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Marginal Adaptation of CAD/CAM Hybrid Ceramic Crowns Made on Preparations With and Without Surface Finishing

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Purpose: This in vitro study evaluated the marginal adaptation of ceramic crowns fabricated with a chair-side CAD/CAM system on preparations completed with and without surface finishing to identify if finishing preparation protocols affect the marginal fit. The null hypothesis was that there was no difference in the mean marginal adaptation of ceramic restorations between the two finishing protocols.

Materials and Methods: A total of 10 maxillary right central incisor acrylic teeth were screwed into precision restorative typodont with soft gum and attached to a portable bench mount. Teeth were divided into two groups (Control group CG, Finished group FG) and prepared for all ceramic crowns with medium only/and fine grit burs under dental loupes with 4.5x magnification. The CG was prepared using the medium grit bur only, while the FG was prepared using the medium grit bur and then refined with the fine grit bur for two minutes. Preparations were scanned with an intraoral scanner and hybrid ceramic crowns were designed, milled and hand polished following the manufacturer's recommendations. The hybrid ceramic crowns were cemented on the prepared teeth using a dual cure resin cement system. Design, milling and cementation were made by the same operator. To measure the vertical marginal gap between the margin of the crown and the finish line of the acrylic tooth, scanning electron microscope (SEM) images were made (Singh Center for Nanotechnology, University of Pennsylvania) with magnification of ×100. A total of 50 measurements were made per tooth: 25 mid-facial margin area and 25 mid-palatal margin area. The data were analyzed with Mann-Whitney Rank Sum Test to determine differences between the groups. A statistical software program was used for the analysis.

Results: The FG resulted in a significant decrease in the overall mean marginal gap of CAD/CAM all ceramic crowns compared to the CG ($p<0.001$).

Conclusion: Crown preparation finishing with fine grit bur has a significant impact on the marginal gap of all ceramic restorations.

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Thesis

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By

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Dedication

This manuscript is dedicated to my loving parents Alaa Al-Hussainy and Nahla Al-Duajili, my lovely sister Teeba and my dear wife Farah Al Nawab. I am grateful for your endless support, love, care and sacrifices. You taught me how to become a strong and passionate person and encouraged me to follow my dreams in pursuing my post-graduate studies in dentistry.

I. Chapter 1

Introduction

Digital technology has significantly influenced dentistry. In particular, digital manufacturing using milling manufacturing technologies have provided the ability to produce dental prostheses with predictable accuracy and fit.[1–4] In addition to the goal set on increased efficiency, cost reduction, and higher patient satisfaction; the technology of CAD/CAM software enables for excellent communication between dentists, technicians, and patients. [5]

The marginal accuracy is one of the most important factors affecting long-term success in fixed restorations.[6] An acceptable marginal fit maintains the gingival health and protects the tooth from physical, chemical, bacterial, and thermal injuries.[7]

The vertical marginal gap measured in this study is the vertical distance measured parallel to the path of withdrawal of the restoration and the respective preparation at mid of buccal, and lingual areas. A marginal misfit can be considered acceptable when it is visually imperceptible or cannot be detected using a dental probe. A marginal gap of less than 80 μm is proven to be very difficult to detect clinically.[8] Marginal gap values between 100 and 150 μm are considered clinically acceptable. [9,10] However, they can be a source of housing for the bacteria ultimately leading to the inflammation of the gingiva around the margins.[8–11]

Recently, new hybrid CAD/CAM blocks were introduced to the dental field, composed of two matrices: a polymer and a ceramic network. This dual network structure reduced brittleness and surface hardness of the material allowing easier milling in a shorter time. [12]

An in vitro study demonstrated a statistically significant difference in marginal gap between the hybrid ceramic and crystallized lithium disilicate copings with the greater mean marginal gaps measured for crystallized lithium disilicate copings. [13]

Similar to marginal accuracy, internal adaptation and retention are important factors for the longevity of crown restorations. Although surface finish can be a critical variable in clinical performance, there is a dearth of information regarding surface characteristics of teeth prepared for fixed restorations.[14]

For example, A study by Li et al, demonstrated that teeth prepared with the finer grit rotary instruments have smoother tooth surfaces and crown restorations with better internal adaptation.[15] Similarly, a study by Ayad et al demonstrated statistically significant differences in the surface topography of prepared teeth. Mean surface roughnesses (Ra) were 8.6 and 6.8 µm for teeth prepared with diamond and tungsten carbide burs. Teeth completed with finishing burs appeared to result in a smoother surface (1.2 µm). [14]

The purpose of this study is to evaluate the marginal gap of restorations fabricated using CAD/CAM systems to determine if preparation quality including surface finish has an impact on marginal adaptation of the milled restorations and if the marginal gap will vary between unfinished, and finished preparations. The null hypothesis is that there is no difference in the mean marginal gap of restorations of different surface finish.

a. Review of literature

i. All ceramic restorations

In 1903 Land introduced the first feldspathic porcelain crown. [16] Since then, there has been an exponential growth in demand for non-metallic restorations.[16]

In 1965, McLean achieved significant improvement in mechanical and physical properties by adding aluminum oxide to feldspathic porcelain.[17]

In 1969 Helmer and Driskell published the first paper on biomedical application of zirconia.[18]

In 1988, Christel presented the use of zirconia to fabricate artificial femoral heads in total hip replacement.[19]

Kelly believed that dental ceramics can be categorized into three main domains. A. A predominantly glassy material, which has similar optical properties as enamel and dentin. B. A material where filler particles are added to improve mechanical and optical properties (Particle filled glasses). One of the first fillers to be used in dental ceramics was Leucite. [20,21]One subset of this group is the glass-ceramics. Examples are Dicor (Dentsply) and Empress 2 (Ivoclar-Vivadent). C. Polycrystalline ceramics, which have densely packed atoms in regular arrays. They are much tougher and stronger but relatively opaque compared to glass ceramics. Polycrystalline ceramics can serve as substructure materials which can be veneered with glass ceramics for better esthetics. [22]

Blatz et al; classified dental ceramics into 3 groups: resin matrix ceramics (RMCs), silicate ceramics, and oxide ceramics.

Resin matrix ceramics were classified as ceramics based on the 2013 version of the American Dental Association Code on Dental Procedures and Nomenclature. [23]

Resin matrix ceramics are divided into 2 subgroups: resin-based ceramics and hybrid ceramics.

Silica-based ceramics are divided into feldspathic and silicate ceramics and are defined as mainly nonmetallic inorganic ceramic materials that contain a glass phase.

High-strength polycrystalline metal oxide–based CAD/CAM ceramics such as zirconium dioxide (zirconia) are characterized by excellent mechanical properties, which are significantly greater than those of silica-based ceramics. [24]

ii. Hybrid Ceramics

Ceramics and composites are some of the materials available for definitive machined restorations. Ceramics have excellent mechanical and optical properties, as well as biocompatibility; however, they are fragile, rigid, and hard to repair. On the other hand, composites are easy to manipulate and repair, more flexible, and less abrasive on the antagonist tooth, but their poor wear resistance and difficulty to obtain good polish put them in a disadvantage compared to ceramics.[25] Recently, the characteristics of both were combined on the called "polymer-infiltrated ceramic-network" (PICN). The dominant ceramic network is reinforced with a polymer network. Each network penetrates the other to create a hybrid material.[26] The inorganic ceramic portion comprises 86 % by weight of this material. The organic polymer part comprises 14 % by weight of the structure mass.[27]

Due to the ceramic polymer network, hybrid ceramic blocks possess similar physical properties as enamel and dentin. Vita Enamic has an elasticity of 30 GPa, which unlike no dental material is in the same range as human dentin. [28] This material shows high flexural strength and a high level of color stability due to the ceramic composition.[28] Table 2 summarizes the physical properties of Vita Enamic.[27]

In addition to mechanical properties, other characteristics are desirable in these materials. For example, good marginal adaptation and bond strength to teeth are essential for the longevity of restorations.[29] Periodontal diseases, secondary caries, and endodontic problems can be caused by poor marginal adaptation through the accumulation of biofilm or the penetration of fluids from the oral cavity. [30,31]Even with the evolution of (CAD/CAM) technology, in which restorations can be milled with fewer defects due to the homogeneity of the materials used, [32] achieving excellent marginal adaptation is still difficult.[33] The manufacturer claims that the new hybrid material presents improved machinability, which, in turn, results in improved marginal adaptation.

