth. Looking into the specific inaccuracies for each crown, it is seen that for the ceramometal crown with metal margin, marginal fit (vertically measured) can easily be masked by the crown material itself. This is likely the reason it led to a greater incidence of closed margins being accurately identified and a greater incidence of open margins being inaccurately identified (i.e. more false positives than negatives). What this potentially means is a clinician is more likely to cement an ill-fitting crown. This is an issue that would

primarily affect the patient. As stated earlier, ill-fitting crowns can lead to periodontal issues, higher risk of caries, and eventual restoration replacement or tooth loss associated with money spent on that tooth/tooth area. False positives do not impact the clinician unless the crown fails so soon that the patient seeks compensation for the additional treatment.

As for the ceramic crown materials (lithium disilicate and fluorapatite) clinicians were significantly better at identifying open crown margins than closed and thus, had more false negatives than positives. One reason influencing this result might be that the customary restoration was the ceramometal restoration. The ceramometal crown has historically been the gold standard for providing esthetics and strength because newer restorative materials had yet to be developed. Lithium disilicate and other millable or pressable restorations are replacing the ceramometal crown. Zirconia appears radiographically similar to ceramometal (radiopaque, Figure 6), and one may infer would be evaluated similarly, especially if monolithic, but the lithium disilicate restoration is very radiolucent (as traditional all ceramic crowns) and shows the margin of the tooth preparation very cleanly in the radiograph, as is seen in Figure 3. This also is seen, to a lesser extent, in the alumina core crown used in Ossa's research (Figure 5) which appears as a radiolucent line, imitating an open margin. The ability to distinguish between actual open margins and closed margins thus becomes more difficult, particularly when a dentist is accustomed to viewing ceramometal crowns radiographically. In this study, the all ceramic crowns were evaluated more likely to be unacceptable whether measured well adapted or poorly adapted.

Another reason for these results might be the lack of research into this topic. There has been no consensus on what a radiolucent, well adapted margin should look like and therefore little evidence-based teaching on the subject. Older dentists are learning through their experience and the newer generation of dentists is learning from the older. Researching further into the matter would be prudent, at the very least, to help in providing a baseline to how a closed margin of an all ceramic or radiolucent crown appears on a radiograph. Going with what we know and are taught about radiopaque restorations, dentists are more likely, when seeing a radiolucent line or area, to assume the crown doesn't fit well.

Figure 6: Procera and In-Ceram Porcelain Fused to Zirconia Crown Radiographs from Dr. Ossa's Research



The impact of calling an acceptably fitting crown unacceptable is twofold. It primarily inconveniences the clinician and their practice, as opposed to the patient, by requiring additional chair time and cost through lab fees and materials. It affects the patient forcing another appointment upon them and potentially taking more time from work or their family. If you are able to get the crown remade for free or reduced cost, it would also shift the burden to the dental lab. The lab loses out on the time, materials, and money to make a new crown or crowns for your patient.

Hypothesis 2:

The other purpose of this study was to determine if there was a significant difference between the general dentist's and prosthodontist's radiographic evaluation of marginal adaptation. The study accepted the null hypothesis that there was no significant difference between the two clinician types. The reason there was no difference might be due to the study having used dental school general dentists and prosthodontists. This fact might mean the faculty dentists are more critical of what is acceptable and what is unacceptable because they are teaching students on a regular basis and need to illustrate clinical superiority as opposed to clinical adequacy. Another possibility is not having the adjunctive tactile and visual input to add into the equation may have provided too little information to the general dentist and prosthodontist to make the best possible evaluations of the marginal adaptation of a crown. One would hope that there was no difference between prosthodontists and general dentists for the sake of the patient. This can at least provide reassurance to the patient that by going to a general dentist, he or she can [radiographically] evaluate the fit of a crown as well as a prosthodontist and thus still provide a high level of care to the patient. There are certainly other factors that

prosthodontic training provides that should ensure a prosthodontist would provide superior care, but in this category, specifically, it does not appear to be the case.

The fact that both prosthodontists and general dentists were only approximately 50% correct at identifying ceramometal marginal adaptation reinforces the fact that radiographs are not a sole means of diagnosis for marginal fit. The additional input of clinical examination of the crown plays an important role, and all methods of gathering information should be utilized to make the most informed diagnosis possible.

Limitations:

There are several limitations to this study that should be taken into consideration. The design of the crown preparation is a factor. If a marginal configuration is flat from buccal to lingual then there is a potential for a better reading of the radiograph if the angle of the radiograph is perpendicular to the long axis of the tooth. This study's crown preparation was made with a papilla in mind and thus a more coronal marginal height was present in the mid-interproximal area compared to the buccal or the lingual marginal heights. This would have increased the amount of overlap of the material during a radiographic verification of marginal fit and might have led to greater incidence of inaccurate evaluations.

