Radiographic Evaluation Consistency of CAD/CAM Crowns and Conventional Crowns among Different Clinicians

A Thesis

Presented to the Faculty of Tufts University School of Dental Medicine

in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Dental Research

by

Jongil Park

August 2015

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THESIS COMMITTEE

Thesis Advisor

Ali Müftü, DMD, MS, PhD

Professor

Department of Prosthodontics

Tufts University School of Dental Medicine

Committee Members

Nopsaran Chaimattayompol DMD, MPH

Clinical Professor

Department of Prosthodontics

Tufts University School of Dental Medicine

Matthew Finkelman, Ph.D.

Associate Professor

Department of Public Health and Community Service

Tufts University School of Dental Medicine

Ala O. Ali, B.D.S., M.Sc., D.Sc.

Assistant Professor

Department of Prosthodontics

Tufts University School of Dental Medicine

ABSTRACT

Aim & Hypothesis

This study aimed to evaluate the consistency of dentists in assessing the radiographic marginal gap of crown restorations. The concordance between the crown marginal gaps under an optical microscope and evaluator judgment was assessed among different clinicians.

Materials and methods

In vitro, a mandibular molar was prepared to receive twelve different types of crown followed by radiographs and an evaluation survey. Three groups of the crowns were fabricated with different materials (Cast metal, e.max (lithium disilicate) and Zicornia) and each groups of the crowns had four different marginal gaps (75 microns, 150 microns, 225 microns and 300 microns) using an optical microscope. Twelve radiographs of each crown were taken and a radiographic evaluation survey was conducted. The scores of the clinicians' radiographic assessments were analyzed using SPSS.

Data and results

The median total score among all clinicians was 15.5 (scale of 0-24), with an interquartile range of 5. The median was highest in the operative faculty group (median = 18) and lowest in the dental student group (median = 14). The result of the Kruskal-Wallis test showed a significant difference between groups ($p=0.003$). In post-hoc Mann-Whitney U tests with Bonferroni correction, the operative faculty group and dental student group showed a significant difference ($p=0.002$). For the comparison of the different crown groups (cast metal crowns, e.max (lithium disilicate) crowns and zirconia crowns), the median of the e.max crown group was 6 (scale of 0-8), which was one point higher than the cast metal and zirconia groups. The result of the Friedman test showed a significant difference between groups ($p<0.001$). The e.max crown group showed a significant difference with the other groups (both $p<0.001$), whereas the difference between the cast metal and zirconia crown groups was not significant ($p=0.326$). For the comparison of different marginal gap groups, the median of the 150 micrometer group was 1 (scale of 0-6), which was significantly different from all the other groups which had a median of 5 ($p<0.001$).

Conclusion

The 150µm marginal gap crown group tended to exhibit false positive perceived acceptable seating on the radiographs. Clinicians tended to have greater success in classifying the marginal gaps of the e.max crown group, possibly due to the favorable radiopacity of e.max crowns. The clinical experience may affect radiographic evaluation of clinicians. The linear measurements of the marginal gaps and the radiographic evaluation of the clinicians can be different depending on the materials and the marginal gap of the evaluated crown.

DEDICATION

To my Father, my mother and my brother

ACKNOWLEDGMENTS

Frank S Chow DMD

Clinical assistant professor

Comprehensive care

TABLE OF CONTENTS

DEDICATION ..... **vi**
ACKNOWLEDGMENTS ..... **vii**
TABLE OF CONTENTS ..... **viiiii**
LIST OF FIGURES ..... **ix**
LIST OF TABLES ..... **x**
LIST OF GRAPHS ..... **xiii**
LIST OF ABBREVIATIONS ..... Error! Bookmark not defined.
Introduction **2**
Aim and Hypothesis **16**
Research Design **18**
Materials and Methods **19**
Statistical Analysis **24**
Results **25**
Discussion **26**
Conclusion **32**
References **33**
APPENDICES **40**
Appendix A: Tables **41**
Appendix B: Figures **42**
Appendix C: Graphs **49**
Appendix D: The Radiographic Survey **51**

LIST OF FIGURES

Figure 1. Terminology for marginal fit: …… 42
Figure 2. A sample preparation 43
Figure 3. The master casts 49
Figure 4. The milled wax patterns 49
Figure 5. A resin jig 45
Figure 6. Measurement of Cast metal crowns 46
Figure 7. Measurement of e.max crowns 47
Figure 8. Measurement of Zirconia crown 48

LIST OF TABLES

Table 1. Scores of Different Clinician types 41
Table 2. Scores of Different Crown types 41
Table 3. Scores between Different Marginal Gap groups 41

LIST OF GRAPHS

Graph 1. All-ceramic crown deliveries per year 49
Graph 2. All-ceramic crowns in comparison to conventional crowns 49
Graph 3. CAD/CAM all-ceramic crowns percentage 50

LIST OF ABBREVIATIONS

3D: Three dimensional

3Y-TZP: yttrium-stabilized zirconia polycrystals

ADA: American Dental Association

Al: Aluminium

CAD/CAM: Computer-aided design and computer-aided manufacturing

CEREC: Chairside Economical Restoration of Esthetic Ceramics

FPD: Fixed partial denture

TOC: Total occlusal convergence

Radiographic Evaluation Consistency of CAD/CAM Crowns and Conventional Crowns among Different Clinicians

Introduction

In response to increased esthetic demands and metal free restorations, many high-strength dental ceramics have recently been introduced to dentistry.(1, 2) Fabrication of such restorations increasingly involves sophisticated technologies adapted from other industries. Compared to the labor-intensive and experience-dependent conventional dental laboratory crown work, CAD/CAM systems offer automation of fabrication procedures with increased quality in a shorter period of time.(2-5) Additionally, dental CAD/CAM systems have the potential to minimize inaccuracies and decrease the cross-contamination associated with conventional laboratory work. Electronic storage of data with a standardized chain of production, the ability to use high-strength ceramic and titanium materials, and the possibility of chairside treatment are all advantages of CAD/CAM.(3, 5, 6)

When fabricating fixed partial dentures, CAD/CAM systems construct virtual models of abutments and their neighboring teeth either via intraoral digital impression or via scanning of traditional impressions or casts. This virtual model can be processed in two different ways. First, the virtual model can be converted into a working cast, either through additive or subtractive manufacturing techniques and the desired restorations are made on the virtual model in a professional dental laboratory or a production facility. An alternative way of processing of the virtual model is to design the restoration virtually without having a solid working model. The design data are sent to a milling machine for fabrication of the restoration. The latter approach is more commonly used by ‘in-office’ CAD/CAM systems

such as CEREC, Chairside Economical Restoration of Esthetic Ceramics or CEramic REConstruction, (Sirona Behnheim, Germany) and E4D (D4D Technologies LLC, Richardson, TX, USA).(7)

A major requirement for the long-term survival of dental prosthesis is the accuracy of fit.(8, 9) Marginal adaptation of a restoration can be assessed generally in terms of seating and sealing. Poor adaptation and inadequate fit could create a potential space between the restoration and the prepared tooth, as a result, exposing the cement layer to the oral environment leading possibly to marginal discoloration, dissolution of cement, micro leakage, more plaque retention and secondary caries.(10-12) Furthermore, variations in the fit can create stress concentrations which may reduce the strength of the restoration and consequently cause its fracture.(13) Despite all technological advances, obtaining an effective, long-lasting marginal seal at the tooth-crown interface is still a great challenge due to the absence of a clinically suitable and consistent evaluation method. (8, 14)

The American Dental Association states in Specification No.8 that the film thickness of the zinc phosphate cement should not exceed 25 μm for Type 1 cements and 40 μm for Type 2 cements. (14) However, studies that examined marginal adaptation have shown that this goal was seldom reached.(15) Gardner observed that, even under ideal conditions, it was rare to achieve this level of accuracy. (16) After a 5-year study conducted on more than 1000 restorations, McLean and von Fraunhaufer concluded that 120 μm was the maximum tolerable marginal opening. (17) Fortunately, most dental CAD/CAM systems are now able to produce restorations with acceptable marginal adaptation of less than 100 μm. (1, 8)

While sectioning of crown samples is considered to be valuable for the purpose of studying marginal gaps, the intrinsic errors in the measurement system e.g. microscope can

affect the resultant measured values. Current attempts are directed towards the use of industrial 3D software scanners such as FlexScan3D by 3D3 solutions, Geomagic Qualify by geomagic, ATOS SO4M, etc. The nondestructive virtual 3D measurement of scanned surfaces allows for measuring horizontal, vertical and absolute marginal discrepancy, providing an important aspect when studying the fit quality of a restoration. (18)

There are three clinical methods to examine fit of fixed dental prosthesis: 1) tactile examination using an explorer, 2) radiographs, and 3) examination of the marginal fit using an impression material.(19) While digital dental radiographs are commonly used to assess the fit of such restorations, there is no clear agreement on the degree of accuracy in the evaluation of fit/misfit that can be detected by this method. Moreover, evaluating the gap size, or even the presence or absence of a gap between the abutment tooth preparation and the crown through a radiograph could be misleading.(20) Restorations made with newer technologies and materials, however, are evaluated for fit using the same methods.

The use of digital radiography enabled clinicians to enlarge and enhance images. Since the new ceramic materials vary in their radiographic appearance, the radiographic evaluation of marginal fit, in terms of seating and sealing may also vary significantly among different types of crown restorations. While some high crystalline ceramics look as radiopaque as metal restorations, some particle filled ceramics have a more radiolucent appearance. This relative radiolucency allows visualization of the cement space beneath some ceramic restorations, a phenomenon that does not exist with traditional porcelain fused to metal restorations and may be misinterpreted as clinically unacceptable. To date, no studies have been cited in the dental literature comparing radiographic assessment of CAD/CAM and traditional full coverage restorations.

In this study, the radiographic assessment of different types of CAD/CAM crowns and conventional crowns will provide valuable information on examiner assessment versus actual fit. We expect the results to have significant impact on establishment of clinical guidelines on evaluation of radiographic verification of the marginal fit of crowns.