Table 1: Summary of physical and mechanical properties of Vita Enamic

	Vita Enamic	Standard Value
Static fracture load [N]	2766 (98)	None specified
Density [g/cm3]	2.1	None specified
Flexural strength [MPa]	150-160	ISO 10477: ≥ 50 ISO 6872: ≥ 100
Modulus of elasticity [Gpa] (SD)	30 (2)	None specified
Abrasion [um]	In the same range as Mark II, veneering ceramics	None specified
Extension in the case of fracture [%] (SD)	0.5 (0.05)	None specified
Weibull modulus	20	None specified
Hardness [Gpa]	2.5	None specified
Fracture toughness [Mpa √m]]	1.5	None specified
Adhesion with veneering material [Mpa]	Without silane: 12 With silane: 27	ISO 10477: ≥5
Shear strength, cementation [Mpa]	RelyX Unicem: approx.21, Vriolink II: approx. 27, RelyX Ultimate: approx. 31	None specified
Shade stability	Excellent ΔE <2	None specified
Machinability, edge stability	Excellent	None specified
Milling times, normal milling mode MXCL	Inlay: 7:56 min Anterior crown: 7:10 min Posterior crown: 9:07 min	None specified
Milling times, fast milling mode MC XL	Inlay: 4:40 min Anterior crown: 4:19 min Posterior crown: 5:13 min	None specified
Milling tool service life: posterior crowns	Normal: 148 Fast: 132	None specified
Biocompatibility	Confirmed	ISO 10993
Chemical solubility [ug/cm2]	0.0	ISO 6872: ≤100
Water absorption [ug/mm3]	5.7	ISO 10477: ≤40
Solubility in water [ug/mm3]	≤1.2	ISO 10477: ≤7.5

iii. Marginal and internal fit

Apart from fracture resistance and aesthetics, marginal fit is valued as one of the most important criteria for the clinical quality and success of all-ceramic crowns. [29,34,35]

Misfit leads to plaque accumulation, which can cause caries or periodontal diseases, especially in restorations with subgingival margins. [36] In addition, a poor fit could contribute to cement dissolution and consequent bacterial infiltration, as well as reduced fracture resistance. [37,38]

Holmes et al. introduced a classification for marginal gap in 1989. They measured “misfit” as internal gap, marginal gap, vertical marginal discrepancy, horizontal marginal discrepancy, overextended margin, underextended margin, absolute marginal discrepancy and seating discrepancy. According to their classification “the perpendicular measurement from the internal surface of the casting to the axial wall of the preparation is called the “internal gap”, and the same measurement at the margin is called the “marginal gap”. “Absolute marginal discrepancy “was defined as the angular combination of horizontal and vertical discrepancies and represents the total misfit of the restoration.[8]

Unfortunately, there is no consensus on what constitutes a clinically acceptable marginal and internal misfit. Threshold values reported in the literature vary from 18 to 200 μm for the marginal fit, although a maximum clinically acceptable marginal discrepancy according to most researchers is less than 120 μm.[39]

Although digital dentistry applications afford significant advantages to patients (such as crown preparation and delivery in one appointment and increased patient comfort with digital impressions), many clinicians are hesitant to adopt this new technology chairside. Previously, one main concern was the large marginal gap that was found on restorations milled by early generations of the CEREC systems.[30,40]

According to a meta-analysis, [41,42] single CADCAM restorations made by intraoral scanners (IOS) have similar marginal gaps as traditional elastomer impression methods.

iv. Cementation and marginal fit

In 1994 Wilson found a correlation between increased cement space and decreased seating discrepancy. His study showed that for a minimal amount of seating discrepancy, at least 40 μm of cement space is required when luting an artificial crown with zinc phosphate cement. He further concluded that the amount of cement space has a significant effect on crown seating.[43]

Cement thickness has been found to have an effect on the fracture resistance and flexural stress loads on the ceramic crowns.[44]

Nakamura et al. achieved better marginal fit of CEREC 3 CAD/CAM all-ceramic crowns when the cement space was increased to 30-50 um compared to 10 um cement space.[45]

One of the factors that can influence the measurement of marginal fit of crowns is whether the marginal gap is measured on a cemented or an uncemented crown. Marginal discrepancy can be increased following cementation. Some studies have found a significant increase in marginal gap values after cementation of all-ceramic crowns.[46,47]

Ural et al. evaluated the marginal adaptation of restorations made with five different ceramic systems: 1.CAD/CAM, 2. heat-press, 3. glass-infiltration, and 4. conventional lost-wax techniques, before and after cementation. In their investigation ceramic restorations fabricated with the CEREC 3 system showed the least marginal discrepancy. The result of the comparison of marginal gap values before and after cementation suggested significantly higher marginal gap values after cementation.[48]

v. Measurement methods for marginal fit

In 1990, Sorenson[49] categorized the measurement methods for marginal and internal discrepancies of crowns into 4 groups:

1. Direct view technique

2. Cross sectional

3. Impression technique

4. Visual examination (explorer).

A literature review reported in 2013, looked at 180 articles related to methods used for measuring the marginal adaptation of crowns and fixed dental prosthesis. According to this study, six methods of measurement had been reported in the literature. The direct view technique was used most frequently. The Cross-sectioning method and impression replica technique were the next most popular methods.[16]

The methods reported in literature for measuring the marginal gap of crowns can be categorized into two groups:

1) Non-destructive (non-invasive): methods such as replica technique.[50]
2) Destructive (invasive): methods such as cross-sectioning method.[50]

1. Direct view technique

This is an in vitro, non- destructive method that does not require any damaging of the restoration and die.[50]

This method can achieve more accurate results due to elimination of error accumulation from multiple steps.[50]

However, this method has some disadvantages:

1. Differentiation between the tooth margin and the cement layer can be challenging.[50]
2. Accurately finding the points of measurements can be difficult.[37,50]
3. Projection error due to magnification can make the margins appear rounded.[37,51,52]

Examples of this method are direct view of marginal adaptation of the restorations under high power microscopy or utilizing Scanning Electron Microscopy (SEM).

To measure internal gap, the crowns are luted to the die and then cross sectioned. Measurements are made on the gap area filled with the cement.[53]

Groten et al. compared the marginal fit of copy-milled ceramic crowns utilizing two different measuring techniques. They utilized light microscopy and SEM. The results of their study showed no significant difference in the accuracy between the two different methods. However according to the authors observations can be more realistic and appropriate with SEM than with light microscopy.[51]

2. Cross-sectioning method

This system depends on sectioning the samples after cementation. The cement width at the margin level can be measured directly both in the vertical and horizontal planes (57). This method limits the number of sections and measurements on each specimen. The values might not represent the marginal adaptation of the complete crown.[37] Another disadvantage of this destructive method is that it eliminates the possibility of making measurements before and after processing the samples.[54,55]

3. Impression/Replica technique

Several studies have used the replica technique as a non-invasive method to evaluate the fit of restorations.[31,56–60]

One replica method described by Molin and Karlsson was used to fabricate a replica from the intermediate space between the preparation surface of the tooth and inner surface of the crown. This was accomplished by filling the intaglio of the crown with light body silicone impression material before placing the crown on the die.[37] After the impression material had set, the crown was removed. Heavy body silicone impression material was used to stabilize the thin layer of light body material inside the crown. The light body film could then be removed from the inside of the crown and sectioned for measuring thickness at different areas.[61] Another method is making an external impression from the marginal gap after fixing the crown on the die.[16]

This technique has several disadvantages:

-Identifying the crown margin and the finish line can be challenging.[16]

-With a replica technique only a limited number of measurements can be made for each specimen.[37]

- The thin film layer can easily tear upon removal.[56]

- Sectioning errors can lead to overestimated measurements.[56]

A variation of the replica technique was employed by Luthardt et al., which it involved digitizing the dies and the replica film (the space between the die and the crown) with a digital scanner. In this study, a 3-D analysis of the internal fit of CAD/CAM crowns fabricated after direct optical versus indirect laser scan digitizing was made. Result s of this study showed that scanning the impression made from the master die can result in fabrication of crowns with better marginal fit compared to direct optical acquisition of the master die. However, the differences were minimal.[62]

