The influence of finishing line curvature on marginal gap width of all-ceramic copings

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in
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ผลกระทบต่อระดับความโค้งต่างเส้นสิ้นสุดต่อความกว้างช่องว่างแทรกของโครงฟันเซรามิกทั้งซี่

นางสาวชุติมา อัศวภาณุมาศ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตร์มหาบัณฑิต
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ชุติมา อัศวภาณุมาศ : ผลกระทบต่อระดับความโค้งต่างเส้นสิ้นสุดต่อความกว้างช่องว่างแทรกของโครงฟันเซรามิกทั้งซี่. (The influence of finishing line curvature on marginal gap width of all-ceramic copings) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ. ทพ. เฉลิมพล ลี้ไวโรจน์, 60 หน้า.

วัตถุประสงค์ เพื่อศึกษาผลกระทบของระดับความโค้งต่างเส้นสิ้นสุดที่แตกต่างกัน 3 ระดับต่อความกว้างช่องว่างแทรกของโครงฟันเซรามิกทั้งซี่ **วิธีการทดลอง** กรอเตรียมฟันไอโวรีนซี่ตัดกลางบนด้านขวาให้เป็นฟันหลักสำหรับทำโครงฟันเซรามิกทั้งซี่โดยให้มีระดับความโค้งต่างเส้นสิ้นสุดที่แตกต่างกัน 3 ระดับ (ระยะห่าง 1 มม., 3 มม. และ 5 มม. ระหว่างเส้นสิ้นสุดด้านริมฝีปากหรือด้านลิ้นกับด้านประชิดของฟันหลัก) ทำการพิมพ์แบบของฟันหลักทั้ง 3 ระดับความโค้งต่างเส้นสิ้นสุด 36 ครั้ง โดยแบ่งเป็น 3 กลุ่ม กลุ่มละ 12 ชิ้นสำหรับทำโครงฟันเซรามิกทั้งซี่ 3 ระบบ ได้แก่ ระบบเซอร์คอน, ระบบอีแมกซ์ และ ระบบลาวา จากนั้นทำการวัดความกว้างช่องว่างแทรกแนวดิ่งระหว่างขอบของฟันหลักกับขอบของโครงฟันเซรามิกโดยใช้เครื่องสเตอริโอไมโครสโคป ผลการทดลองที่ได้วิเคราะห์ด้วยสถิติความแปรปรวนแบบสองทางและสถิติความแปรปรวนแบบทางเดียวที่ระดับนัยสำคัญ 0.05 **ผลการทดลอง** กลุ่มที่มีระดับความโค้งต่างเส้นสิ้นสุด 5 มม. (เซอร์คอน, 76.59 ± 23.01 ไมโครเมตร; อีแมกซ์, 106.44 ± 18.48 ไมโครเมตร; ลาวา, 128.34 ± 20.79 ไมโครเมตร) พบความกว้างช่องว่างแทรกมากกว่าอย่างมีนัยสำคัญเมื่อเปรียบเทียบกับกลุ่มที่ระดับความโค้งต่างเส้นสิ้นสุด 3 มม. (เซอร์คอน, , 60.18 ± 9.74 ไมโครเมตร; อีแมกซ์, 81.79 ± 16.20 ไมโครเมตร; ลาวา, 99.19 ± 15.32 ไมโครเมตร) และ กลุ่มที่มีระดับความโค้งต่างเส้นสิ้นสุด 1 มม. (เซอร์คอน, 38.3 ± 6.85 ไมโครเมตร; อีแมกซ์, 52.22 ± 10.66 ไมโครเมตร; ลาวา, 69.99 ± 6.77 ไมโครเมตร) ตามลำดับ **สรุป** สำหรับทั้งโครงฟันเซรามิกทั้งซี่ทั้ง 3 ระบบ กลุ่มที่มีระดับความโค้งต่างเส้นสิ้นสุดมากจะพบความกว้างช่องว่างแทรกมากด้วยเช่นกัน

สาขาวิชา ทันตกรรมบูรณะเพื่อความสวยงาม และทันตกรรมรากเทียม

ลายมือชื่อนิสิต..

ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์..........................

ปีการศึกษา 2554

5176153432 : MAJOR Esthetic Restorative and Implant Dentistry
KEYWORDS : All-ceramic copings/ Marginal gap/ marginal fit/ Finishing line curvature/ Cercon system/ Lava™ system/ IPS Empress system

CHUTIMA ASAVAPANUMAS : THE INFLUENCE OF FINISHING LINE CURVATURE ON MARGINAL GAP WIDTH OF ALL-CERAMIC COPINGS. ADVISOR: ASSOC. PROF. CHALERMPOL LEEVAILOJ, 60 pp.