Literature Review

History of CAD/CAM in Dentistry

Use of CAD/CAM in dentistry has been widely spreading with the development of diverse systems.(21, 22) The technology has been applied not only to fixed dental prostheses on natural teeth but also to fixed or removable implant prostheses for its accuracy(23, 24) and efficiency.(25)

Dr. Duret was the first developer of a dental CAD/CAM device, making crowns based on an optical impression of the abutment tooth and using a numerically controlled milling machine in 1971.(26) He produced the first dental CAD/CAM restoration in 1983 (27).

Dr. Mörmann developed the first commercial CAD/CAM system. With Dr. Marco Brandestini, an electrical engineer, he used the optic scanner for the teeth. In 1985, the first chairside inlay was done using a combination of the optical scanner and milling device, which was named CEREC (computer-assisted ceramic reconstruction).(28)

Dr. Rekow worked on a dental CAD/CAM system in the 1980s, which was designed to acquire data using photographs and a high-resolution scanner, and to mill restorations using a 5-axis machine.(29)

Dr. Andersson developed the Procera (now known as NobelProcera, Nobel Biocare, Zurich, Switzerland) method of manufacturing high-precision dental crowns in 1983. He was also the first person to use CAD/CAM for composite veneered restorations.(30)

Early technology permitted the creation of inlays, onlays, veneers, and crowns. More recently, CAD/CAM systems have been able to provide fixed partial dentures and implant abutments.

Marginal Fit of the crowns

Evidence-based dentistry is an essential guideline for successful treatment.(13) American Dental Association (ADA) Specification No. 8 states that the luting cement film thickness for a crown restoration should be no more than 25 μm when using a Type I luting agent, or 40 μm with a Type II luting agent.(14) Marginal fit of cemented restorations that range from 25 to 40 μm has been suggested as a clinical goal, but marginal openings in the range of these dimensions clinically are realistically hard to achieve.

Through sectioning of the crowns, researchers have attempted to determine the amount of marginal opening that is not visible to the naked eye, undetectable with an explorer but still considered clinically acceptable.(7) After evaluating over 1000 crowns in 5 years, McLean and von Fraunhofer proposed that a restoration would be successful if marginal gaps and cement thickness of less than 120 μm could be achieved.(17)

Christensen evaluated the fit of subgingival and supragingival margins and stated that the least acceptable marginal discrepancy in visually accessible surfaces was 39 μm, according to the linear regression prediction formula. He suggested a clinical goal of 25 μm to 40 μm for the marginal adaptation of cemented restorations, which is hard to achieve even in an ideal situation. (31)

Lofstrom and Barakat used a scanning electron microscope to measure the supragingival margins of the crowns and considered a suitable clinical fit by several dentists and reported marginal discrepancy values in a range of 7 to 65 μm.(7, 20) However, more recent data concluded that the clinically tolerable gap could range between 50 and 150 μm. (1, 8, 10, 32) Fortunately, most dental CAD/CAM systems are now able to produce restorations with acceptable marginal adaptation of less than 100 μm. (1, 8)

It is hard to set a gold standard number of clinically acceptable marginal gap measurement. To determine the acceptable crown margin gap for this study, the value of less than120 μm was used as acceptable marginal gap according to McLean and von Fraunhofer. (17)

Accuracy of intra-oral digital impression

Digital impressions can be more efficient than conventional impressions by reducing total treatment time.(25) They eliminate the conventional impression procedure including mixing of the impression material, a tray loading and intraoral positioning for setting.

A number of studies have shown that the accuracy of digital impression is comparable or even better than conventional impression.(33-36) A randomized clinical trial by Syrek et al. compared the mean marginal gap of crowns fabricated from conventional impression versus intraoral scanning (Lava C.O.S.). It was found that the crown margins had better fit in the digital impression group (median marginal gap 49 μm) than the conventional impression group (median marginal gap 71 μm) (35).

Monolithic Zirconia Restoration

The use of all-ceramic restorations has been increasing thanks to their superior esthetic features and improved mechanical properties compared to metal-ceramic restorations. The application of all-ceramic restorations has been expanded and now all-ceramic fixed partial dentures (FPDs) are routinely used in dental practice not only on the anterior but also on the posterior area.

Failures have been reported with posterior all-ceramic FPDs and the main cause of

failure was fracture of the prosthesis. (37) A number of ceramic materials have been developed to overcome this kind of mechanical problem with all-ceramic FPDs. The most commonly used ceramic material for posterior FPDs currently is zirconia.

The majority of zirconia-based dental ceramic systems now being used are yttrium-stabilized zirconia polycrystals (3Y-TZP).(38) This zirconia has 3 mol % yttria (Y_2O_3) as a stabilizer. Major advantages of this material are high fracture toughness (5.5 – 7.4 MPa $m^{1/2}$) and superior flexural strength (900-1000 MPa) (39).

The processing of 3Y-TZP is usually done by CAD/CAM with a pre-sintered zirconia block. After the pre-sintered block is milled into pre-calculated size and shape of the restoration which compensates for the 20 – 30% firing shrinkage, it is fired at 1350 – 1550 ℃, resulting in a dense sintered product.

Zirconia-based prostheses provide more predictable treatment outcomes for posterior areas where more occlusal force is loaded while functioning. It was shown in a number of studies that zirconia frameworks could provide a strong support to a veneering layer because of their high strength. However, fracture of veneering porcelain was reported in many studies even though it was not failure of a framework which required replacement of the restoration.(40)

In fact, chipping of the veneering porcelain on zirconia-based restorations is the most common complication that limits clinical success(41), especially when it comes to implant-supported fixed prostheses.(42-45) The reason for zirconia veneer failure has been explained

in many ways, and the mismatch of the coefficient of thermal expansion between the veneering porcelain and the zirconia core was thought to be one of the main reasons for failure.(46)

Since the flexural strength of the veneering porcelain (90-120 MPa) is considerably weaker than the zirconia core (900 -1000 MPa), the porcelain is more prone to failure under the loads of masticatory functioning. To overcome this problem, the strength of veneering porcelain should be increased.(43) A number of attempts have been made to improve the mechanical properties of veneering porcelain including pressing Porcelain (IPS e.max ZirPress) onto the zirconia core. However, the reliability of pressed veneer was still comparable to layered veneer.(47, 48) Pressed porcelain also showed cohesive fracture in some clinical trials of zirconia FPDs.(49)

Monolithic zirconia restorations are becoming more popular to overcome the shortcomings of veneered zirconia prostheses. Unlike the porcelain veneered zirconia restoration, monolithic zirconia restorations are fabricated merely through a CAD/CAM process which can be both efficient and economical at the same time. More importantly, monolithic zirconia restorations have shown markedly superior fracture resistance compared to porcelain-veneered zirconia restorations.(50, 51) As was reported in a systematic review(41), in a number of cases the chip fractures were minor and the patients either did not recognize the fracture(52, 53) or even after the fracture was found some patients were just satisfied with polishing the area.(54, 55) However, there were still some restorations that needed a total replacement.(56)(57) When using a monolithic zirconia restoration, the chance of having a chip fracture would be minimized.

A disadvantage of a monolithic anatomical full contour zirconia restoration would be the poor optical property.(58) In some cases, traditional Y-TZP cannot satisfy the patients' esthetic expectations. However, the newly introduced highly translucent Y-TZP and staining techniques improved the esthetics of monolithic zirconia restorations remarkably, offering an attractive option of restorations.(51, 59)

Monolithic Lithium Disilicate restoration

Another alternative to veneered zirconia restorations could be monolithic anatomic full contour lithium-disilicate restorations. They are widely used for single crowns, onlays, or inlays because of their favorable translucency and optimal esthetics.(60) Proper staining and glazing are required for optimal esthetics of final restoration. Also, the mechanical properties of IPS e.max Press from Ivoclar Vivadent are good, with flexural strength of 440 MPa. (61)

The monolithic e.max restorations can be esthetically pleasing with staining and strong enough for 3 unit FPDs replacing anterior teeth and premolars. Even with posterior FPDs, a similar 10 year success rate as conventional metal-ceramic FPDs was reported(62). E.max can also be used to restore posterior single crowns with long term success.(63)

CAD/CAM monolithic anatomical full contour lithium disilicate crowns can have better fracture resistance compared to hand-layer-veneered zirconia-based crowns.(64) IPS e.max Press restorations have been clinically successful since they were first released in 2006. According to a retrospective study with a mean follow-up of 3 years and a maximum observational period of 6 years, both veneered and monolithic, anterior and posterior lithium disilicate restorations were effective and reliable in the short and medium-term.(65)

The marginal fit of lithium-disilicate crowns is comparable to CAD/CAM Y-TZP crowns and conventional metal-ceramic crowns.(66) However, when comparing the internal and marginal discrepancy of heat pressed versus CAD/CAM e.max restorations, pressable restorations showed superior internal and marginal adaptation compared to their CAD/CAM counterpart.(67, 68)

Radiopacity of Dental Restorative Material

Radiopacity is a desirable property of the most of dental materials, including direct-restorative materials,(69) denture base materials,(70) elastomeric impression materials,(71) luting agents(72-74) and adhesive systems.(75) Restorative materials are recommended to have radiopacity greater than that of enamel.(76-78) The radiopacity of restorative materials enables radiological detection of the form or deficiencies of restorations(79) and localization of the dental pulp.(80) It also enables detection of restorative materials with secondary caries and periodontal effects of the overhangs in the restoration.(74, 76)

Akerboom et al.(72) suggested using human teeth as a standard, and reported that variations in the radiopacity of specimens may cause discrepancies between studies. ISO standards require that the minimum radiopacity of restorative materials be equal to or greater than that of an equivalent thickness of Aluminum (Al). The radiopacity of dentin and enamel specimens varies, but pure Al has a constant radiopacity. To make comparisons between different studies, an Al step wedge was used as a standard for measuring radiopacity, because aluminum has the same linear absorption coefficient order as dental enamel.(81) The radiopacity values of human dentin, obtained from this study using an Al-1 step wedge (1.06 ±0.17 mm Al/1 mm dentin for canine teeth and 1.09 ±0.11 mm Al/1 mm dentin for molar

teeth), were found to be comparable to those reported by Turgut et al.(69) (1.13 mm Al/1 mm dentin), El-Mowafy et al.(73)(1.16 mm Al/1 mm dentin), Williams and Billington(82) (1 mm Al/1 mm dentin), and Stanford et al.(80) (0.79 mm Al/1 mm dentin).