Anadioti et al. designed a study to validate the reliability of the triple scan measurement protocol.[50] They used the triple scan protocol described by Holst et al. to evaluate the 2D and 3D marginal fit of pressed and CAD/CAM generated lithium disilicate crowns fabricated from digital and conventional impressions. Thirty casts were made from polyvinyl siloxane impression (PVS) of a dentoform tooth #30 and thirty resin models were made by digital impressions using a Lava scanner. Each group was divided in to two groups of fifteen for fabricating IPS emax pressed crowns and IPS emax CAD crowns. Three scans were made from: 1) The master die, tooth #30, 2) the Intaglio surface of each crown, and 3) Each crown on the master die in the ideal clinical position. The STL data sets were made and used for measuring the marginal gap. Digital sections were delineated on the facial-lingual and the mesio-distal surfaces. The gaps were measured at four standardized points. Result of this study showed that there were no statistical differences between the 2D and 3D measurements of marginal fit for the crowns. It was concluded that this measurement protocol is reliable.[50]

4. Visual examination (explorer).

One of the methods is the use of a dental explorer to detect marginal discrepancies. In a study by Hyashi et al. it was concluded that the diameter of the tip of the explorer can have an effect on detection of horizontal marginal openings but not the vertical gaps.[63] One of the disadvantages of this method is the limitation for detecting crown marginal gaps with subgingival finish lines.

vi. Experimental set-up for marginal gap measurement

In vivo experiments because of the conditions of oral cavity, preparing teeth and accessibility to the margins can be challenging.[61] Also, environmental factors such as, salivary flow, bleeding, location of the finish line and patient compliance can jeopardize the quality of impressions in an in vivo setting.[64] For marginal gap assessment the only in vivo method used in the literature is the replica technique. All other methods have been reported in in-vitro studies.[37]

To minimize the effect of environmental factors and replicate optimized clinical conditions a well- designed in vitro study should be conducted.[37] In an in vitro setting, experiments can be performed under standardized and ideal conditions. An almost perfect preparation and margins can be achieved.[16,37]

vii. Number of measurements per sample

Different suggestions have been made concerning the sample size for assessment of marginal fit of restorations.[52,65]

Groten et al. conducted a study to determine the minimum number of marginal gap measurements in an in vitro study. He measured the marginal gap of 10 all-ceramic crowns fabricated of on a master steel die before and after cementation via SEM. For assessment of marginal adaptation, they recommended a larger number of measurements to compensate for the smaller sample size. He suggested 50 marginal gap measurements per sample.[52]

A study by Lee et al. compared the marginal adaptation of all-ceramic crowns fabricated from two different CAD/CAM systems (Procera and CEREC 3). The marginal gap measurement was made on ten CAD/CAM generated samples. Fifty measurements were made of each sample. Power law calculations showed that for the sample size used to prove any statistically significant difference, the discrepancy between the groups would have had to be greater than 50mm. The results revealed that there were no statistically significant differences in the marginal gap between the three groups of finishing line (Bevel, Chamfer, and Shoulder) regardless the cementation technique used.[66]

Gassino et al. argued that the number of measurements suggested by Groten in an in vitro study in 2004 concluded that 18 measurement sites per sample is necessary for marginal gap assessment of experimental crowns that are fabricated on laboratory made abutments and 90 measurement points for crowns that are fabricated from an intra-oral impression. [65]

b. Review of computer-aided design/computer- aided manufacturing (CAD/CAM) systems and materials

The chairside CEREC system was developed by Mormann and colleagues in mid 1980s and since then demand for CAD/CAM technology in dentistry has increased dramatically. Using computer assisted technology the first generation of the CEREC system was designed for fabrication of ceramic inlays and onlays.[67]

A Swiss dentist, Dr. Werner Mormann, and an Italian electrical engineer, Marco Brandestini, introduced the first digital intraoral scanner. It evolved into CEREC® by Sirona Dental Systems LLC (Charlotte, NC) in 1987, and was the first commercially available CAD/CAM system for dental restorations.[67]

Today many different digital impression systems and CAD/CAM milling systems have been introduced to the dental market. With availability of systems capable of capturing 3D virtual images from the tooth preparation, the restorations can be made directly chairside with CAD/CAM systems or can be made in a remote dental laboratory from an accurate master model of the tooth preparation.[68]

The CAD/CAM process is capable of three types of production:

1) Chairside production: in this type of production the system components are available at the dental office. Scanning, data processing and fabrication all happens chairside.

2) Laboratory production: the workflow in this type is similar to the traditional methods of communication between the dentist and laboratory. An impression is sent to the laboratory and all the CAD/CAM equipment for design and fabrication of the prosthesis are located at the laboratory. The scan of master cast, 3D design of the prosthesis and milling the products takes place remotely.

3) Centralized production: in this type of production the scanner and software are located at the dental office. The imaging and restoration design are under the control of the dentist. Data sets are sent to the laboratory for CAD/CAM fabrication of the product. Production of full arch restorations for extended rehabilitation can be conducted on centralized CAD services.[68]

According to Beuer et al. all three components can be identified for all CAD/CAM systems.[69]

1. Scanner (digitalization tool):

a. optical scanner: This type of scanner uses a “Triangulation procedure” for capturing 3D structures. The illumination source is either white light projection such as Everest scan (KaVo), Lava scan ST (3M ESPE) or laser beam such as esl (etkon).

b. Mechanical scanner: This type of scanner uses a “ruby ball” to read the master cast for 3D measurements. This measurement technique has very high accuracy; it is complicated and expensive. An example of this system is Procera scanner (Nobel Biocare).

2. The data processing software

Different software packages are available for designing various types of restorations. Most software collect data in the standard transformation language (STL) format. Some systems use their own construction format which is designed for that specific manufacturer.

3. A production (milling) system

Three categories of milling devices exist based on their milling axis:

a. 3- axis milling device has degrees of movement in three spatial directions (X-, Y- and Z- values). Therefore, calculation investment is minimal. A milling of subsections, axis divergence and convergences are not possible. In the dental area these devices can turn the component by 180 degree while processing inside and the outside. They have the advantages of short milling time and simplified control by means of three axes. Examples: Inlab (Sirona), Lava (3M ESPE), Cercon brain (DeguDent).

b. 4-axis milling device has three spatial axes and a rotational tension bridge. With this device bridge construction with a large vertical height displacement can be adjusted into the usual mold dimensions and thus save material and milling time. Example: Zeno (Wieland-Imes).

c. 5-axis milling device has the three spatial axes, rotatable tension bridge and rotation of the milling spindle. With this device milling of complex structures with subsections and convergence is possible. Examples: Everest Engine (KaVo), HSC Milling Device (etkon).

There are two variants of milling:

Dry processing: used for zirconium oxide blanks with a low degree of pre-sintering.

Wet processing: The milling burs are protected with a spray of cold liquid mainly to protect all metals and glass ceramic material from heat damaging.[69]

In a study by Beuer et al.[69] CAD/CAM materials are classified into 5 categories:

1. Metals: titanium, titanium alloys, chrome cobalt alloy.

2. Resin Material: They are available for both single crowns and fixed partial denture frameworks for long term provisional restorations.

3. Silica based ceramics: They are used for inlays, onlays, veneers, partial crowns, full crowns. They are produced in monochromatic and polychromatic layered blocks [Vitablocs TriLuxe (Vita), IPS Empress CAD Multi (IvoclarVivadent)].

4. Infiltration ceramics: The blocks are chalky and porous in processing and then they are infiltrated with lanthanum glass. The Vita In-Ceram system has three variants of this class of material.