Objective The aim of this study was to investigate the influence of the curvature of the finishing line on the marginal gaps of all-ceramic copings. Materials and methods An ivorine maxillary central incisor was prepared for three different abutment finishing line curvatures (1mm, 3mm and 5 mm vertical distance between labial or lingual margins and proximal margins), with a total of 36 copings being fabricated for each of these curvatures using Cercon, IPS e.max and Lava™ systems. The marginal gap width was measured using a stereo microscope, with the analysis of the data subsequently being undertaken by means of a two-way ANOVA test followed by a one-way ANOVA test ($\alpha = 0.05$). Results A significantly higher mean marginal gap was observable for the 5 mm curvature group (Cercon, 76.59 ± 23.01 µm; IPS e.max, 106.44 ± 18.48 µm; Lava, 128.34 ± 20.79 µm) as compared to both the 3 mm curvature group (Cercon, 60.18 ± 9.74 µm; IPS e.max, 81.79 ± 16.20 µm; Lava, 99.19 ± 15.32 µm) and the 1 mm curvature group (Cercon, 38.3 ± 6.85 µm; IPS e.max, 52.22 ± 10.66 µm; Lava, 69.99 ± 6.77 µm). Conclusion The greater the finishing line curvature, the wider the marginal gaps for the three all-ceramic systems.

Field of Study: Esthetic Restorative and Implant Dentistry	Student's Signature....................................
Academic Year: 2011	Advisor's Signature………………………….

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CHAPTER I

INTRODUCTION

Rationale and Significance of the problem

The natural appearance of the porcelain used in dental prosthetic restorations has resulted in all-ceramic materials becoming the method of choice for anterior tooth restorations. If consistently predictable satisfactory results are to be achieved, the restorative material must have specific properties of biocompatibility, strength, durability and aesthetic appearance, along with the good marginal fit of the restoration (1).

Insufficient adaptation of restorations may result in an increase in plaque accumulation, ultimately leading to periodontal disease (2, 3), and also giving rise to the possibility of secondary caries which can progress to pulpal inflammation (4). Furthermore, exposure of the dental luting agent at the gap to the oral environment also leads to a rapid increase in cement dissolution (5), which is widely recognized as a major cause of restoration failures.

Christensen suggested that in the visually accessible surfaces of the casting, clinically acceptable marginal openings should be in the range of 34-119 µm for sub-gingival margins, and 2-51µm for supra-gingival margins (6). McLean and von Fraunhofer subsequently undertook a five-year clinical study of 1,000 restorations and concluded that 120 µm was the maximum acceptable marginal opening (ranging from 100-120 µm) (7); however, Byrne also reported that discrepancies of less than 10 µm were routinely possible (8).

The natural bone ridge and tooth anatomy within the anterior region leads to the greater likelihood of abutment preparation presenting a higher degree of finishing line curvature within that region, as compared to the posterior region. Furthermore, the labial finishing line of both incisor and canine teeth is often found to be located more apically, a phenomenon which is attributable to gingival recession. These factors contribute to the requirement for the creation of sharper degrees of curvature for abutment teeth within the anterior region.

The studies carried out by Tao and Han (9) and Tao et al. (10) concluded that the greater the finishing line curvature of metal ceramic crowns (Castwell M.C., GC Corporation, Tokyo, Japan), then the greater the occurrence of wider marginal gaps, although in both studies, the abutment finishing line curvature was found to have no significant influence on the marginal fit of all-ceramic CAD/CAM crowns (Cercon system). There are, however, very few studies currently available on the effects of the curvature of the abutment finishing line for other all-ceramic restoration systems.

Research Question

Do the abutment finishing line curvature and ceramic system have a significant influence on the marginal fit of all-ceramic copings at the different locations of crown margin?

Objective of the Study

The aim of this study was to investigate the influence of the curvature of the finish line and ceramic system on the marginal gaps of 3 ceramic coping systems at the different locations of crown margin.

Statement of Hypothesis

Null hypothesis:

There is no significant difference between the marginal gaps among the different abutment finishing line curvature of all-ceramic copings.

There is no significant difference between the marginal gaps among the different ceramic system of all-ceramic copings.