Excessive radiopacity of restorative materials can be disadvantageous.(77, 82) The higher radiopacity of amalgam restorations may result in under- and over-scoring of secondary caries marginal defects compared to composite resin(77) Caries and marginal defects may be over-diagnosed with highly radiopaque restorations. Moreover, Rasimick et al. stated that a radiopaque core foundation material allows a clinician to radiographically inspect the core material for voids. (83) However, they tested extremely radiopaque metal-reinforced glass ionomer core and concluded that excessively radiopaque core materials could make it hard for the clinician to identify voids or marginal defects. Highly radiopaque restorative materials may mask caries near the buccal or lingual margin of a Class II restoration.

This phenomenon may result from the angulation of the radiographic beam superimposing high radiopaque restorations over carious tooth structure.(84) Moderate radiopacity may be more favorable and could facilitate the detection of caries.(77)

Determination of the Marginal fit of Crowns

When a restoration is not completely adapted, the marginal discrepancy increases. A margin that is not sealed up to a certain level may cause leakage and accumulation of microbiota which could result in dental caries or periodontal disease. Clinically acceptable marginal discrepancy has been discussed in several articles.(17)

Until the late 1980s, investigators who evaluated marginal fit did not always measure the same distances. Holmes et al. (85) proposed a clear terminology in 1989. (Figure 1) Marginal fit is generally evaluated by measuring the marginal gap or the absolute marginal discrepancy.

There are three clinical methods to examine fit of fixed dental prosthesis: 1) tactile examination using an explorer, 2) radiographs, and 3) examination of the marginal fit with the aid of an impression material.(19)

The Fit Checker can be used to check marginal gaps along with clinical and radiographic evaluation. The average film thickness of Fit Checker ranged from 16.7 to 23.7 μm which is thinner than type I or type II cement. (86) It is thin enough to check clinically acceptable marginal gaps.

The radiograph technique proved to be preferable to the impression-material method in some single crown restorations. When the restoration margin did not meet the preparation finish line but did fit the tooth, there was no penetration of the impression material into the crown. The impression does not permit detection of the site of the fault, while the radiograph does. When the margins showed subgingival overhang and yet fit the surface of the tooth, there was no penetration of the impression material into the crown. The radiograph reveals the fault, if only in the case of proximal sites. (19)

Influence of Preparation Design on Marginal Fit of Crowns

There are lots of factors affecting marginal fit of the crown, but the finish line configuration and preparation design is the one of the important factors affecting marginal adaptation of CADCAM all ceramic crowns.(87)

Total occlusal convergence (TOC) values seem to be the most important preparation parameter. The abutment of a partial fixed dental prosthesis should have a minimal total occlusal convergence (TOC), also called a taper, in order to ensure adequate retention of a prosthesis that will be made for the abutment, given the height of the abutment. Recommended TOC values have increased over the past 4 decades from an unachievable 2- to 5-degree taper to a more realistic 10 to 22 degrees. (88)

Occlusal preparation can affect marginal adaptation. Anatomical occlusal preparation designs resulted in better marginal and internal adaptation (139.23±30.85 μm) of Zirconia copings than non-anatomic preparation designs. (155.93±33.98 μm) (89)

Compared to TOC and occlusal anatomy, the finish line did not affect the marginal gap of CAD/CAM all ceramic crowns. Chamfer and shoulder preparations did not show significant differences regarding the gap dimension. Both tested finish lines were able to achieve clinically acceptable marginal fit values of 120 microns. (90)

Aim and Hypothesis

Aim

Using crowns that were fabricated with different marginal gaps and different materials (Lithium disilicate, Zirconia, and metal), the concordance between the marginal gaps and evaluator judgment (based on radiographic examination) was assessed and compared between students, operative instructors, and prosthodontists.

Variables to be tested:

Types of full coverage restorations fabricated from different materials

Different marginal gap levels of the crowns

Radiographic interpretation of the marginal crown fit by various examiners

Hypothesis

Hypothesis 1

Evaluation of the marginal fit of both CAD/CAM crowns and cast metal crowns through dental radiographs will have a substantial disagreement with the measurement of misfit under a microscope.

Hypothesis 2

The concordance between the actual marginal gap and the evaluation of the clinician will appear higher in the prosthodontist and operative instructor group than the student group.

Hypothesis 3

The consistency of dental radiographs in providing reliable information about the marginal fit of crown restorations will be higher for CAD/CAM crowns than cast metal crowns.

Research Design

In vitro, a mandibular molar was prepared to receive different types of crown restorations followed by a radiograph evaluation survey. The crowns were fabricated with different materials and marginal gaps and their radiographic appearances of marginal adaptation as assessed by dentists were compared. A numerical measurement of the actual amount of misfit for each crown was collected under an optical microscope and these measurements were used as the gold standard for the comparison.

Inclusion Criteria

Senior dental students D15 and D16 dental students

Predoctoral operative dentistry faculties

Predoctoral prosthodontic faculties

Exclusion Criteria

Dentists from other specialties

D17 and D18 dental students

Materials and Methods

Sample preparation

An extracted intact mandibular molar tooth was embedded in a dentiform (Colombia Dentoform Corp. New York) with silicone impression material and prepared to receive a full coverage restoration with 8-10 degrees of total occlusal convergence angle, 1.5mm axial and 2mm occlusal reduction with a chamfer finish line. (Figure 2)

An impression of the dentiform was taken with polyether light (Permadyne® , 3M, St. Paul, MN) and regular body (Impregum® , 3M, St.Paul) impression material. Master casts were fabricated using Die-keen® (Heraeus Kulzer, Hanau, Germany) die stone. (Figure 3)

Twelve crowns were fabricated according to the following guideline:

E.max 1: CAD Lithium disilicate (e.max CAD) with 75(±15)µm of marginal gap

E.max 2: CAD Lithium disilicate (e.max CAD) with 150(±15)µm of marginal gap

E.max 3: CAD Lithium disilicate (e.max CAD) with 225(±15)µm of marginal gap

E.max 4: CAD Lithium disilicate (e.max CAD) with 300(±15)µm of marginal gap

Zirconia 1: CAD Zirconia crown with 75(±15) µm of marginal gap

Zirconia 2: CAD Zirconia crown with 150(±15) µm of marginal gap

Zirconia 3: CAD Zirconia crown with 225(±15) µm of marginal gap

Zirconia 4: CAD Zirconia crown with 300(±15)µm of marginal gap

Cast 1: Cast gold crown with 75($\pm$15) µm of marginal gap

Cast 2: Cast gold crown with 150($\pm$15) µm of marginal gap

Cast 3: Cast gold crown with 225($\pm$15) µm of marginal gap

Cast 4: Cast gold crown with 300($\pm$15) µm of marginal gap

All of the marginal gaps were controlled by applying multiple layers of die spacer (20 micron film thickness) on the master casts from impression and after fabrication of the different types of crowns (e.max, Zirconia and cast metal crowns). Manual adjustment was done by extra fine diamond burs and polishing burs to control the small dimension on the margin of the crown. Cast gold was fabricated using the milled wax pattern from the identical digitalized data file of the e.max and Zirconia crowns. (Figure 4)

Radiographs

A total of 12 bitewing radiographs of 4 crowns each of 3 types of crowns described above were taken. Digital bitewing-angled radiographs of each crown were obtained through paralleling technique and using a specially designed custom jig made from Caulk® orthodontic resin (Dentsply, Milford, DE, USA) for standardized bitewing projection geometry in the buccolingual direction. (Figure 5)

Schick Elite CDR digital x-ray sensor size 1 (Sirona, Salzburg, Austria) was used. The digital sensor was placed vertically and horizontally parallel to the crowns of the teeth to prevent possible distortion from sensor angulation. The voltage for intraoral radiography usually ranges between 60 kV and 70 kV and the current from 2 to 8 mA. The vertical angulation of the X-ray beam source was perpendicular to the sensor, with the beam centered to the center of the receptor. Tooth-to-sensor distance was approximately 1cm and x-ray beam source-to-sensor distance was around 30 cm for each radiographic projection, because source-film distance, intensifying screens and grids are also factors that affect measurements of radiopacity.(91) All digital files were saved as DICOM files and converted to JPEG image for use in the online survey. High enhancement and inversion filters were avoided when evaluating the radiographs. (92)

Linear measurement of fit

Marginal gap of the crown was measured using an optical microscope SZX16 (Olympus, Tokyo, Japan) with magnification of X96. Mesial and distal reference points were marked with a pen using a surveyor to determine the most mesial and distal point on the radiograph. (Figure 5). Direct measurement was done using the Buehler Omnimet 9.0 software and the gap between the prepared tooth and the restoration was measured at both mesial and distal reference points. After the measurement, the average distances of the measurements were calculated and the average values were used as a grouping marginal gap value. (Figure 6-8)

Online Survey

The survey was self-administered via an electronic format via Qualtrics (https://tufts.qualtrics.com) and was designed to take no longer than approximately 5-10 minutes to complete. An email with the link to the survey was sent out to the e-lists for the Tufts University School of Dental Medicine students of the class of 2015 (190 students) and 2016 (196 students) and the Prosthodontic and Operative department faculty (129 faculty members). The email was distributed four times, with the second, third, and fourth emails sent within 2 weeks of the first email.

At the end of the survey, participants were given a link to the option of entering their name to receive a gift card. The first 20 respondents in each group were given a gift card. If they chose to participate, they were given a link to another survey in Qualtrics which allowed them to input their names.

The first part of the survey conducted information about the participant's current degree and clinical experience. The participants evaluated each radiograph and chose one of two options: Acceptable fit or Unacceptable fit.