5. Polycrystalline Ceramics

a. Aluminum Oxide (Al_2O_3): This material is milled in a pre-sintered phase and then sintered at a temperature of 1520 °C. Indication: anterior and posterior crown copings, primary crowns and three-unit anterior fixed partial denture frameworks.

b. Yttrium stabilized zirconium oxide (ZrO_2, Y-TZP): An yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramic is formed by addition of a stabilizer, such as yttria, to zirconia-based ceramics which stabilizes the zirconia in the tetragonal phase.[70,71]

Stabilizing the tetragonal phase at room temperature can prevent the transition to the monoclinic phase and progression of cracks in the ceramic which is referred to transformation strengthening.[72–74]

Intra-oral scanning devices can capture three dimensional virtual images of tooth preparations; Using CAD/CAM systems restorations may be directly fabricated from these images, or accurate master models can be made in dental laboratory.[67]

The latest version of the CEREC® system are capable of producing inlays, onlays, crowns, laminate veneers, and even fixed partial dentures. It combines a 3D digital scanner with a milling unit to create in- office dental restorations from commercially available blocks of ceramic or composite material in a single appointment.[67]

The latest version of the milling system, CEREC inLab® MC XL, can mill a crown in as little as 4 minutes. CEREC® systems may be described as measurement devices that operate according to the basic principles of confocal microscopy and according to the active triangulation technique.[68]

Even with evolution of CAD/CAM systems and materials, the literature demonstrates conflicting evidence regarding the marginal fit of CAD/CAM restorations. Similar to marginal accuracy, internal adaptation and retention are important factors for the longevity of crown restorations. Although surface finish can be a critical variable in clinical performance, there is a dearth of information regarding surface characteristics of teeth prepared for fixed restorations.[14]

Research objectives

The purpose of this in vitro study was to evaluate the marginal adaptation of hybrid ceramic crowns (Vita Enamic) fabricated using a chairside CAD/CAM (computer aided design/computer aided manufacturing) system on preparations completed with and without surface finishing to identify whether finishing preparations protocols affect the marginal fit.

Research hypothesis

H0: There is no difference in the mean marginal adaptation of ceramic restorations between unfinished and finished surface preparations.

HA: There is a difference in the mean marginal adaptation of ceramic restorations between unfinished and finished surface preparations.

II. Chapter 2

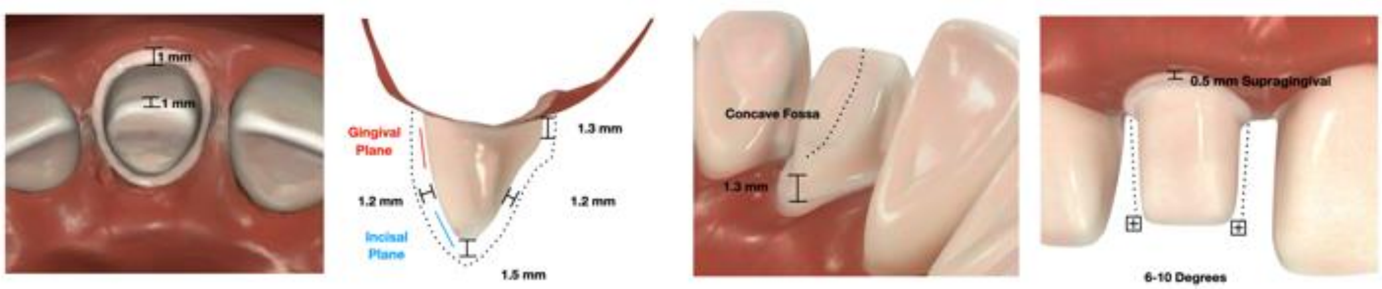
Methods and materials

i. Tooth preparation

Ten upper right central incisor typodont teeth (M300 Series, ACADENTAL) were prepared for all ceramic crowns by the investigator as shown in Figure 1.

Each tooth was screwed into precision restorative typodont with soft gum (ModuPRO, ACADENTAL), and attached to a portable bench mount.

Figure 1: Ideal Ceramic Anterior Crown Preparation



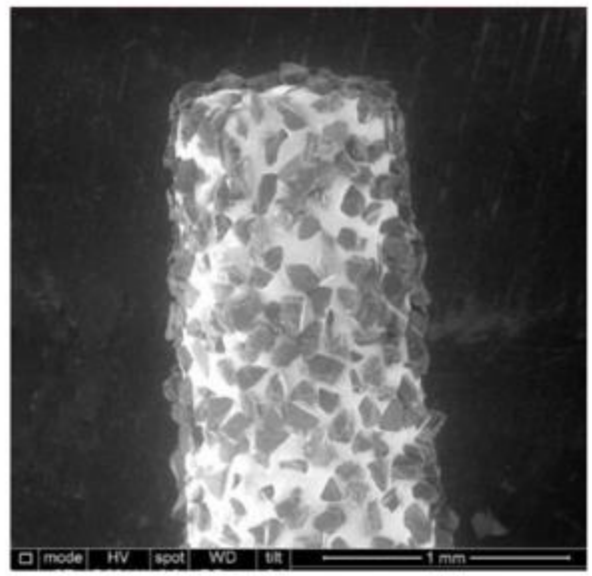
The teeth were prepared to an ideal ceramic anterior crown preparation with a 1.5 mm occlusal reduction, 0.5 mm supragingival margin and width of 1mm, axial reduction of 1.2mm, a 1.3mm lingual wall height and a 6–10° taper.

Teeth were divided into two groups (Control group CG, Finished group FG) (n = 250) and prepared for all ceramic crowns with varying bur grits (K0394 Blatz/Conejo: CAD/CAM Preparation System, BRASSELER USA, Figure 2) under dental loupes with 4.5x magnification (ZEISS EyeMag Smart). The CG was prepared using the medium grit bur (847KR 016), while the FG was prepared using the medium grit bur (847KR 016) and then refined with the fine grit bur (8847KR 016) for two minutes Figure 3.

Figure 2: K0394 Blatz/ Conejo: CAD/CAM Preparation System BRASSELER USA

<u>Figure 3: (A) Image of Fine grit bur (8847KR 016), (B) Image of Fine grit bur (8847KR 016) under SEM.</u>

A



B

ii. Crown design and fabrication.

An intraoral scanner (CEREC Omnicam, Dentsply Sirona) was used to scan the preparations.

CEREC software 5.1 was used to design the hybrid crowns (Figure 4). In the administration tab, tooth #8 was selected as the site for crown fabrication with the setting of biogeneric copy.

Figure 4: CEREC software 5.1 used to design the hybrid crowns.

The material of choice was selected as Enamic, Vita Zahnfabrik Figure 5.

Figure 5: Hybrid ceramic crown (Enamic, Enamic, Vita Zahnfabrik).

In the model tab, each preparation was trimmed, and the margin manually traced.

In the design tab, the copy and mirror design technique was used as a reference for calculating the restorations.

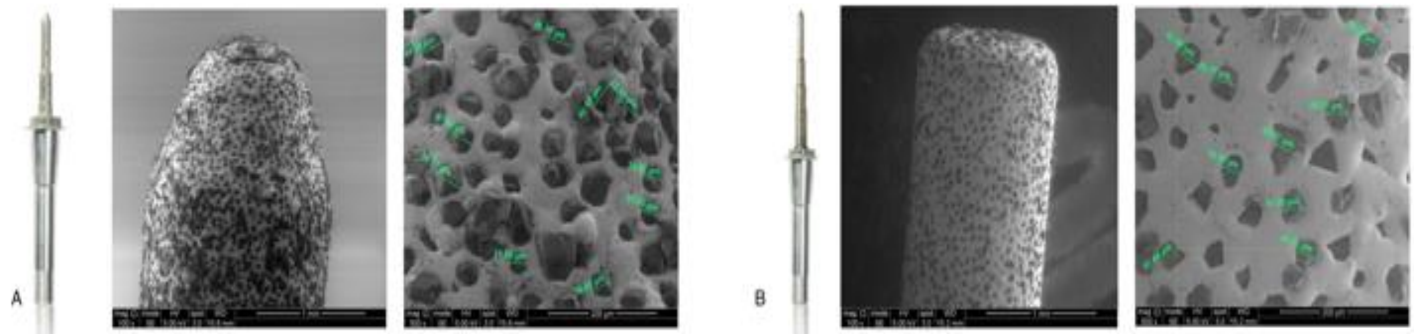
System parameters were set according to the manual for fabrication of all ceramic crowns. Cement radial and occlusal space was set to 120 μm extending up to the preparation margin. [75]

The final image was saved for fabrication of Enamic crowns.

Two groups of Samples were then milled with CEREC MC XL milling machine.