There is no significant difference between the marginal gaps among the different location of measurement of all-ceramic copings.

Alternative hypothesis:

There is a significant difference between the marginal gaps among the different abutment finishing line curvature of all-ceramic copings.

There is a significant difference between the marginal gaps among the different ceramic system of all-ceramic copings.

There is a significant difference between the marginal gaps among the different location of measurement of all-ceramic copings.

Scope of the Study

This research is an experimental research for evaluate the effect of the curvature of the finishing line and ceramic system on the marginal gaps of three all-ceramic coping systems at the different locations of crown margin. This study utilizes a maxillary central Ivorine tooth specimens. Therefore, the result cannot be generalized to natural teeth or other teeth in different areas and differ from normal clinical situation. Moreover, the results found here may not be able to be extrapolated to crowns of other systems because different systems of ceramics have different mechanical properties

Basis Assumption

1. All procedures were performed using one Ivorine tooth under well controlled conditions and prepared by one operator and evaluated by one examiner.
2. The popular ceramic systems in Thailand with reliable fabrication procedures were chosen to be included in this study (Cercon, IPS e.max and Lava^{TM}).
3. The metal abutment were used in order to decrease wear of the die during the manufacturing processes and measurements.
4. In order to control the comparable thickness of restorations and minimize the distortion from several firing cycles, the copings without veneering materials will be evaluated for marginal gaps. Therefore, the result cannot be inferred to full veneered all-ceramic crowns.

5. The specimens were fabricated according to the recommendations of the respective manufacturers by a single technician from each of the centers (Cercon Center, Dental Art Laboratory and Lava Milling Center, Thailand).
6. The all-ceramic copings were measured the marginal gaps on their respective metal abutments to mimic the real clinical situation.
7. We used the direct view method to carry out the repeat seating of the specimens without destruction which provides less information, less precision of measurement and differ from normal clinical situation.

Study Limitation

1. Due to a limited budget in this study, all brands cannot be evaluated. Thus, three ceramic systems in common use were chosen to be tested in this study.
2. There is no an instrument to control seating force horizontally of specimens. Therefore, we used a digital caliper micrometer with fine adjustment to seat and stabilize the specimens on their respective metal abutments during gap measurements.

Keywords

All-ceramic copings/ Marginal gap/ marginal fit/ Finishing line curvature/ Cercon system/ Lava™ system/ IPS Empress system

The Expected Benefits

The expected benefits of this study are: to determine if the marginal gap of copings varies with different finishing line curvatures, to be supporting evidence as primary data in used in making the best decision on material for fabricating crowns for patients, and to be the foundation for future research in related fields.

CHAPTER II

Review of Literatures

Dental ceramics are inorganic compounds with nonmetallic properties primarily containing compound of oxygen with one or more metallic or semimetallic elements (aluminum, calcium, lithium, magnesium, phosphorus, potassium, silicon, sodium, titanium and zirconium) (11). The first feldspatic porcelain crown was introduced to dentistry by Land in 1903 (11). Due to the excellent esthetics, biocompatibility and improvement of mechanical and physical properties, all-ceramic restorations become more popular for restoring anterior and posterior teeth (12). Many different materials and systems of dental ceramic are available for anterior restorations.

Crowns fabricated with all-ceramic systems may use different techniques such as slip casting, heat pressed, copy-milling, or computer-aided design/computer-assisted manufacture (CAD/CAM) techniques (11).

For slip cast ceramics (In-Ceram, In-Ceram Spinell and In-Ceram Zirconia), a slurry of liquid and particles of alumina, magnesia-alumina silicate (spinell) or zirconia is applied and sintered to a refactory die at 1120^{0}C for 10 hours. During the second firing at 1100^{0}C for 4 hours, the lanthanum glass melts and infiltrates the porous skeleton of alumina particles to eliminate porosity, increase strength, and limit potential sites for crack propagation (13). The coping is veneered with feldspatic porcelain.

Pressable ceramics (IPS Empress, IPS Empress2, Finesse All-Ceramic, OPC, and OPC-3G) use a heat-press method to produce a high-strength core (14), which is primarily lithium-disilicate glass. A glass ceramic ingot is heated at 920^{0}C and subjected to hydrostatic pressure and pressed into an investment mold under vacuum. After removal and divesting, the framework is veneered with feldspatic-based veneering porcelain to enhance light transmission (15).