Power Calculation

A power calculation was conducted using nQuery Advisor (Version 7.0). Assuming that the mean number of correct answers on the questionnaire would be one point higher for prosthodontists than for operative instructors, and three points higher for operative instructors than for dental students, as well as a common within-group standard deviation of 2, a sample size of n=20 per group was adequate to obtain a Type I error rate of 5% and a power greater than 99% for comparing the three types of clinicians.

Statistical Analysis

From the survey, each correct answer was scored as 1, and each incorrect answer was scored as 0. An individual's total score was the sum of his/her item scores; since there were 24 items, the possible range of scores was 0-24. An individual's score for each crown type could range from 0-8; an individual's score for each marginal gap group could range from 0-6.

Descriptive statistics (counts and percentages for categorical variables, medians and interquartile ranges for continuous variables) were computed. The normality of results for each group was tested and all data were not normally distributed, so nonparametric tests were used. The comparison of the number of correct answers between the three types of clinicians was conducted via the Kruskal-Wallis test alongside the Mann-Whitney U test with Bonferroni correction. The Friedman test alongside the Wilcoxon signed-rank test with Bonferroni correction was used to compare other categorical independent variables (types of crown (CAD Lithium disilicate, CAD Zirconia, and cast gold) and level of marginal gap (75, 150, 225, and 300μm)). P-values less than 0.05 were considered statistically significant, with the exception of tests in which the Bonferroni correction was used. SPSS Version 22 was used in the analysis.

Results

The median total score among all clinicians was 15.5, with an interquartile range of 5.

Table 1 shows descriptive statistics of total scores of the three types of clinicians: prosthodontists, operative faculty and dental students. The median was highest in the operative faculty group (median = 18) and lowest in the dental student group (median = 14). The result of the Kruskal-Wallis test showed a significant difference between groups ($p=0.003$). In post-hoc testing conducted via Mann-Whitney U tests with Bonferroni correction, the operative faculty group and dental student group showed a significant difference ($p=0.002$). There was no significant difference between the prosthodontist group and the operative faculty group ($p=0.041$), or between the prosthodontist group and the dental student group ($p=0.034$), when using the Bonferroni correction to adjust for multiple comparisons.

Table 2 shows descriptive statistics of the scores of the different crown groups (cast metal crowns, e.max (lithium disilicate) crowns and zirconia crowns). The median of the e.max crown group was 6, which was higher than the cast metal and zirconia groups' medians (both of which were 5).The result of the Friedman test showed a significant difference between groups ($p<0.001$). In post-hoc testing conducted via Wilcoxon signed-rank tests with Bonferroni correction, the e.max crown group was significantly different from the cast metal crown group ($p<0.001$) and the zirconia crown group ($p<0.001$). There was no significant difference between the cast metal and zirconia crown groups ($p=0.326$).

Table 3 shows descriptive statistics of the scores of the different marginal gap groups (75 microns, 150 microns, 225 microns and 300 microns). The median of the 150 micrometer group was 1, which was very different from all the other groups which had a median of 5. The result of the Friedman test showed a significant difference between groups ($p<0.001$). In post-hoc testing conducted via Wilcoxon signed-rank tests with Bonferroni correction, the 150 micrometer crown group was significantly different from the 75 micrometer crown group ($p<0.001$), 225 micrometer crown group ($p<0.001$) and 300 micrometer crown group ($p<0.001$). The 225 micrometer crown group and 300 micrometer crown group showed a statistically significant difference as well ($p<0.001$), with the 300 micrometer crown group tending to exhibit higher scores. The 75 micrometer crown group showed no significant difference with the 225 and 300 micrometer crown groups ($p=0.135$ and $p=0.484$, respectively).

Graph 1 presents information on the reported number of porcelain crowns delivered per year among the clinicians in the study. 18.3% of the clinicians reported delivering no all-ceramic crowns. 31.7% reported delivering 1 to 10 all-ceramic crowns per year, while 10.0% reported delivering 11 to 20, 8.3% reported delivering 21 to 30, and 31.7% reported delivering more than 30.

Graph 2 shows information about the clinicians' opinions regarding the marginal seal of CAD/CAM all-ceramic crowns. 68.3% of the clinicians reported thinking that conventional cast metal crowns have better marginal seal than CAD/CAM all-ceramic crowns.

Graph 3 displays the reported percentage of crowns delivered by the clinicians that are CAD/CAM all-ceramic crowns. Only the prosthodontist group and the operative faculty group were included for the calculation because the student group did not have enough crowns for the calculation to be meaningful. 72.5% of the clinicians reported doing less than 25% of their crown deliveries with all-ceramic crowns, while 15.0% of the clinicians reported doing 25% to 50% of their cases with all-ceramic crowns. Only 5.0% of the clinicians reported doing 51-75% of their cases with all-ceramic crowns, with 7.5% reporting a percentage above 75%.

For the question, 'What were your criteria to classify crown margins as acceptable or unacceptable on the radiographs? Please describe', two clinicians did not answer, whereas 58 clinicians answered the question. Forty-three clinicians named the radiographically visible marginal gap as their evaluation criterion. Seven clinicians cited radiolucency around margin of the crown, and five clinicians cited both the radiographic open margin and radiolucency at the same time. Thirteen clinicians who named the radiographic marginal gap as their decision criterion also described that not only vertical open margins but also the overhangs of the crown in the radiograph were in consideration as well.

Discussion

The detection of marginal gap is important for the long term success of the fixed dental prosthesis including different types of crowns. Assif et al has described multiple ways of evaluating crown margins. (19) Tactile examination with an explorer is widely used clinically because of time efficiency but is limited by the inability to access mesial and distal aspects of the crown margin, especially the mesial and distal aspect. Impression material such as Fit checker^{TM} may also be used as an aid for checking marginal gap but cannot detect horizontal discrepancy well. Thus, radiographic evaluation has its advantage compared to the methods previously mentioned especially when determining mesial or distal margins. However, determination of an acceptable margin on the radiograph can be subjective depending on individual clinicians.

In Table 1, the operative instructors scored 4 points higher than the dental students in determining acceptable margins on radiographs ($p=0.002$). It can be suggested that more clinical experience can improve radiographic evaluation of crown margins. In addition, the results imply that didactic education from the radiology course was not sufficient for dental students' mastery of the radiographic evaluation of crown margins. However, this generalization could not be accepted because there was no significant difference between the prosthodontist group and the other groups even though score was higher on the prosthodontist group than the dental students. ($p=0.034$ after Bonferroni correction, 3 post hoc tests)

In Table 2, the e.max group exhibited better result compared to the cast metal crown group and the Zirconia crown group ($p<0.001$). This result may be explained by the different

radiopacity of each material. Restorative materials are recommended to be more radiopaque than enamel (76-78). Radiopacity of restorative materials allows for radiographic detection of defective restorations, secondary caries, and periodontal effects of crown overhangs (74, 76, 79). Despite the advantages radiopaque restoration materials, excessive radiopacity of restorative materials can be problematic (77, 82). Excessive radiopacity of restorations may result in under- or over-scoring of secondary caries and marginal defects compared to moderately radiopaque restorative material (77). Rasimick et al tested extremely radiopaque core material and concluded that excessive radiopacity makes it hard to identify voids or marginal defects (83). Moderate radiopacity may be more favorable and could facilitate the detection of caries (77). In this study, detection of marginal gaps in the e.max crown group was better than in the cast metal crown group and Zirconia crown group because of its favorable moderate radiopacity.

Table 3 presents the scores of the crown groups with different level of marginal gaps. The 150µm group exhibited the lowest score compared to the other crown groups. Most clinicians had difficulty to determine the level of 150µm compared to 75µm, 225 µm and 300 µm. In 1970, Bjorn et al evaluated ceramic crown margins radiographically and found that defects less than 300µm could not be detected. (93) However, our study showed that 225µm was also detectable. This result could be due to difference between the ideal parallel radiographs of an in vitro experimental environment and clinical radiographs which are often taken at poor angulations of sensor and anatomy of patient. There is also a possibility that an advanced digital radiographic system enabled the clinicians to have better predictability in determination of acceptable crown margin, but a recent study showed that there was no significant difference between the conventional radiography and the digitalized radiography.

Liedke et al stated that the detection accuracy of marginal gaps associated with metal restorations was not affected by the radiographic system (92). Because there are limits to the use of dental radiographs in determining acceptable crown margins, clinicians should consider using different methods as adjunctive measures to increase predictability of proper marginal adaptation. If direct access to margins of restorations is possible, sharp explorers offer better sensitivity to marginal gaps and can detect up to 36µm gaps with 95% accuracy (94).

There were several limitations to this study. First, this study was done on one identical abutment. If multiple abutments with different preparation designs were used for the study, the results may have been different. Second, the crowns were not cemented with any type of cements prior to radiographic evaluation to allow for insertion of all the crowns included in the study. Applying cement may have affected seating. Third, this study was completed in vitro. There is more uncertainty in a clinical environment including intraoral sensor position, patient anatomy, and movement. In a clinical setting, if a radiograph is not ideally taken with the proper sensor to X-ray source angulation (underangulation or overangulation), the radiograph can be distorted and may induce false positive evaluation on crown marginal seating because of overlap. The last limitation is that replicating radiographic property of all the tissue in the oral cavity into in vitro study model was not possible, likely affecting the quality of the radiograph.

For the future study, an in vivo randomized clinical trial can be planned to overcome shortcomings of in a vitro study design. Because of uncertainties in clinical environment and variable preparation designs of abutments, the future study may require more sample size.

Conclusion

1. The marginal gap (150μm) which is close to acceptable clinical crown margin (120μm) did not show enough sensitivity for clinicians to determine the acceptable crown marginal gap in the radiographs and caused false positive evaluation results.