The study only looked at radiographs and had no other clinical exam associated with it. As mentioned above, any crown that is evaluated would go through a visual, tactile, and radiographic evaluation prior to determining if it fits well and is deemed acceptable. This study required the clinicians to make judgements based upon radiographs alone and could have been the source of increased error.

Although lighting conditions and the equipment used were the same, the fact that the radiographs were random caused some brighter radiographic images to follow brighter images and darker to follow darker and every combination therein. This could have had a role in conditioning the eyes of the evaluator and could have altered their answers had a different order been presented or a blank screen been present between each image. Similarly, no teeth were adjacent to the single prepared tooth with a try-in crown. Having other teeth or restorations around the prepared tooth could have played a role in the determination of the closure of the crown. Although these were digital images, there was no allowance of the evaluator to adjust the contrast or brightness of the images. This could have allowed for a more critical evaluation of the radiograph and potentially more correct evaluations. This option was not permitted because the operator familiarity with the software could have had an impact on the evaluations.

There were two angles for each adaptation increment of each crown, but there is a wide range of what could be present in patient's mouth. Eighty degrees would be a conservative angulation error that might present itself in a patient, especially if tori or a shallow and flat palatal vault are present. Non-perpendicular angles would potentially impair the reader's ability to correctly evaluate marginal adaptation. This would be likely due to the overlap present. Again, this is dependent on the configuration of the marginal preparation and could be improved if off angles in the radiographic unit corresponded to preparation angles. Difference in angulation, however, and its impact on clinician evaluation of marginal adaptation was not one of the aims of the study; therefore the 80 and 90 angulations were grouped together. Although this might have been studied, patient

factors often limit what angulation can be achieved clinically and including different angles attempted to account for this.

The material selection for the two ceramic materials was specifically from Ivoclar®. The lithium disilicate restorations function well as stand-alone restorations or layered with fluorapatite after pressing or milling. The ZirPress material is specifically used for press technique onto zirconia frameworks. The fact that zirconia appears similar to metal radiographically was the reason this was left out. A ZirPress external margin for esthetics was the goal to show, albeit this was not an accurate representation because of the lack of radiopaque material that would be directly adjacent to it. This relates back to having radiopaque materials adjacent to radiolucent materials and there being a potential difference in evaluation accuracy because of it.

The accepted marginal closure of 80 µm was determined based upon detectable margins sub- and supragingivally by Christiansen[7] and the radiographic studies of McLean et al, Weyns et al, and Opdam et al[21, 26, 47] that ranged from 40 µm being the threshold to radiographically detect, to 100 µm being unable to be detected correctly. There is no current maximal opening that is defined as an "acceptable" margin, thus the definition in this study of 80 µm being the threshold may or may not be an accurate estimate.

There is a discrepancy that could affect the ceramometal crowns more than the ceramic crowns in this study. Because the ceramometal crown was found to statistically have more false positives, the fact that this study had more increments labeled as "open" marginal adaptations meant potentially more inaccurate evaluations for ceramometal and more accurate evaluations for the ceramic restorations. An ideal study would have had an

equal number of acceptable and unacceptable measurements. As it were, four acceptable marginal measurements and six unacceptable were studied. This difference of 40 responses per crown in each analysis might have made for very different percentages of correct evaluations, such that the ceramometal crown might have an increased correct evaluation percentage and the ceramic crowns a lessened correct evaluation percentage.

One last thing should be considered. With technology developing, newer and more accurate ways to produce well-fitting crowns, the question that comes to mind becomes “is this still applicable into the future?” The answer is most certainly yes. Even though crowns can be milled with an accuracy better than the studied 80 µm threshold for fit, there is still the requirement of an accurate impression, whether digital or traditional. With deep margins we need to use all the tools at hand to ensure we are delivering optimal restorations to our patients.

VII. Conclusions

The goal of this study was to provide information to aid in marginal closure determination when evaluating crowns radiographically and to provide guidance when examining crowns of different materials with relation to the common inaccuracies found in the study.

In this study, the percentages of correct marginal identification without clinical examination were not as high as might be expected. It is important to rely on all parts of the protocol to determine marginal fit of restorations at the time of their delivery and not focus entirely on any one factor, such as radiographs. Ceramometal crowns tend to be evaluated as well-adapted whether the measured margins are well or poorly adapted. This affects the patient more than the clinician and should be remembered if questioning the fit ceramometal crown with metal interproximal margins. Ceramic crowns (lithium disilicate and fluorapatite) tend to be evaluated as poorly adapted whether measured margins are well or poorly adapted. This has a financial and time cost to the clinician, personal time cost to the patient, and potentially a cost to the dental lab as well.