Copy-milling restorations (Celay In-Ceram crown) are fabricated through copy-milling technique (Celay; Mikrona Technologie AG, Spreitenbach, Switzerland) (16).These restorations are milled by duplicating a direct acrylic resin pattern replica of the restoration. Some authors report the copy-milling is less accurate compared with other methods (17).

For the computer-aided design/computer assisted manufacture (CAD/CAM) process, the restoration design and manufacture is accomplished by computer software according to the ceramic systems. In the Cercon system (Dentsply Ceramco NY, USA), a die is scanned by the internal laser scan unit of the CAD/CAM system in the Cercon Brain to design the yttrium tetragonal zirconia polycrystals (Y-TZP) framework (18). The presintered blank is milled to fabricate the framework and then the framework is sintered at 1,350°C in the Cercon Heat. The shrinkage of framework in the sintering process is homogeneous, reaching approximately 20%, which is compensated for by increasing the size of the framework, designed in the Cercon Art system.

Another ceramic system of CAD/CAM fabrication technique is Lava™ (3M ESPE, St. Paul, Minn), in which a die is scanned by a contact-free optical process. The CAD software designs an enlarged framework to compensate for the shrinkage of softer presintered blanks after sintering in a special automated oven for 8 hours (19).

There are many factors affecting the success rate of all-ceramic restorations. Apart from mechanical properties and esthetics, marginal accuracy is one of the most important criteria for the clinical quality and success of all-ceramic crowns (20). Poor marginal adaptation of restorations increases plaque accumulation and induces the onset of periodontal disease and bone resorption (2, 3). Also, microleakage from the oral cavity can cause secondary caries which can progress to induce pulpal inflammation (4). Furthermore, exposure of the dental luting agent at the gap to the oral environment rapidly increases cement dissolution (5) which is a major cause of failure of restorations.

Several factors have an effect on the marginal discrepancy of crowns such as; ceramic systems, fabrication processes, and margin design. Although there are different manufacturing processes from several ceramic systems, the castable (heat pressed) ceramic crowns made by the lost wax technique exhibited an excellent marginal fit of the crowns (21). However, misfit at the margins of the ceramic crowns was still found because of the effect of the ceraming process which combined with investing, casting, and cementation errors. Moreover, the misfit is most often associated with the proximal margins of teeth exhibiting a large degree of rise and fall of the cavosurface margin in an occlusogingival direction due to asymmetry of the tooth preparation (21).

All-ceramic crowns which previously fit prepared abutments, do not always fit as well after porcelain application. Potential causes of this distortion include: (1) porcelain firing shrinkage, (2) differences in the coefficient of thermal expansion between the veneering porcelain and coping, (3) substructure design, (4) tooth preparation, (5) contamination of the casting, and (6) contamination of the internal surface of the casting with porcelain etc (22, 23).

Regarding the margin design, the effect of margin shapes such as chamfer, shoulder, chamfer with bevel and shoulder with bevel have been reported. The type of finishing line of the preparation may affect the marginal seal of full crown preparations (24). Shearer et al. showed no significant difference between chamfer and shoulder margins in the fit of In-Ceram crowns (25). Syu et al. reported no significant differences for marginal gaps among metal ceramic crowns with shoulder, shoulder- bevel, and chamfer finishing lines (26). However, Goodacre et al. recommended a shoulder margin design for all-ceramic restorations (27).

Moreover, in daily practice, other factors such as die spacer thickness, expansion of die and model stone, polymerization shrinkage of impression materials, amount of tooth reduction, and skill of technicians also have an effect on the marginal discrepancy of crowns (28).

“Misfit” is used to define the fit of a casting which can be measured at various points between the preparation and the casting surface such as; points on the external surface of the casting, at the margin or along the internal surface (21). The figure 1 illustrates the different types of measurements and casting misfit terminologies.