A new set of burs (Sirona CEREC/inlab step bur 12S and Cylinder pointed bur 12S) were inserted into CEREC MC XL (Sirona) for milling of the 10 hybrid ceramic crowns Figure 6.

<u>Figure 6: Milling Burs for CEREC MC XL; A: step bur 12S under SEM, B: Cylinder pointed bur 12S under SEM.</u>



All the crowns were designed and milled under the supervision of one operator assisted by one lab technician. The water supply was changed according to the software's notification. All crowns were steam cleaned to remove any milling residue from the intaglio of the copings after the milling process. The crowns were numbered according to the milling sequence.

The crowns were then hand polished following the manufacturer's recommendations (Vita Enamic Technical polishing set) Figure 7. First, a medium grit diamond polishing wheel was used to remove the sprue. Second, the crowns were pre-polished with the pink polishers at 8,000 RPM and light pressure. Third, the high gloss grey polishers were used at 7,000 RPM and light pressure.

<u>Figure 7: Polishing protocol for hybrid ceramic crowns.</u>

The crowns were acid etched with VITA Ceramic Etch 5% hydroflouric acid for 60 seconds and silane was applied.

A primer/bond system was applied on the preparation.

The hybrid crowns were then cemented on their respective preparations using a dual cure resin cement system (PANAVIA V5, Kuraray Noritake) and following the Vita Enamic Bonding Protocol. Excess cement was removed Figure 8.

Figure 8: Cementation protocol of hybrid ceramic crowns.

iii. Measuring marginal gap

A scanning electron microscope (FEI Quanta 600 ESEM; FEI Co) in the Singh Center for Nanotechnology at University of Pennsylvania was used to image and evaluate the marginal areas (Figure 9).

Figure 9: Scanning electron microscope (FEI Quanta 600 ESEM; FEI Co).

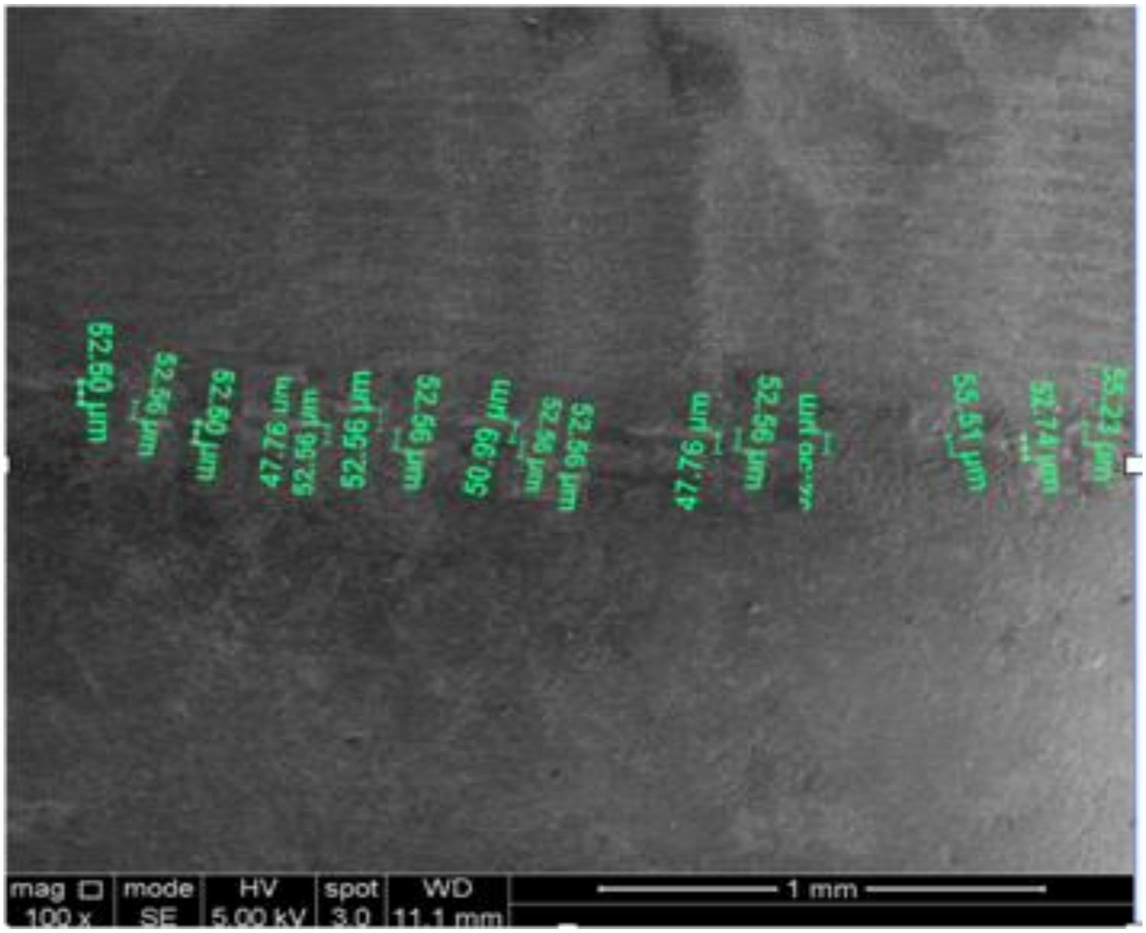
The cemented crowns on the preparations were unscrewed from the typodont and labelled. The teeth were then secured on the microscope stage with wax. The teeth were then viewed under a magnification of 100x.

Two consistent sites (buccal, and palatal) were recorded for each sample and images were saved. At the end of each imaging session the software millimeter ruler was imaged to be used for calibration of the measurements on the pictures taken in that session.

The marginal gap was measured in micrometers with a line measurement tool which measured the vertical distance between the margin of the crown and the margin of the tooth according to Holmes definition of marginal gap.

Twenty-five-line measurements were recorded per surface. A total of fifty measurements were made for each tooth: Figure 10. The measurements were saved in Microsoft Office Excel 2021 software for future statistical analysis.

Figure 10: Image of measurements of marginal gap using SEM.



iv. Power analysis

Historical data was used to calculate the sample size for this study.[17] Assuming an alpha level of 0.05 and power of 80%, at least 50 measurements were needed to determine if a there was a significant difference between the marginal fit of hybrid crowns before and after finishing.

v. Methods for data analysis

Two sets of data were collected during this study:

1) Marginal gap values for unfinished preparations.

2) Marginal gap values for finished preparations.

A non-parametric Mann-Whitney Rank Sum Test was used to determine the difference in marginal gap between the finished and unfinished groups. A statistical software program (Sigma Stat 3.5 for Windows; Systat Software Inc) was used for the analysis.

IV. Chapter 3

Results

i. Overall mean difference in marginal gap between control group and finished group.

Mann-Whitney Rank Sum Test was used to compare differences in marginal gap between control group and finished group. The mean difference in marginal gap showed that finished group, on average had a decrease of 10 um in marginal gap compared to the unfinished group. This difference was statistically significant (p<0.001).

<u>Table 2: Overall mean difference in marginal gap between CG and FG.</u>

Group	N	Median	25%	75%
CG	250	81.565	62.500	107.500
FG	250	50.000	37.990	65.400
Mann-Whitney U Statistic= 12687.000				
T = 82938.000 n(small)= 250 n(big)= 257 (P = <0.001)				

ii. Overall mean difference in marginal gap in the mid-facial margin area between the control group and the finished group.

Mann-Whitney Rank Sum Test was used to compare differences in marginal gap in the mid-facial margin between control group and finished group. The mean difference in marginal gap showed that the mid-facial margin area in the finished group, on average had a decrease of 46 um in marginal gap compared to the unfinished group. This difference was statistically significant (p<0.001).