2. Clinicians tended to have greater success in classifying the marginal gaps of the e.max crown group.

3. More clinical experience may improve the ability of radiographic evaluation of crown marginal gaps.

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APPENDICES

Appendix A: Tables

Appendix B: Figures

Appendix C: Graphs

Appendix D: Radiographic Survey

Appendix A: Tables

Table 1. Scores of Different Clinician types (N=20 per group)

	Median*	IQR	Significance
Prosthodontists	17[ab]	4	P=0.003
Operative Faculty	18[a]	5	
Dental Students	14[b]	3	

*Rows with the same letter exhibit non-significant differences

Table 2. Scores of Different Crown types (N=60 per group)

	Median*	IQR	Significance
Cast Metal	5[a]	2	p<0.001
e.max	6[b]	1	
Zirconia	5[a]	3	

*Rows with the same letter exhibit non-significant differences

Table 3. Scores between Different Marginal Gap groups (N=60 per group)

	Median*	IQR	Significance
75 micrometer	5[ab]	0.75	p<0.001
150 micrometer	1[c]	2	
225 micrometer	5[a]	3	
300 micrometer	5[b]	2	

*Rows with the same letter exhibit non-significant differences

Appendix B: Figures

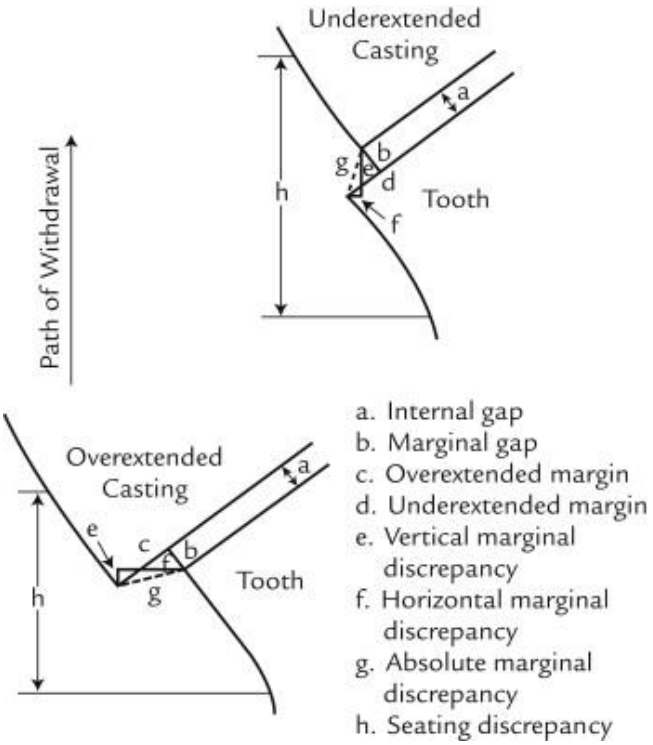


Figure 1. Terminology for marginal fit. (85).

Figure 2. A mandibular molar was embedded in a dentiform and prepared for crown restoration.

Figure 3. Master casts were fabricated using Die-keen® stone.

Die spacer applied to create the marginal gap planned for each crown group.

Figure 4. The wax pattern was milled from the identical CAD digitalized files

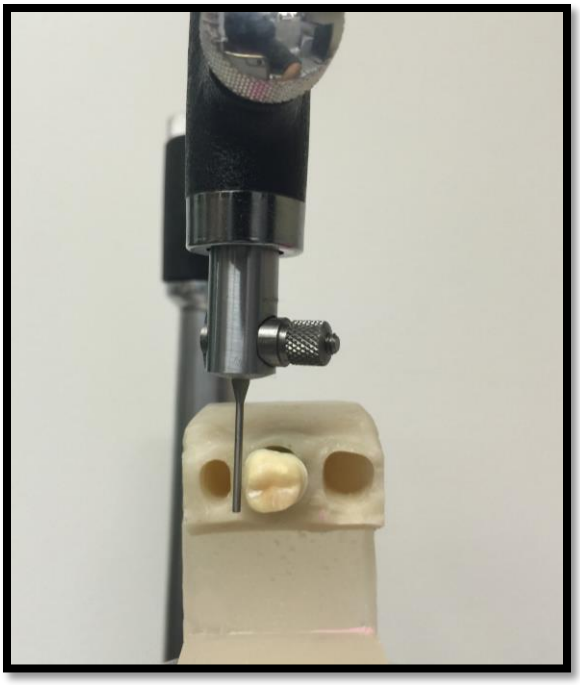


Figure 5. A resin jig was fabricated to take radiographs with paralleling technique. Using a surveyor, the mesial and distal reference points were marked to locate exact mesial and distal point in the radiograph.

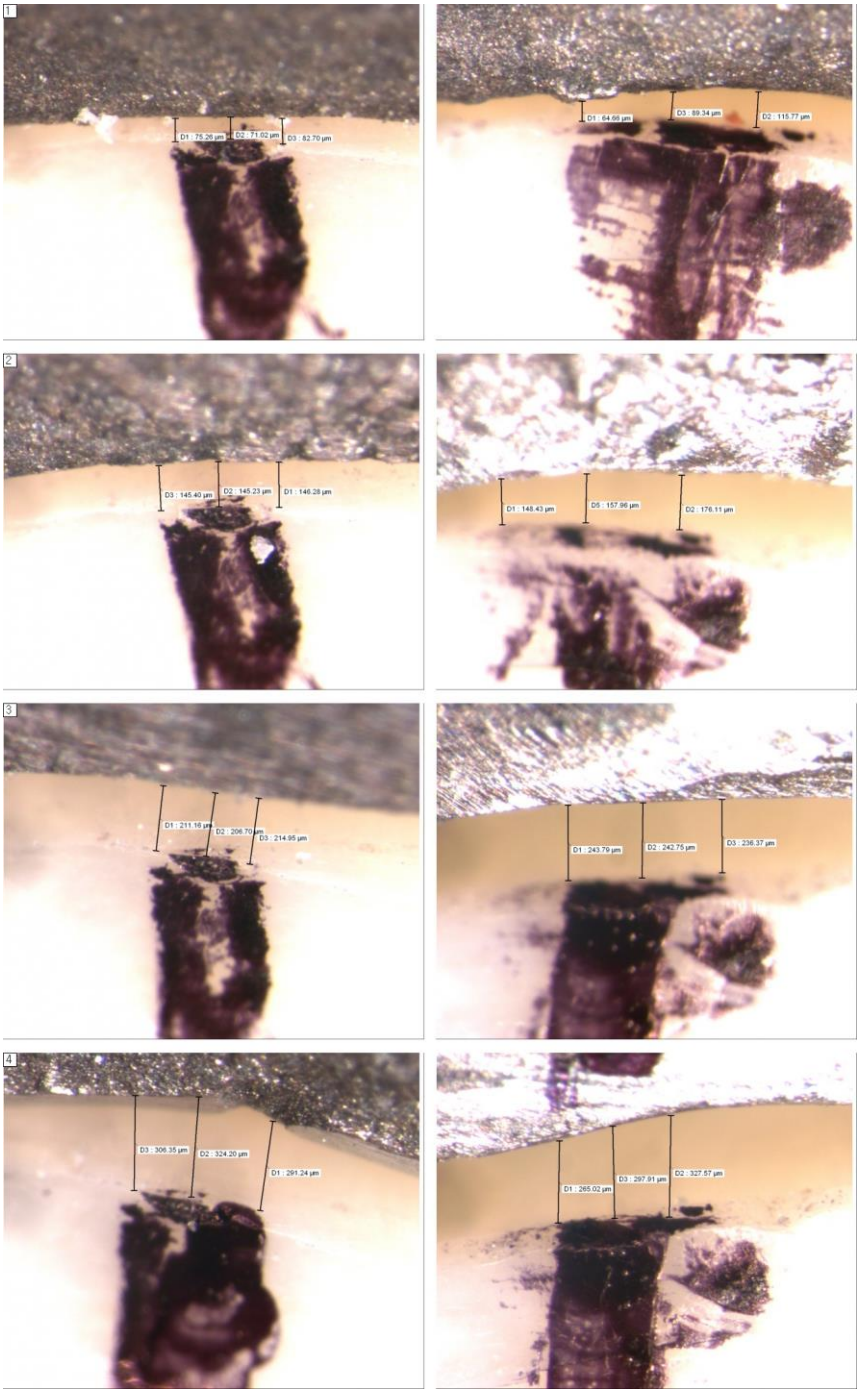


Figure 6. Measurement of the marginal gap of zirconia of Cast metal crowns 1) 75 µm: Mesial 76.33 µm (Left) Distal 89.92 µm (Right) 2) 150 µm: Mesial 145.63 µm (L) Distal 160.83 µm (R) 3) 225 µm: Mesial 210.94 µm (L) Distal 240.97 µm (R) 4) 300 Microns: Mesial 307.26 µm (L) Distal 296.83 µm (R)