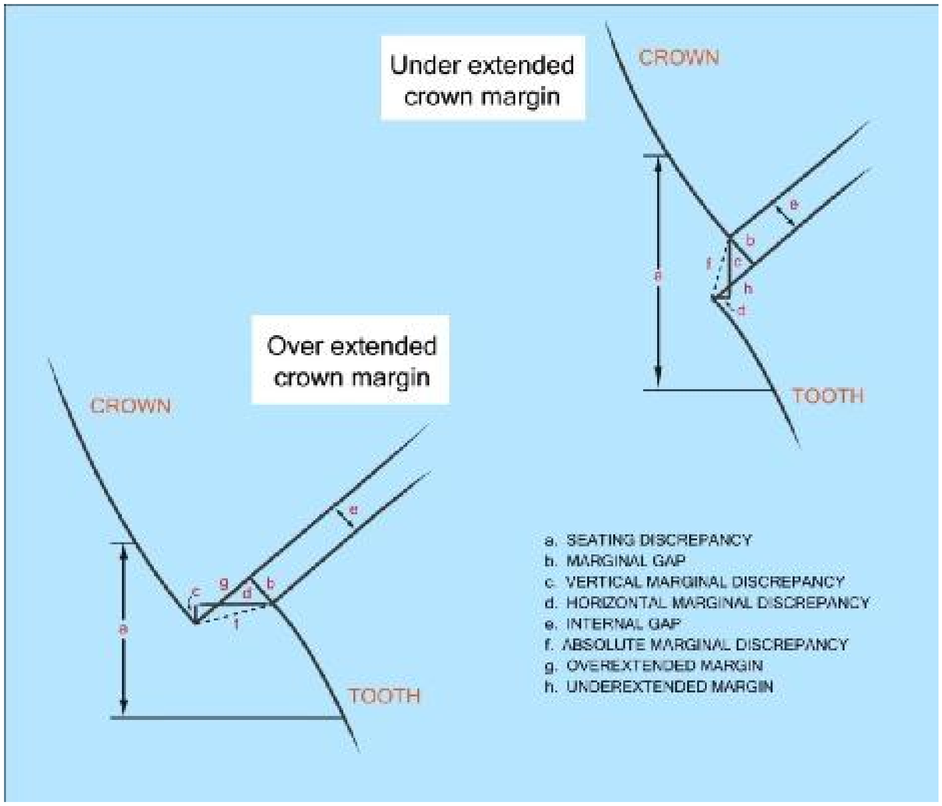

Figure 1. Casting misfit terminologies

The terminologies of the measurement of marginal fit were suggested by Holmes JR et al. (21). “The seating discrepancy” is the perpendicular measurement between the path of draw horizontally on the external surface of the casting and tooth away from the margin. At the margin, the perpendicular measurement from the axial surface of prepared tooth and the internal surface of the casting is called “the marginal gap”. The vertical and horizontal marginal misfit from the margin of the prepared tooth to the margin of the casting measured parallel to the vertical and horizontal line are consequently called “the vertical marginal discrepancy” and “the horizontal marginal discrepancy”. The perpendicular measurement along the internal surface between the axial surface of prepared tooth and the surface of the casting is called “the internal gap”.

The methods for measurement of the marginal gap include the following: (1) direct view of the crown on a die, (2) cross-sectional view, (3) impression replica technique, and (4) clinical examination (29). The advantages and disadvantages of the different techniques need to be considered.

The direct view technique is simple and less time-consuming because it does not require additional steps such as; cementation, embedment and sectioning method. Due to the non- destructive nature of this technique, this method is used for measuring the restoration margin during various steps of the fabrication process which requires the repositioning of specimens to a master die (29). This method has been used in order to evaluate the marginal discrepancy of restorations in many studies (30-34). For example, Wanserski DJ et al. used this method to measure the marginal distortion during the porcelain firing process of different types of ceramic systems (34).

However, there are many factors causing less accuracy and validity of measurements from the direct view technique. Wearing and damaging of a master die due to repeating seating specimens cause measurement errors from changing of the measurement point. A rounded margin of a master die and inaccuracies in repositioning crowns are situations in which it is difficult to mark the actual point of measurements. Overcontouring of crown margins is also difficult to assess by this method (29).

The cross-sectional method requires additional steps, which are time-consuming and may destroy the specimens. However, additional steps provide more information and greater precision of measurement due to greater precision in determination of measuring points even allowing for overcontoured crown measurements (22). A number of studies have used this method to assess the marginal discrepancy of restorations (35-37). For example, Campbell SD et al. used this method to evaluate the fit and strength of all-ceramic fixed partial dentures (35).

Ideally, there is no marginal discrepancies between the tooth and restoration and the emergence profile of the restoration is coincident with the submarginal surfaces of the prepared tooth (38).The attainable limits of marginal fit theoretically should result in zero discrepancy at the cavosurface margin of the preparation. From a clinical standpoint, a perfect result is not possible (21).