<u>Table 3: Overall mean difference in marginal gap in the Mid-Facial Marginal area between the CG and FG.</u>

Group	N	Median	25%	75%
CG	125	81.190	62.500	108.350
FG	125	42.300	37.525	50.651
Mann-Whitney U Statistic= 1493.000				
T = 22257.000 n(small)= 125 n(big)= 127 (P = <0.001)				

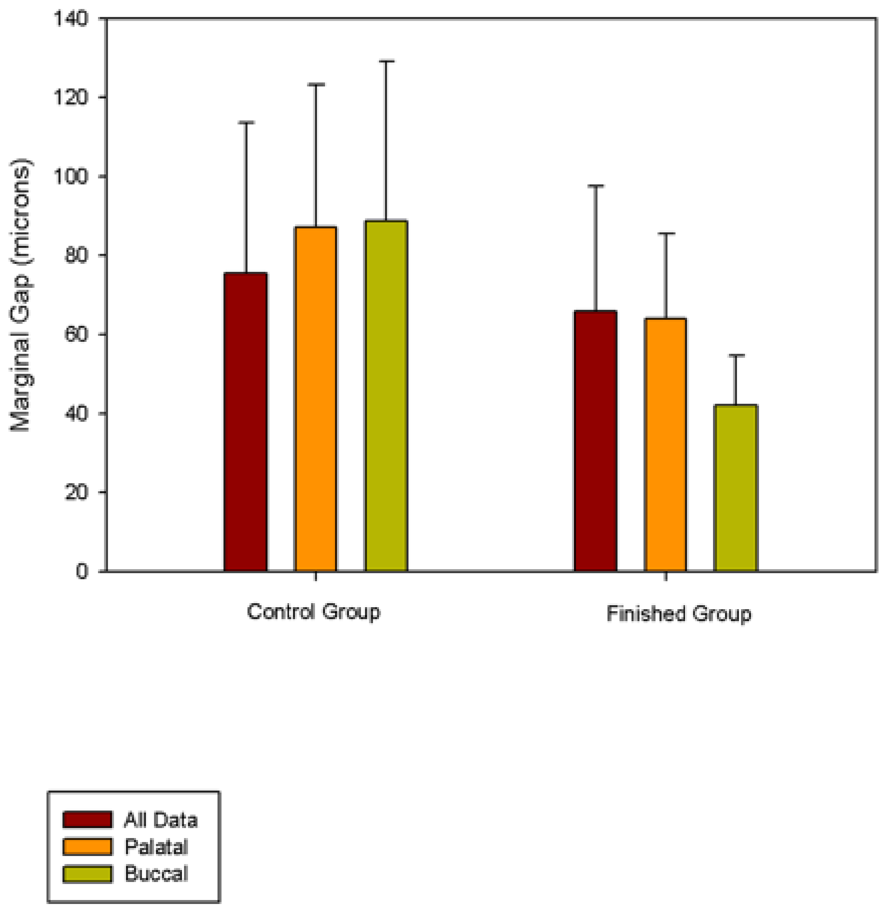
iii. Overall mean difference in marginal gap in the mid-palatal margin area between the control group and the finished group.

Mann-Whitney Rank Sum Test was used to compare differences in marginal gap in the mid-palatal margin between control group and finished group. The mean difference in marginal gap showed that the mid-palatal margin area in the finished group, on average had a decrease of 23 um in marginal gap compared to the unfinished group. This difference was statistically significant ($p<0.001$).

<u>Table 4: Overall mean difference in marginal gap in the Mid-Palatal Marginal area between the CG and FG.</u>

Group	N	Median	25%	75%
CG	125	82.500	62.500	107.050
FG	125	64.318	45.800	78.300
Mann-Whitney U Statistic= 4757.000				
T = 19368.000 n(small)= 125 n(big)= 130 (P = <0.001)				

Figure 11: Comparison of marginal gaps of the control group and finished group.



V. Chapter 4

Discussion

The marginal accuracy is one of the most important factors affecting long-term success in fixed restorations.[6] An acceptable marginal fit maintains the gingival health and protects the tooth from physical, chemical, bacterial, and thermal injuries.[7]

Digital manufacturing using milling manufacturing technologies have provided the ability to produce dental prostheses with predictable accuracy and fit.[5]

In addition, hybrid CAD/CAM blocks were introduced to the dental field, composed of two matrices: a polymer and a ceramic network. This dual network structure reduced brittleness and surface hardness of the material allowing easier milling in a shorter time.[12] This material demonstrated a statistically significant smaller difference in marginal gap compared to crystallized lithium disilicate copings.[13]

The purpose of this in vitro study was to identify if finishing preparation protocols affect the marginal fit. The null hypothesis was rejected as a statistically significant difference was found between the groups; therefore, surface finish had a direct effect on the mean marginal adaptation of restorations. Within the limitations of this study, it was shown that surface finishing had a favorable effect on the marginal fit of the restorations fabricated by the latest CAD/CAM systems. This conclusion is in agreement with other studies.

One study demonstrated that teeth prepared with the finer grit rotary instruments have smoother tooth surfaces and crown restorations with better internal adaptation.[15] Another demonstrated statistically significant differences in the surface topography of prepared teeth where the mean surface roughness (Ra) were 8.6 and 6.8 μm for teeth prepared with diamond and tungsten carbide burs and teeth completed with finishing burs appeared to result in a smoother surface (1.2 μm).[14]

Unlike other in-vitro studies in the literature, the teeth were prepared and finished using diamond burs of different grits (K0394 Blatz/Conejo: CAD/CAM Preparation System, BRASSELER USA). Further polishing burs of silicone were not used in order to limit the variables in this study. In addition, further polishing of the teeth using polishing burs of 25 um would not have an impact on the marginal adaptation as the milling burs are only able to mill to 35 um.

The finish line design for the master die in this study was designed to be a circumferential shoulder. In the literature there are studies that have investigated the influence of finish line design on the fit of CAD/CAM ceramic crowns. All studies concluded that there is no significant difference between marginal fit of ceramic crowns using finish lines of different designs.[76]

Hybrid ceramic crown was the material of choice as it promises according to the manufacturer marginal integrity, strength, and more conservative tooth preparation.[24]

Restorations made from hybrid ceramic material do not need the additional firing cycle for crystallization as do the lithium disilicate CAD/CAM crowns. In addition, they are hand polished and hence glazing is unnecessary. These factors could have introduced variables to the marginal fit and by eliminating them, a true representation of the marginal gap was evaluated. No studies are available that have evaluated the marginal adaptation of this newly introduced hybrid ceramic or which have compared it to any other available CAD/CAM blocks.

Three different comparisons were made of the marginal gap of the milled crowns. The first test compared the marginal adaptation of control and finished groups. Results indicated that there was a significant difference between the mean marginal gap values of the two groups.

The control group resulted in a mean marginal gap of 88um which is clinically acceptable according to studies done by McLean and Von Fraunhofer (<120 um).[17] The finished group however resulted in a mean marginal gap of 52um which is a statistically significant decrease.

The second test compared the difference in marginal gap in the mid facial and mid-palatal marginal area between the control and finished groups. Results indicated that there was a significant difference between the mean marginal gap values of the two groups with the control group having greater marginal gaps in both areas and a decreased marginal gap on the mid-facial marginal area. No studies in the literature have reported similar results. It could be speculated that having direct vision while preparing the mid-facial marginal areas would result in a better surface finish and hence a better marginal adaptation.

Different studies on marginal adaptation of ceramic CAD/CAM crowns have been inconsistent in their findings. Such differences could be due to several factors such as: study design variations, scanning systems, milling systems, abutment design (stainless steel die, typodont teeth, extracted teeth, etc.), and measurement system used. Limitations in the study design include the small sample size which was compensated with the number of measurements made per tooth, and the cementation protocol which simulated a clinical situation of using finger pressure to seat the crowns on the preparations. Additionally, scanning preparations on a typodont and in the absence of oral fluids such as saliva and heme is not indicative of how challenging it can be to scan intraorally.

No studies could be found in the literature that addresses the effect of milling bur wear on the marginal discrepancy of the milled crowns. There is a need for research to investigate the correlation between the milling bur wear and marginal discrepancy of CAD/CAM crowns.

VI. Chapter 5

Conclusion

Within the limitations of this in vitro study, it can be concluded that:

- The surface finish has a significant impact on the marginal gap of all ceramic restorations.

-Finished preparations have a smaller marginal gap than unfinished preparations for hybrid ceramic restorations.

-In addition, the mid-facial marginal area of unfinished and finished preparations has a smaller marginal gap when compared to the mid-palatal margin area and within each group.

Common preparation errors are difficult for the milling system to replicate adequately because of the size and shape of the diamond rotary cutting instrument; therefore, extra care should be taken regarding the smoothness and quality of all-ceramic chairside CAD/CAM preparations.