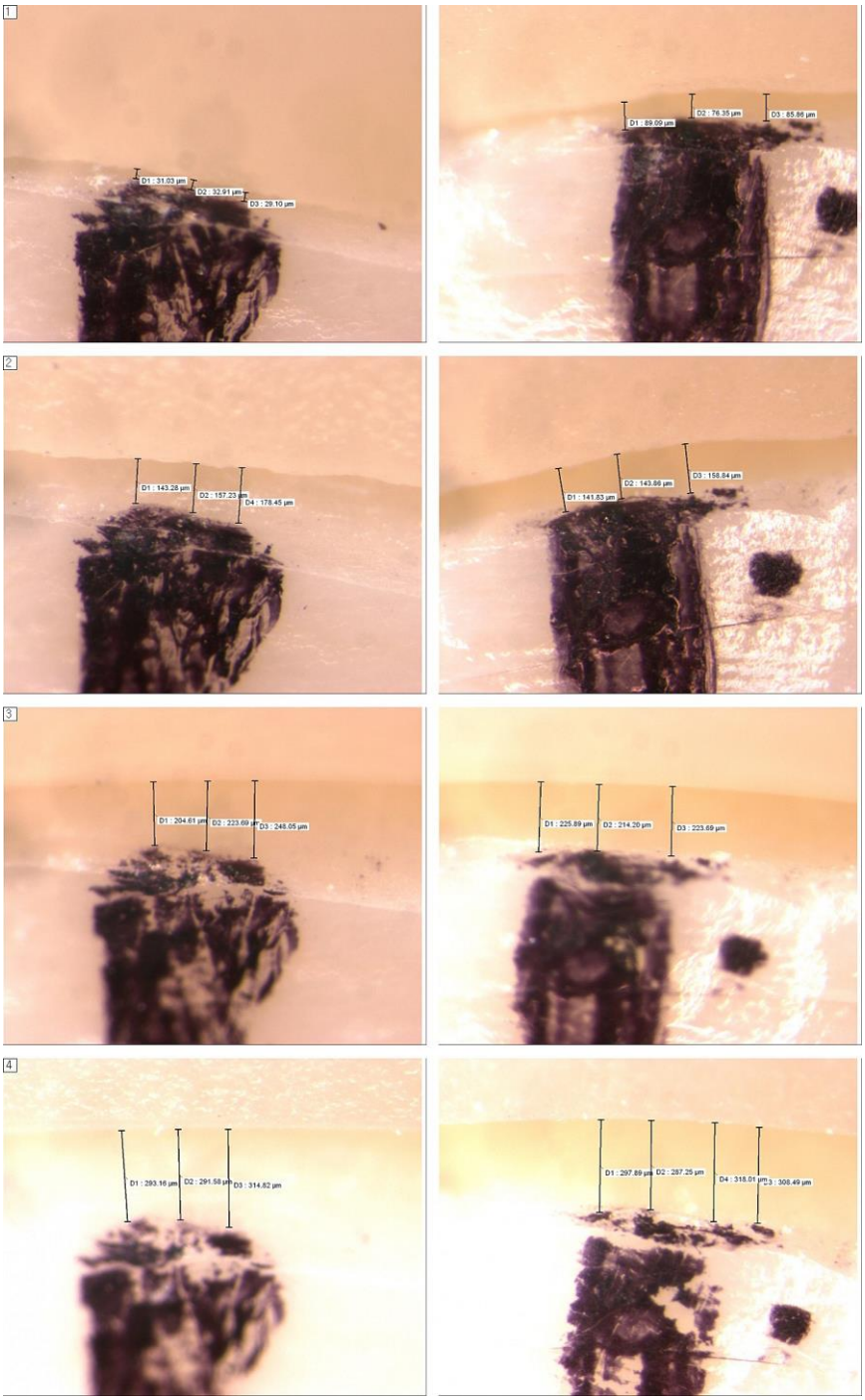


Figure 7. Measurement of the marginal gap of zirconia of e.max crowns 1) 75 µm: Mesial µm (Left) Distal 83.76µm (Right) 2) 150 µm: Mesial 159.65µm (Left) Distal 148.17µm (Right) 3) 225 µm : Mesial 225.45µm (Left) Distal 221.26µm (Right) 4) 300 µm: Mesial 299.85 µm (Left) Distal 301.05 µm (Right)

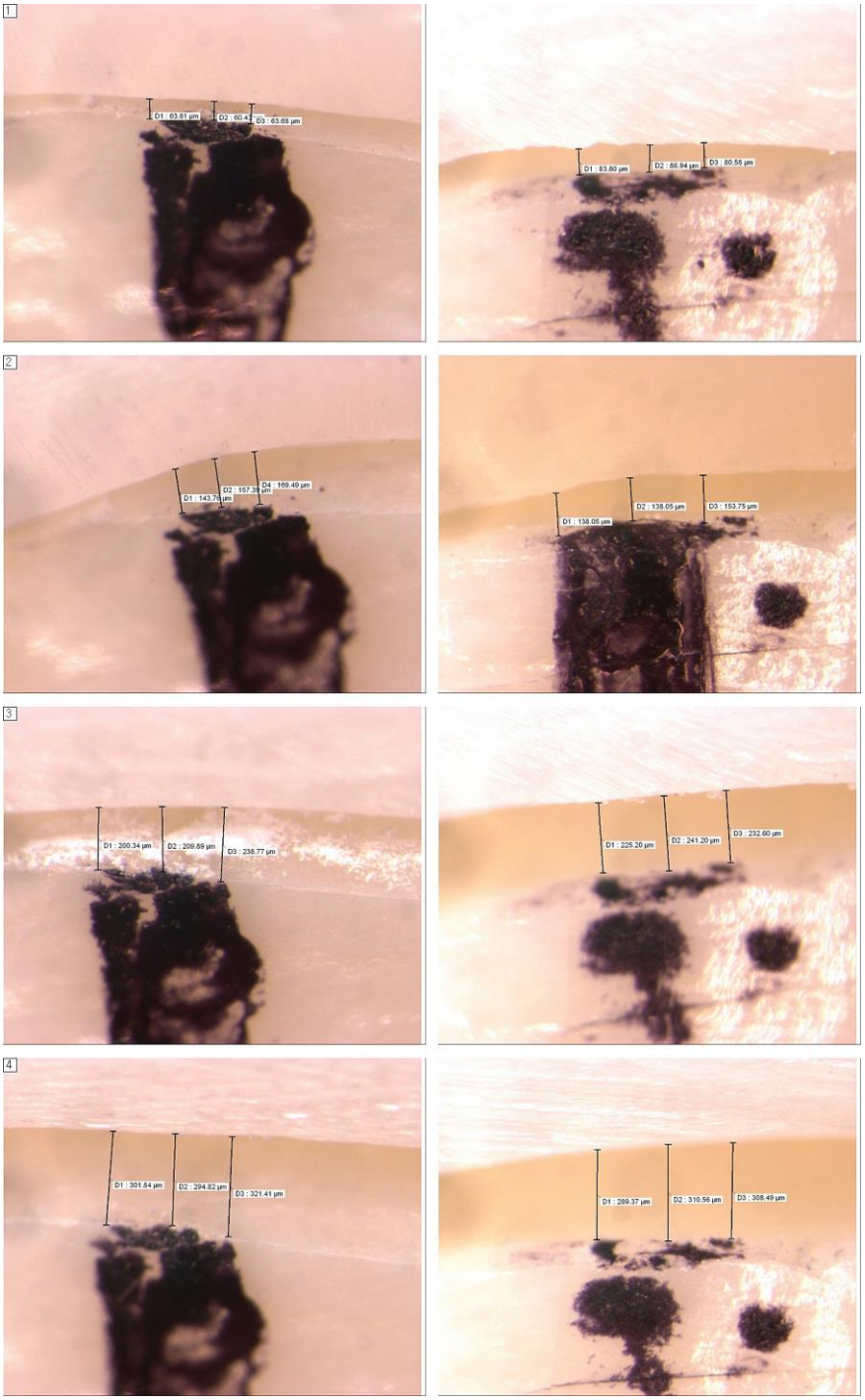
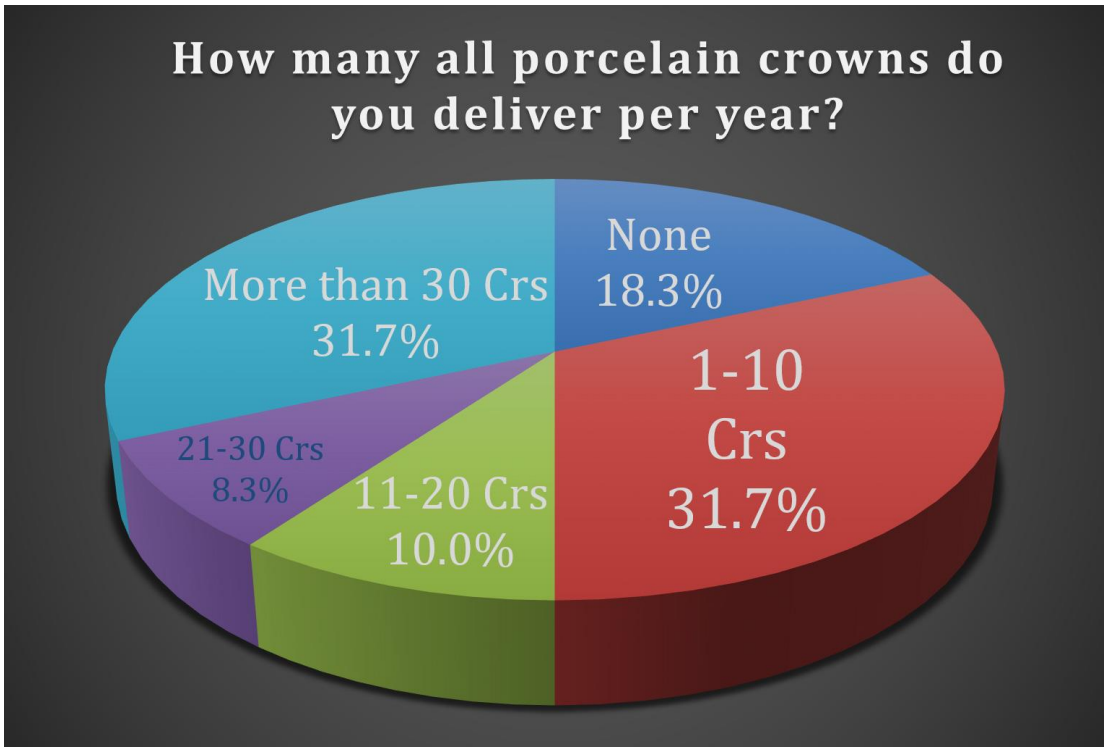