Christensen demonstrated a range of 34-119 µm for subgingival margins and 2-51 µm for supragingival margins as clinically acceptable marginal opening in visually accessible surfaces of the casting (6).The value for subgingival margins was greater because they were more difficult to assess. Subsequently, a 5-year clinical study of 1000 restorations Mclean and von Fraunhofer concluded 120 µm was the maximum acceptable marginal opening (range from 100-120 µm) (7). However, Byrne reported discrepancies of less than 10 µm as routinely possible (8).

There are several studies reporting the marginal gap in different ceramic systems. Bindl A et al. demonstrated a value of 44 µm as a mean marginal gap of IPS Empress 2 (4). Study by Coli P et al. showed the high precision of milling densely sintered zirconia which ranged from 60-74 µm (39). The Cercon system (DeguDent) uses the option of milling semi-sintered zirconia. The sintering procedure is associated with shrinkage of approximately 20% which may cause the marginal misfit of the restorations (40). Clinical study from Reigh S et al. reported a mean marginal gap of 64 µm for fixed dental prostheses made by the Lava™ system (3M ESPE), which mills semi-sintered zirconia (41).

CHAPTER III

MATERIALS AND METHODS

Research Design

Experimental research

Sample Description

1. The population of this study was a maxillary right central incisor Ivorine tooth (A5A-500, Acteon, Satelec Company, Bordeaux, France) to create all-ceramic copings based upon three types of abutment finishing line curvatures (1mm, 3mm and 5mm).
2. Sample size estimation was calculated from this formula;

$$\sigma^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}$$

Where: σ^2 represents the variance of the variable as estimated by the data from previous study (9)

n_i represent the required sample size per group ($n_1 = 5$ and $n_2 = 5$)

S_i represent the standard deviation ($S_1 = 3.2$ and $S_2 = 2.38$)

$$n/\text{group} = \frac{2(Z_{\alpha/2}+Z_\beta)^2\,\sigma^2}{(x_1+x_2)^2}$$

Where: Z represents the Z value ($Z_{\alpha/2} = 1.96$ for type I error (α) equal to 0.05 and $Z_\beta = 1.28$ for type II error (β) equal to 0.1)

At 95% confident interval and 90% power of test, the result from sample size estimation was 11.88. Therefore, the number of specimens per group in this study should be 12.

Dental Materials

1. An ivorine maxillary right central incisor tooth (A5A-500, Acteon, Satelec Company, Bordeaux, France)
2. Polyether impression material (Impregum™ Penta™ Soft, 3M ESPE, St. Paul, Minn)
3. Cobalt chromium molybdenum-based casting alloy (Vitallium alloy, Dentsply, USA)
4. Class IV resin-reinforced die (Galaxy, Ultima, Lafarge, Seiches Sur Le Loir, France)
5. Three systems of all-ceramic coping used in this study were;
    a. Cercon (Dentsply Ceramco, NY, USA)
    b. IPS e.max (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein).
    c. Lava™ (3M ESPE, St. Paul, Minn)

Methods of Data collection

<u>Preparation of specimens</u>

1. An ivorine maxillary right central incisor was prepared by a single operator for all-ceramic copings.
2. The tooth preparation, illustrated in Figure 2, generated a 1.2mm shoulder margin and a 2mm incisal reduction, along with a 1.5mm labial and axial reduction with a 6-degree taper.

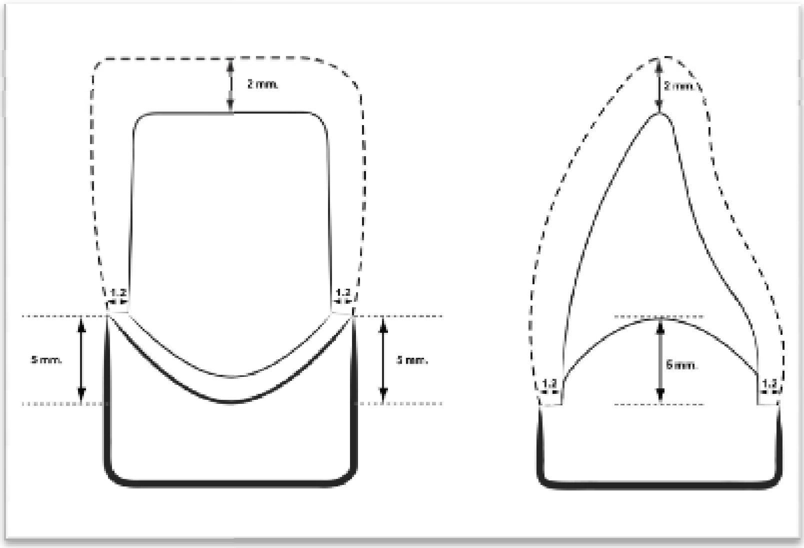

Figure 2. Labial and distal views of 5mm curvature abutment dimensions

3. For the 1mm curvature finishing line abutment, the tooth was first of all prepared with a bucco-lingual margin level which was 1mm apical to the proximal margin level, as shown in Figure 3A.