References

1. Almasri R, Drago CJ, Siegel SC, Hardigan PC. Volumetric Misfit in CAD/CAM and Cast Implant Frameworks: A University Laboratory Study. J Prosthodont. 2011;20(4):267-274. doi: https: //doi.org/10.1111/j.1532-849X.2011.00709.x

2. Fasbinder DJ. Clinical performance of chairside CAD/CAM restorations. J Am Dent Assoc. 2006; 137:22S-31S. doi: 10.14219/jada.archive.2006.0395

3. Wittneben J-G, Wright RF, Weber H-P, Gallucci GO. A Systematic Review of the Clinical Performance of CAD/CAM Single-Tooth Restorations. Int J Prosthodont. 2009;22(5):466-471.

4. Gonzalo E, Suárez MJ, Serrano B, Lozano JFL. A comparison of the marginal vertical discrepancies of zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. J Prosthet Dent. 2009;102(6):378-384. doi:10.1016/S0022-3913(09)60198-0

5. Stein JM. Stand-Alone Scanning Systems Simplify Intraoral Digital Impressioning. Compend Contin Educ Dent 15488578. Published online November 2, 2011:56-59.

6. Ferrini F, Sannino G, Chiola C, Capparé P, Gastaldi G, Gherlone EF. Influence of Intra-Oral Scanner (I.O.S.) on The Marginal Accuracy of CAD/CAM Single Crowns. Int J Environ Res Public Health. 2019;16(4). doi:10.3390/ijerph16040544

7. Rifaiy MA. Evaluation of vertical marginal adaptation of provisional crowns by digital microscope. Niger J Clin Pract. 2017;20(12):1610-1610.

8. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent. 1989;62(4):405-408. doi:10.1016/0022-3913(89)90170-4

9. Nejatidanesh F, Lotfi HR, Savabi O. Marginal accuracy of interim restorations fabricated from four interim autopolymerizing resins. J Prosthet Dent. 2006;95(5):364-367. doi: 10.1016/j.prosdent.2006.02.030

10. Givens EJ, Neiva G, Yaman P, Dennison JB. Marginal Adaptation and Color Stability of Four Provisional Materials. J Prosthodont. 2008;17(2):97-101. doi: https://doi.org/10.1111/j.1532-849X.2007.00256.x

11. Tjan AHL, Castelnuovo J, Shiotsu G. Marginal fidelity of crowns fabricated from six proprietary provisional materials. J Prosthet Dent. 1997;77(5):482-485. doi:10.1016/S0022-3913(97)70140-9

12. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. Dent Mater. 2013;29(4):419-426. doi: 10.1016/j.dental.2013.01.002

13. Azarbal A, Azarbal M, Engelmeier RL, Kunkel TC. Marginal Fit Comparison of CAD/CAM Crowns Milled from Two Different Materials. J Prosthodont. 2018;27(5):421-428. doi:10.1111/jopr.12683

14. Ayad MF, Rosenstiel SF, Hassan MM. Surface roughness of dentin after tooth preparation with different rotary instrumentation. J Prosthet Dent. 1996;75(2):122-128. doi:10.1016/S0022-3913(96)90087-6

15. Li Y, Wang H, Wang Y, Chen J. Effect of different grit sizes of diamond rotary instruments for tooth preparation on the retention and adaptation of complete coverage restorations. J Prosthet Dent. 2012;107(2):86-93. doi:10.1016/S0022-3913(12)60029-8

16. Land CH. Porcelain Dental Art; the New Process of Restoring Decayed and Defective Teeth to Their Original Appearance, in Shape, Size, and Color. O.S. Gulley, Bornman & Co., 1888.

17. McLean JW, Hughes TH. The reinforcement of dental porcelain with ceramic oxides. Br Dent J. 1965;119(6):251-267.

18. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999;20(1):1-25. doi:10.1016/S0142-9612(98)00010-6

19. Christel P, Meunier A, Dorlot J-M, et al. Biomechanical Compatibility and Design of Ceramic Implants for Orthopedic Surgery. Ann N Y Acad Sci. 1988;523(1):234-256. doi: https://doi.org/10.1111/j.1749-6632.1988.tb38516.x

20. Denry IL. Recent Advances in Ceramics for Dentistry. Crit Rev Oral Biol Med. 1996;7(2):134-143. doi:10.1177/10454411960070020201

21. Kelly JR. Ceramics in restorative and prosthetic dentistry. Annu Rev Mater Sci. 1997;27(1):443-468. doi: 10.1146/annurev.matsci.27.1.443

22. Robert Kelly J. Dental ceramics: current thinking and trends. Dent Clin North Am. 2004;48(2):513-530. doi: 10.1016/j.cden.2004.01.003

23. Conejo J, Nueesch R, Vonderheide M, Blatz MB. Clinical Performance of All-Ceramic Dental Restorations. Curr Oral Health Rep. 2017;4(2):112-123. doi:10.1007/s40496-017-0132-4

24. Blatz MB, Conejo J. The Current State of Chairside Digital Dentistry and Materials. Dent Clin North Am. 2019;63(2):175-197. doi: 10.1016/j.cden.2018.11.002

25. Argyrou R, Thompson GA, Cho S-H, Berzins DW. Edge chipping resistance and flexural strength of polymer infiltrated ceramic network and resin nanoceramic restorative materials. J Prosthet Dent. 2016;116(3):397-403. doi: 10.1016/j.prosdent.2016.02.014

26. VITA Zahnfabrik H. Rauter GmbH & Co.KG. Vita Enamic. The first hybrid with dual network structure for superior absorption of masticatory forces. Manufacturer’s manual.

27. VITA Zahnfabrik H. Rauter GmbH & Co.KG. Vita Enamic. Technical and Scientific Documentation. Published online 2013.

28. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Kapusevska B, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary Dental Ceramic Materials, A Review: Chemical Composition, Physical and Mechanical Properties, Indications for Use. Open Access Maced J Med Sci. 2018;6(9):1742-1755. doi:10.3889/oamjms.2018.378

29. Pera P. In vitro marginal adaptation of alumina porcelain ceramic crowns. Journal of Prosthetic Dentistry. 1994; 72:585-590.

30. Bindl A, Mörmann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil. 2005;32(6):441-447. doi: https://doi.org/10.1111/j.1365-2842.2005.01446.x

31. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Steyern PVV, Fukushima S. Clinical marginal and internal gaps of Procera All Ceram crowns. J Oral Rehabil. 2005;32(7):526-530. doi: https://doi.org/10.1111/j.1365-2842.2005.01458.x

32. El Zohairy AA, De Gee AJ, Mohsen MM, Feilzer AJ. Microtensile bond strength testing of luting cements to prefabricated CAD/CAM ceramic and composite blocks. Dent Mater. 2003;19(7):575-583. doi:10.1016/S0109-5641(02)00107-0

33. Zaruba M, Kasper R, Kazama R, et al. Marginal adaptation of ceramic and composite inlays in minimally invasive mod cavities. Clin Oral Investig. 2014;18(2):579-587. doi:10.1007/s00784-013-0988-1

34. Rinke S, Huls A, jahn L. Marginal Accuracy and Fracture Strength of Conventional and Copy-Milled All-Ceramic Crowns. Int J Prosthodont. 1995;8(4):303-310.

35. Sulaiman F, Chai J, jameson LM, Wozniak WT. A Comparison of the Marginal Fit of In-Ceram, IPS Empress, and Procera Crowns. Int J Prosthodont. 1997;10(5):478-484.

36. Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. J Clin Periodontol. 1983;10(6):563-578. doi: https://doi.org/10.1111/j.1600-051X.1983.tb01295.x

37. Contrepois M, Soenen A, Bartala M, Laviole O. Marginal adaptation of ceramic crowns: A systematic review. J Prosthet Dent. 2013;110(6):447-454.e10. doi: 10.1016/j.prosdent.2013.08.003

38. Pelekanos S, Koumanou M, Koutayas S-O, Zinelis S, Eliades G. Micro-CT Evaluation of the Marginal Fit of Different In-Ceram Alumina Copings. Eur J Esthet Dent. 2009;4(3):278-292.