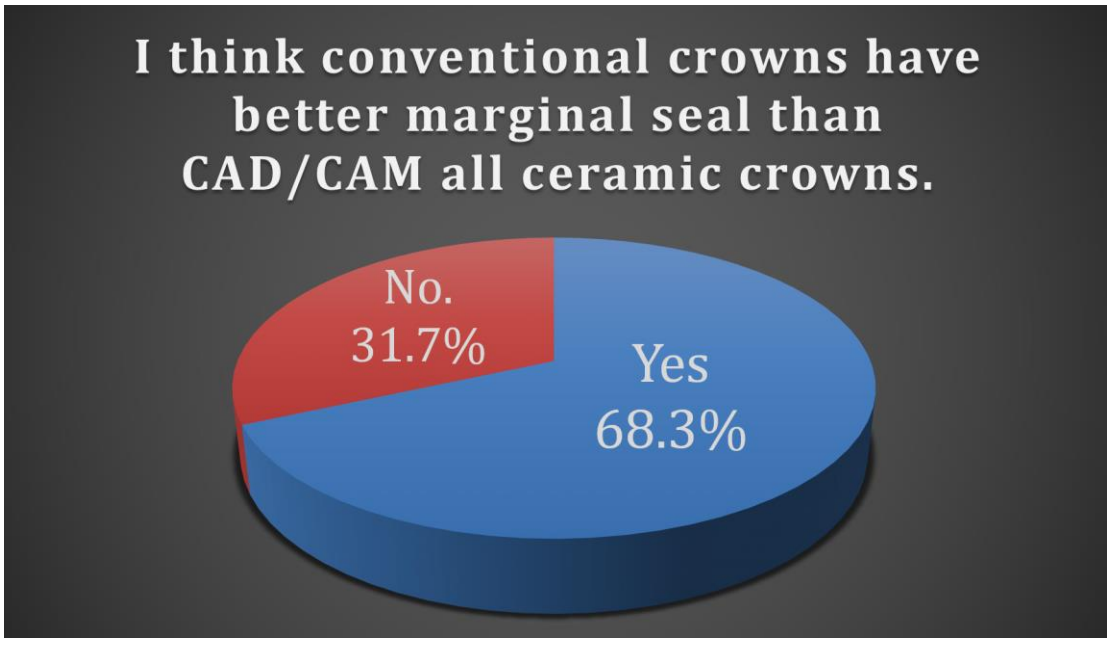
Figure 8. Measurement of the marginal gap of zirconia crown 1) 75 µm: Mesial 62.57 µm (Left) Distal 83.70 µm (Right) 2) 150 µm: Mesial 156.88 µm (L) Distal 143.28 µm (R) 3) 225 µm: Mesial 216.33 µm (L) Distal 232.67 µm (R) 4) 300 µm: Mesial 306.02 µm (L) Distal 302.80 µm (R)

Appendix C: Graphs

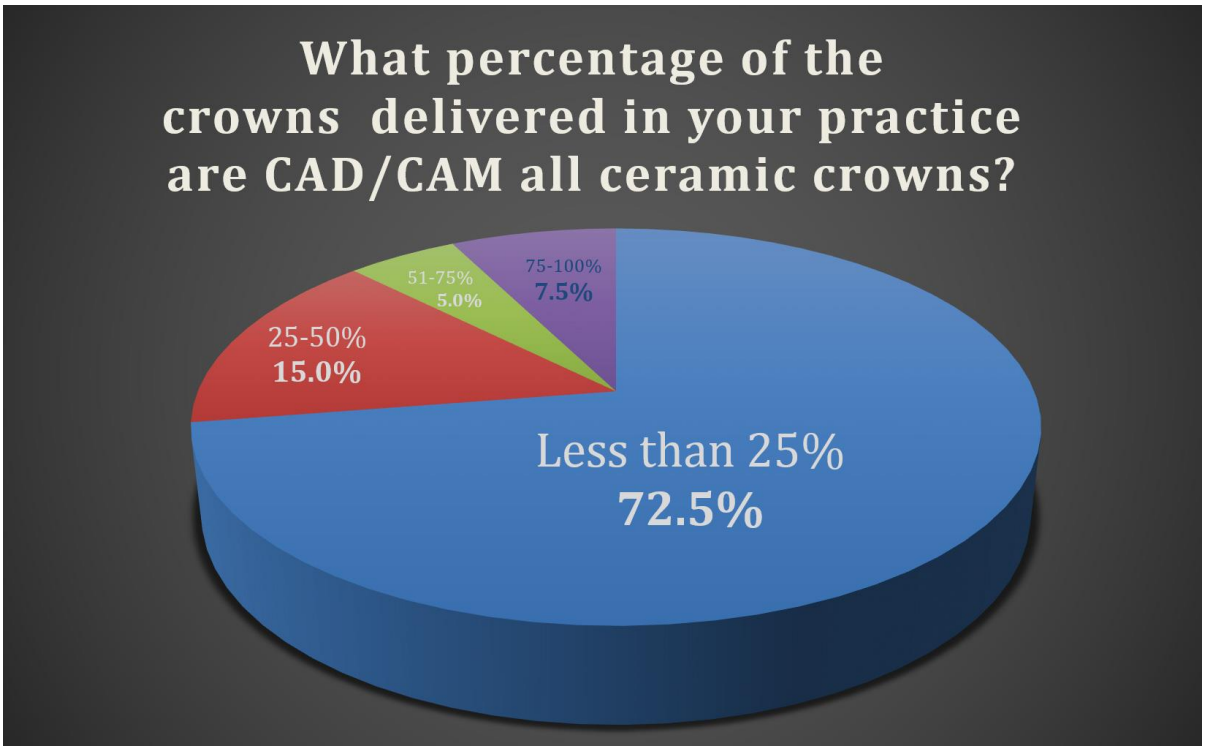
Graph 1. Reported number of all-ceramic crown deliveries per year



Graph 2. Opinion about the marginal seal of CAD/CAM all-ceramic crowns in comparison to conventional crowns



Graph 3. Reported percentage of the clinicians' crown deliveries per year that are CAD/CAM all-ceramic crowns



Appendix D: The Radiographic Survey

1. I am a :

   __Prosthodontist __ General Dentist __ IS15 Student __IS16 Student

   __ D15 Student __ D16 Student

2. How many all porcelain crowns do you deliver per year?

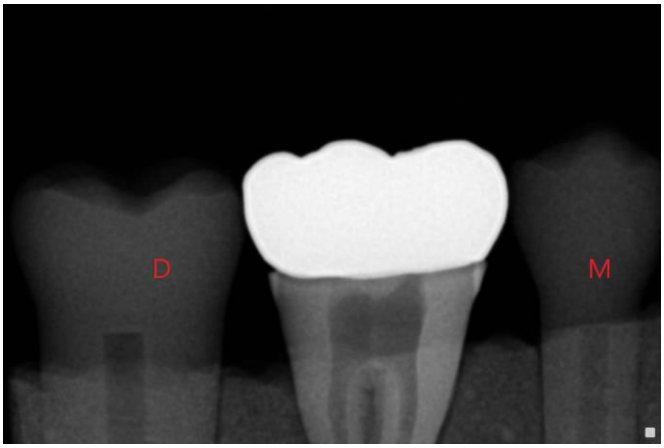
   __None __1-10 __11-20 __21-30 __>30

3. I think conventional crowns have better marginal seal than CAD/CAM all ceramic crowns.

   __Agree_ Disagree

4. What percentage of the crowns delivered in your practice are CAD/CAM all ceramic crowns?

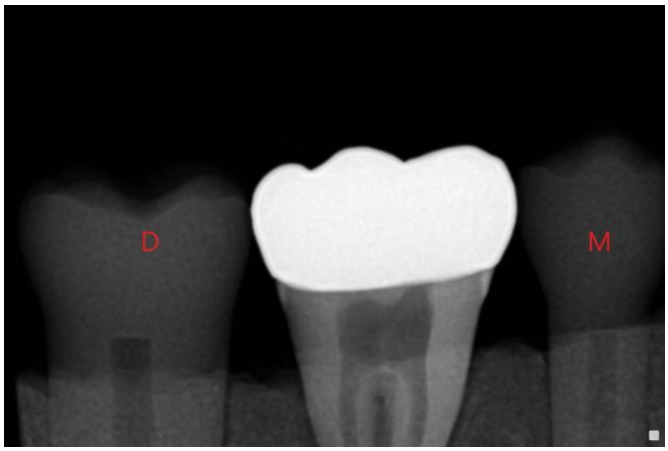
   __ Less than 25% __ 25-50% __ 51-75% __ More than 75%