For the second main hypothesis, there was no difference between prosthodontists and general dentists evident in this study in relation to percentage of evaluations that were correct.

Appendix:

Evaluation responses from Prosthodontists (p#) and General Dentists (d#)

		p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11		d1	d2	d3	d4	d5	d6	d7	d8	d9	d10
C90	1	a	a	a	a	a	a	a	a	a	a	a	C90	a	a	a	a	a	a	a	r	a	a
	2	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	r	a	a
	3	a	a	a	a	r	a	a	a	r	a	a		a	a	a	a	a	r	a	r	a	a
	4	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	r	a	a
	5	a	a	a	a	a	a	a	a	r	a	a		a	a	a	a	a	a	a	r	a	a
	6	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	a	a	r	a	a
	7	r	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	r	a	r	a	a
	8	a	a	a	r	a	a	a	a	a	a	a		a	a	a	a	a	a	a	r	a	r
	9	a	r	a	a	r	r	a	a	r	r	a		r	a	a	r	r	r	a	r	a	r
	10	r	r	a	a	r	r	a	a	r	a	a		r	a	r	r	r	r	r	r	a	r
C80	11	r	a	a	a	a	a	a	a	a	a	a	C80	a	a	a	a	a	a	a	r	a	a
	12	r	a	a	a	a	a	a	a	a	a	a		a	a	a	r	a	a	a	r	a	a
	13	a	a	a	a	a	a	a	a	a	a	a		a	a	a	r	a	r	a	r	a	a
	14	a	a	a	a	a	a	a	a	a	a	a		a	a	a	r	a	r	a	r	a	a
	15	a	a	a	r	a	a	a	a	a	a	a		a	a	a	r	a	r	a	r	a	a
	16	a	a	a	a	a	a	a	a	r	a	a		a	a	a	r	a	a	a	r	a	a
	17	a	a	a	a	r	a	a	a	a	a	a		a	a	a	r	a	r	a	r	a	a
	18	a	a	a	a	a	a	a	a	r	a	a		a	a	a	r	r	a	a	r	a	a
	19	a	a	a	r	a	a	a	a	a	a	a		a	a	a	a	a	r	a	r	a	a
	20	a	a	a	a	a	a	a	a	a	a	a		a	a	a	a	a	r	a	r	a	a
E90	21	a	r	a	a	a	a	a	a	a	a	a	E90	a	a	r	r	a	a	a	r	r	a
	22	r	r	r	r	r	r	a	r	r	a	r		r	a	r	r	r	r	r	r	r	r
	23	a	r	a	r	r	a	a	a	r	a	r		r	a	r	a	r	a	r	r	r	r
	24	r	r	r	r	r	r	r	a	r	r	r		r	r	r	r	r	r	r	r	r	r
	25	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	26	r	r	r	a	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	27	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	28	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	29	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	30	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
E80	31	r	r	a	r	r	a	a	a	r	a	r	E80	r	a	r	a	r	a	r	r	r	a
	32	a	r	a	r	a	a	a	a	a	a	r		a	a	r	r	r	r	r	r	r	a
	33	r	r	a	r	r	r	r	a	r	a	r		r	a	r	r	r	r	r	r	r	r
	34	r	r	a	r	r	r	r	a	r	a	r		r	r	r	r	r	a	r	r	r	r
	35	r	r	r	r	r	r	a	a	r	a	r		r	r	r	r	r	a	r	r	r	r
	36	r	r	r	a	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	37	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	38	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	39	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	40	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r

Z90	41	a	r	a	r	a	a	a	a	r	a	r	Z90	a	a	a	a	r	a	a	r	r	a
	42	a	r	a	a	a	a	a	a	r	a	r		r	a	a	a	r	a	a	r	r	r
	43	r	r	r	a	r	a	r	a	a	a	r		r	r	r	r	r	a	r	r	r	r
	44	a	r	a	r	r	a	r	a	r	a	r		r	r	r	r	r	a	r	r	r	r
	45	r	r	a	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	46	r	r	r	r	r	a	r	r	r	r	r		r	r	r	r	r	a	r	r	r	r
	47	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	48	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	49	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	59	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
Z80	50	a	r	a	r	a	a	a	a	a	a	a	Z80	a	a	a	a	a	a	a	r	a	a
	51	a	r	a	a	r	a	r	a	a	a	a		a	a	r	r	a	a	r	r	r	a
	52	a	r	a	r	a	a	a	a	a	a	r		a	r	r	a	r	a	r	r	r	a
	53	r	r	a	r	a	a	r	a	a	a	r		a	r	r	r	r	a	r	r	a	r
	54	r	r	a	r	r	r	r	a	r	a	r		r	a	r	r	r	a	r	r	r	r
	55	a	r	a	r	r	r	r	a	r	a	r		a	r	r	r	r	a	r	r	r	a
	56	r	r	a	r	r	r	r	r	r	a	r		r	r	r	r	r	a	r	r	r	r
	57	r	r	r	r	r	r	r	a	r	r	r		r	r	r	r	r	a	r	r	r	r
	58	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r
	60	r	r	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r