39. Nordlander J, Weir D, Stoffer W, Ochi S. The taper of clinical preparations for fixed prosthodontics. J Prosthet Dent. 1988;60(2):148-151. doi:10.1016/0022-3913(88)90304-6

40. Siervo S, Pampalone A, Siervo P, Siervo R. Where is the gap? Machinable ceramic systems and conventional laboratory restorations at a glance. Quintessence Int. 1994;25(11):773-779.

41. Nagarkar SR, Perdigão J, Seong W-J, Theis-Mahon N. Digital versus conventional impressions for full-coverage restorations. J Am Dent Assoc. 2018;149(2):139-147.e1. doi: 10.1016/j.adaj.2017.10.001

42. Tsirogiannis P, Reissmann DR, Heydecke G. Evaluation of the marginal fit of single-unit, complete-coverage ceramic restorations fabricated after digital and conventional impressions: A systematic review and meta-analysis. J Prosthet Dent. 2016;116(3):328-335.e2. doi: 10.1016/j.prosdent.2016.01.028

43. Wilson R. Effect of increasing cement space on cementation crowns. ET J. 1994;71(6):5.

44. Kim JH, Miranda P, Kim DK, Lawn BR. Effect of an adhesive interlayer on the fracture of a brittle coating on a supporting substrate. J Mater Res. 2003;18(1):222-227. doi:10.1557/JMR.2003.0031

45. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and Internal Fit of Cerec 3 CAD/CAM All-Ceramic Crowns. Int J Prosthodont. 2003;16(3):244-248.

46. Beschnidt SM, Strub JR. Evaluation of the marginal accuracy of different all-ceramic crown systems after simulation in the artificial mouth. J Oral Rehabil. 1999;26(7):582-593. doi: https://doi.org/10.1046/j.1365-2842.1999.00449.x

47. Quintas AF, Oliveira F, Bottino MA. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: an in vitro evaluation. J Prosthet Dent. 2004;92(3):250-257. doi: 10.1016/j.prosdent.2004.06.023

48. Ural Ç, Burgaz Y, Saraç D. In vitro evaluation of marginal adaptation in five ceramic restoration fabricating techniques. Quintessence Int. 2010;41(7):585-590.

49. Sorensen JA. A standardized method for determination of crown margin fidelity. J Prosthet Dent. 1990;64(1):18-24. doi:10.1016/0022-3913(90)90147-5

50. Anadioti E, Aquilino SA, Gratton DG, et al. 3D and 2D Marginal Fit of Pressed and CAD/CAM Lithium Disilicate Crowns Made from Digital and Conventional Impressions. J Prosthodont. 2014;23(8):610-617. doi: https://doi.org/10.1111/jopr.12180

51. Groten M, Girthofer S, Pröbster L. Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro. J Oral Rehabil. 1997;24(12):871-881. doi: https://doi.org/10.1111/j.1365-2842.1997.tb00288.x

52. Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. J Prosthet Dent. 2000;83(1):40-49. doi:10.1016/S0022-3913(00)70087-4

53. Davis DR. Comparison of fit of two types of all-ceramic crowns. J Prosthet Dent. 1988;59(1):12-16. doi:10.1016/0022-3913(88)90098-4

54. Mitchell CA, Pintado MR, Douglas WH. Nondestructive, in vitro quantification of crown margins. J Prosthet Dent. 2001;85(6):575-584. doi:10.1067/mpr.2001.114268

55. Shearer B, Gough MB, Setchell DJ. Influence of marginal configuration and porcelain addition on the fit of In-Ceram crowns. Biomaterials. 1996;17(19):1891-1895. doi:10.1016/0142-9612(95)00302-9

56. Coli P, Karlsson S. Fit of a New Pressure-Sintered Zirconium Dioxide Coping. Int J Prosthodont. 2004;17(1):59-64.

57. Nakamura T, Tanaka H, Kinuta S, et al. In Vitro Study on Marginal and Internal Fit of CAD/CAM All-ceramic Crowns. Dent Mater J. 2005;24(3):456-459. doi:10.4012/dmj.24.456

58. Kokubo Y, Nagayama Y, Tsumita M, Ohkubo C, Fukushima S, Steyern PV von. Clinical marginal and internal gaps of In-Ceram crowns fabricated using the GN-I system. J Oral Rehabil. 2005;32(10):753-758. doi: https://doi.org/10.1111/j.1365-2842.2005.01506.x

59. Reich S, Uhlen S, Gozdowski S, Lohbauer U. Measurement of cement thickness under lithium disilicate crowns using an impression material technique. Clin Oral Investig. 2011;15(4):521-526. doi:10.1007/s00784-010-0414-x

60. Wolfart S, Wegner SM, Al-Halabi A, Kern M. Clinical Evaluation of Marginal Fit of a New Experimental All-Ceramic System Before and After Cementation. Int J Prosthodont. 2003;16(6):587-592.

61. Boening KW, Wolf BH, Schmidt AE, Kästner K, Walter MH. Clinical fit of Procera AllCeram crowns. J Prosthet Dent. 2000;84(4):419-424. doi:10.1067/mpr.2000.109125

62. Luthardt RG, Bornemann G, Lemelson S, Walter MH, Hüls A. An Innovative Method for Evaluation of the 3-D Internal Fit of CAD/CAM Crowns Fabricated After Direct Optical Versus Indirect Laser Scan Digitizing. Int J Prosthodont. 2004;17(6):680-685.

63. Hayashi M, Watts DC, Ebisu S, Wilson NHF. Influence of vision on the evaluation of marginal discrepancies in restorations. Oper Dent. 2005;30(5):598-601.

64. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent. 2010;38(7):553-559. doi: 10.1016/j.jdent.2010.03.015

65. Gassino G, Monfrin SB, Scanu M, Spina G, Preti G. Marginal Adaptation of Fixed Prosthodontics: A New In Vitro 360-Degree External Examination Procedure. Int J Prosthodont. 2004;17(2):218-223.

66. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent. 2007;35(1):68-73. doi: 10.1016/j.jdent.2006.04.008

67. Mörmann WH, Brandestini M, Lutz F, Barbakow F. Chairside computer-aided direct ceramic inlays. Quintessence Int. 1989;20(5):329-339.

68. Scotti R, Cardelli P, Baldissara P, Monaco C. Clinical fitting of CAD/CAM zirconia single crowns generated from digital intraoral impressions based on active wavefront sampling. J Dent. Published online October 2011: S0300571211002442. doi: 10.1016/j.jdent.2011.10.005

69. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2008;204(9):505-511. doi: 10.1038/sj.bdj.2008.350

70. Curtis AR, Wright AJ, Fleming GJP. The influence of surface modification techniques on the performance of a Y-TZP dental ceramic. J Dent. 2006;34(3):195-206. doi: 10.1016/j.jdent.2005.06.006

71. Swain MV, Garvie RC, Hannink RHJ. Influence of Thermal Decomposition on the Mechanical Properties of Magnesia-Stabilized Cubic Zirconia. J Am Ceram Soc. 1983;66(5):358-362. doi: https://doi.org/10.1111/j.1151-2916.1983.tb10049.x

72. Masaki T. Mechanical properties of toughened ZrO2-Y2O3 Ceramics. J Am Ceram Soc. 1986;69(8):638-640. doi: https://doi.org/10.1111/j.1151-2916.1986.tb04823.x

73. Swain MV. Limitation of Maximum Strength of Zirconia-Toughened Ceramics by Transformation Toughening Increment. J Am Ceram Soc. 1985;68(4):C-97-C-99. doi: https://doi.org/10.1111/j.1151-2916.1985.tb15305.x

74. Swain MV, Hannink RHJ. Metastability of the Martensitic Transformation in a 12 mol% Ceria-Zirconia Alloy: II, Grinding Studies. J Am Ceram Soc. 1989;72(8):1358-1364. doi: https://doi.org/10.1111/j.1151-2916.1989.tb07652.x

75. Densply Sirona. Operator’s Manual CEREC 5. Published online 2019.

76. Renne W, McGill ST, Forshee KV, DeFee MR, Mennito AS. Predicting marginal fit of CAD/CAM crowns based on the presence or absence of common preparation errors. J Prosthet Dent. 2012;108(5):310-315. doi:10.1016/S0022-3913(12)60183-8