5. Please classify the marginal seal of radiograph #1 (mesial and distal sides) as acceptable or unacceptable.

   Mesial: acceptable__ unacceptable__

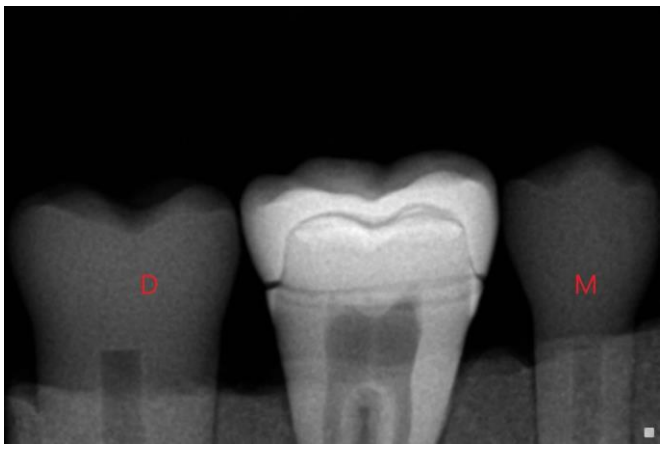
   Distal: acceptable__ unacceptable__



6. Please classify the marginal seal of radiograph #2 (mesial and distal sides) as acceptable or unacceptable.

   Mesial: acceptable__ unacceptable__

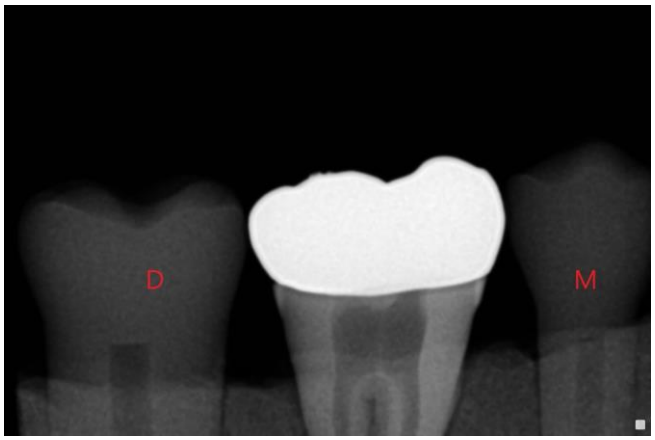
   Distal: acceptable__ unacceptable__



7. Please classify the marginal seal of radiograph #3 (mesial and distal sides) as acceptable or unacceptable.

   Mesial: acceptable__ unacceptable__

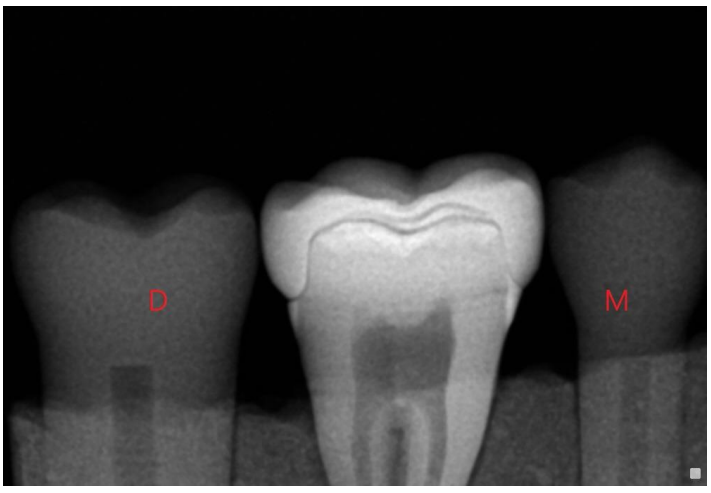
   Distal: acceptable__ unacceptable__



8. Please classify the marginal seal of radiograph #4 (mesial and distal sides) as acceptable or unacceptable.

   Mesial: acceptable__ unacceptable__

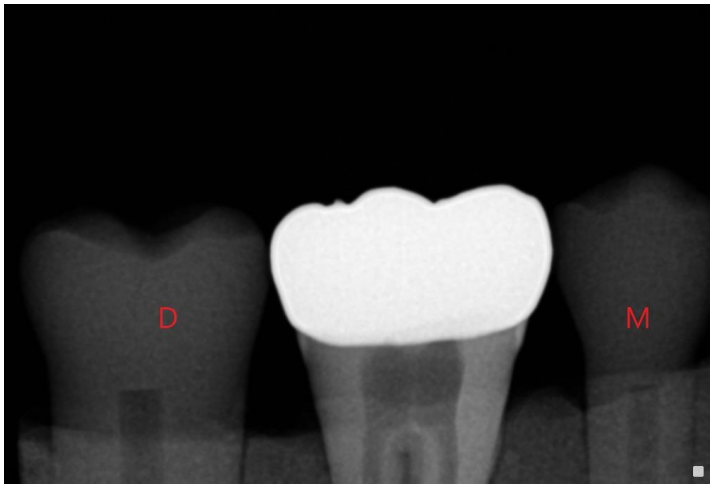
   Distal: acceptable__ unacceptable__



9. Please classify the marginal seal of radiograph #5 (mesial and distal sides) as acceptable or unacceptable.

Mesial: acceptable__ unacceptable__

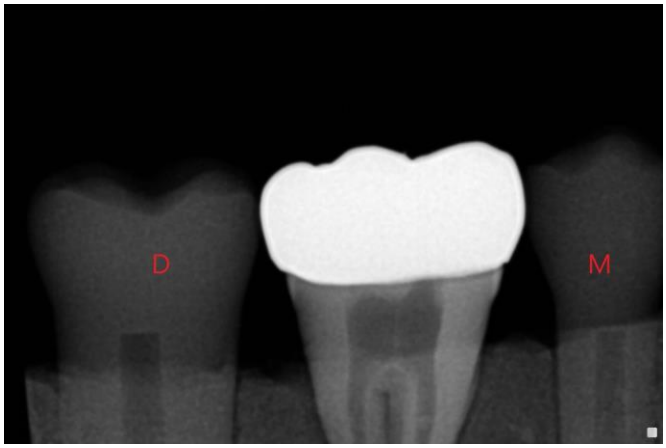
Distal: acceptable__ unacceptable__



10. Please classify the marginal seal of radiograph #6 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

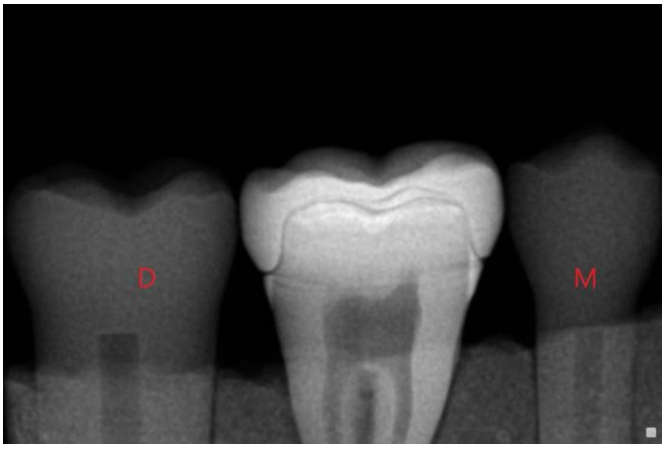
    Distal: acceptable__ unacceptable__



11. Please classify the marginal seal of radiograph #7 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

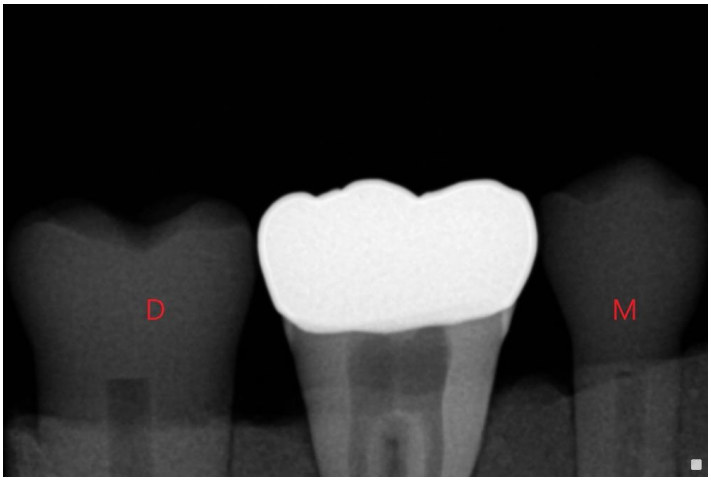
    Distal: acceptable__ unacceptable__



12. Please classify the marginal seal of radiograph #8 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

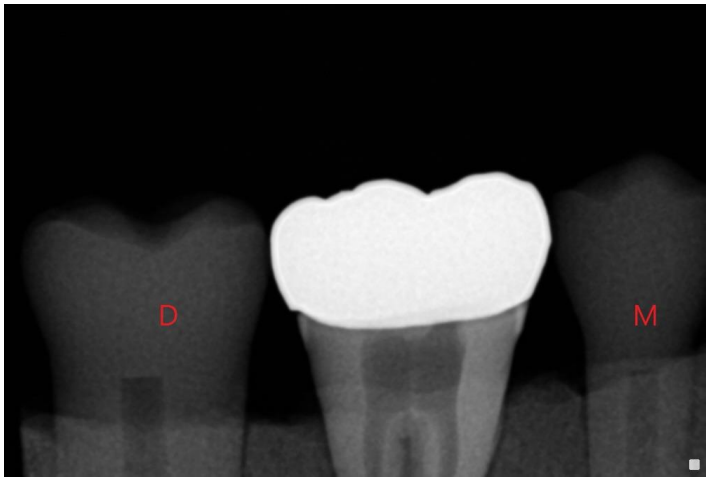
    Distal: acceptable__ unacceptable__



13. Please classify the marginal seal of radiograph #9 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

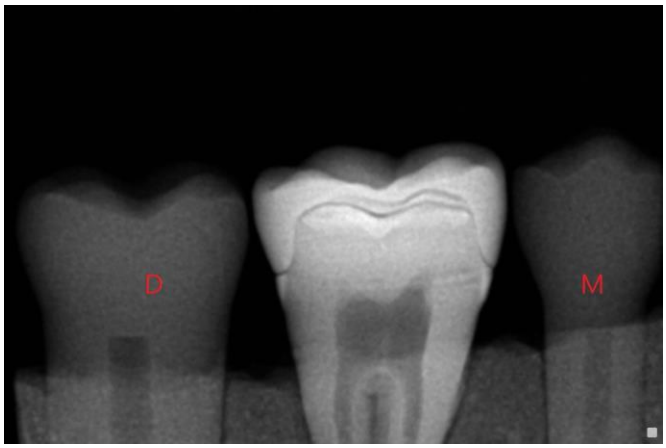
    Distal: acceptable__ unacceptable__



14. Please classify the marginal seal of radiograph #10 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

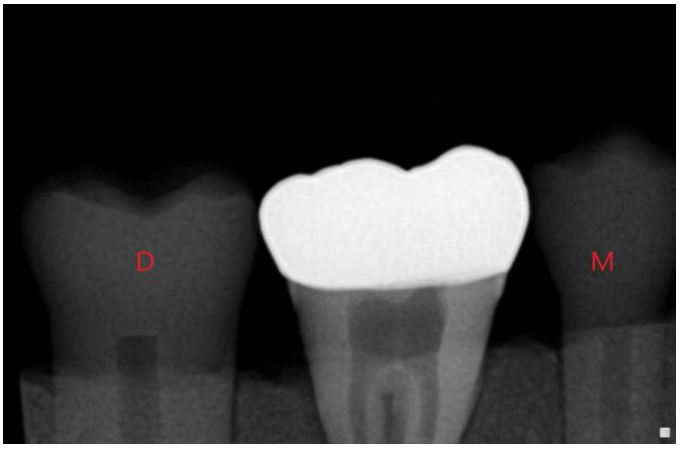
    Distal: acceptable__ unacceptable__



15. Please classify the marginal seal of radiograph #11 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

    Distal: acceptable__ unacceptable__



16. Please classify the marginal seal of radiograph #12 (mesial and distal sides) as acceptable or unacceptable.

    Mesial: acceptable__ unacceptable__

    Distal: acceptable__ unacceptable__

17. What were your criteria to classify crown margins as acceptable or unacceptable on the radiographs? Please describe.