Green denotes measured acceptable

Yellow denotes measured unacceptable

“a” denotes an evaluation of acceptable by the general dentist or prosthodontist

“r” denotes an evaluation of reject by the general dentist or prosthodontist

Sample Evaluation Sheet:

Dear Colleague,

My name is Max Wahle, and I would like to ask you to participate in my master's research. It will be used to assess the radiographic evaluation of all ceramic crowns. It is important because there are no current recommendations on all ceramic radiograph evaluation of crown fit. I and my mentor, Dr. Masri, are hoping for publication of this study in the upcoming year. For your portion of the evaluation, I am asking that you determine a crown margin to be acceptable or unacceptable (i.e. would you send it back to the lab for refabrication) based upon the radiographic image. Understandably, there would be more to the evaluation of a well-fitting crown, but the radiographs are the focus of this study. You will be presented with 60 radiographic images to evaluate and please indicate, on the sheet attached, whether you would accept the crown margin seen in the radiograph or reject it. It is imperative that you follow the order given in the PowerPoint. Evaluate these radiographs in the designated darkened room on the standardized 22" monitor in slideshow on PowerPoint. Once you are finished, please return the completed answer sheet to the prosthodontic resident room 4453, where you can find me or notify me and I can retrieve your sheet. I wish for your answers to remain anonymous so please do not identify yourself on any of the attached forms.

Thank you for taking the time. It is truly appreciated!

Sincerely,

Max Wahle, DDS
PG Prosthodontics, 3rd year
max.wahle@umaryland.edu
319-270-5838

#1	– –	Accept	Reject
#2	– –	Accept	Reject
#3	– –	Accept	Reject
#4	– –	Accept	Reject
#5	– –	Accept	Reject
#6	– –	Accept	Reject
#7	– –	Accept	Reject
#8	– –	Accept	Reject
#9	– –	Accept	Reject
#10	– –	Accept	Reject
#11	– –	Accept	Reject
#12	– –	Accept	Reject
#13	– –	Accept	Reject
#14	– –	Accept	Reject
#15	– –	Accept	Reject
#16	– –	Accept	Reject
#17	– –	Accept	Reject
#18	– –	Accept	Reject
#19	– –	Accept	Reject
#20	– –	Accept	Reject
#21	– –	Accept	Reject
#22	– –	Accept	Reject
#23	– –	Accept	Reject
#24	– –	Accept	Reject
#25	– –	Accept	Reject
#26	– –	Accept	Reject
#27	– –	Accept	Reject
#28	– –	Accept	Reject
#29	– –	Accept	Reject
#30	– –	Accept	Reject

1) Please **Circle** the response you deem appropriate.
2) Be sure the image and response numbers correspond
3) Accept is a crown you would cement
4) Reject is a crown you would send for refabrication

#31	– –	Accept	Reject
#32	– –	Accept	Reject
#33	– –	Accept	Reject
#34	– –	Accept	Reject
#35	– –	Accept	Reject
#36	– –	Accept	Reject
#37	– –	Accept	Reject
#38	– –	Accept	Reject
#39	– –	Accept	Reject
#40	– –	Accept	Reject
#41	– –	Accept	Reject
#42	– –	Accept	Reject
#43	– –	Accept	Reject
#44	– –	Accept	Reject
#45	– –	Accept	Reject
#46	– –	Accept	Reject
#47	– –	Accept	Reject
#48	– –	Accept	Reject
#49	– –	Accept	Reject
#50	– –	Accept	Reject
#51	– –	Accept	Reject
#52	– –	Accept	Reject
#53	– –	Accept	Reject
#54	– –	Accept	Reject
#55	– –	Accept	Reject
#56	– –	Accept	Reject
#57	– –	Accept	Reject
#58	– –	Accept	Reject
#59	– –	Accept	Reject
#60	– –	Accept	Reject

1) Please **Circle** the response you deem appropriate.
2) Be sure the image and response numbers correspond
3) Accept is a crown you would cement
4) Reject is a crown you would send for refabrication

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