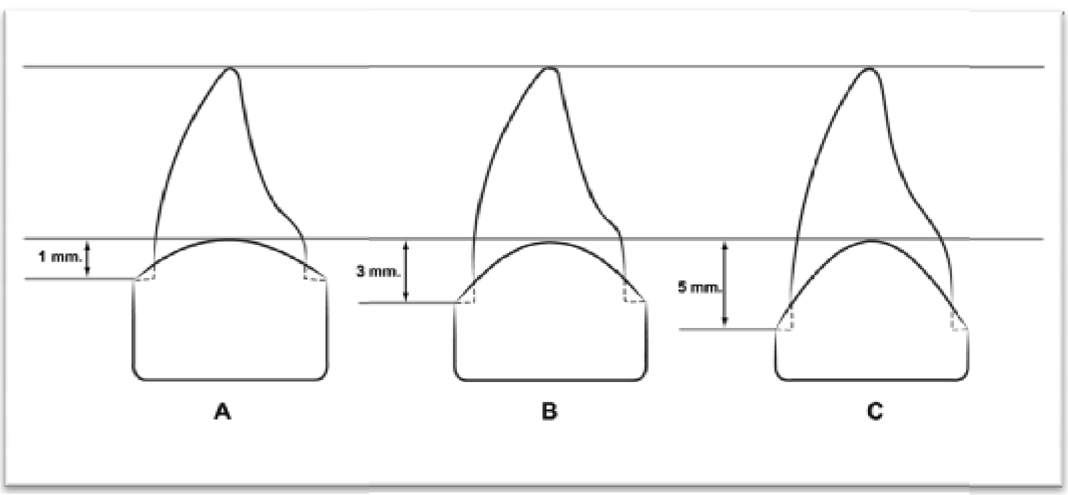

Figure 3. Distal views of three types of finishing line curvature abutments

4. The tooth was then further prepared apically to create 3mm and 5mm curvature abutments, as shown in Figure 3B and 3C, with the proximal margin level remaining unchanged.

5. During each stage, impressions were taken of each new preparation design using polyether impression material (Impregum™ Penta™ Soft, 3M ESPE, St. Paul, Minn).
6. A die was subsequently cast in cobalt chromium molybdenum-based casting alloy (Vitallium alloy, Dentsply, USA) using lost wax technique, as shown in Figure 4.

Figure 4. Labial view of three metal abutments

7. For each metal abutment, a total of 36 polyether impressions were produced for all three types of abutment finishing line curvatures using polyether impression material with the plastic molds, as shown in Figure 5.

Figure 5. Plastic mold

8. These were poured into molds with a class IV resin-reinforced die (Galaxy, Ultima, Lafarge, Seiches Sur Le Loir, France).

9. Twelve of the 36 dies for each type of finishing line curvature were used to fabricate copings using the three different types of all-ceramic systems (Cercon, IPS e.max and Lava™).
10. A die was scanned for the fabrication of the Cercon (Dentsply Ceramco, NY, USA) and Lava™ (3M ESPE, St. Paul, Minn) system copings, fabricated according to the recommendations of the respective manufacturers, with the constant coping margin thickness of 0.4 mm on a 30 µm die spacer being modeled by a single technician from each of the centers (Cercon Center and Lava Milling Center, Thailand).
11. The fabrication of the IPS e.max Press system copings was undertaken in accordance with the manufacturer's recommendations (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein). A coping with a constant thickness of 0.6 mm was waxed on a die for each type of finishing line curvature with a 30 µm die spacer, after which each of the wax patterns were finally checked by an individual investigator. All of the wax patterns were invested and pressed by a single lab technician at the Dental Art Laboratory, Bangkok, Thailand.

<u>Methods of measurement</u>

1. The metal abutments were embedded in square shaped acrylic resin, illustrated in Figure 6, to create the same position in four sites of measurement.

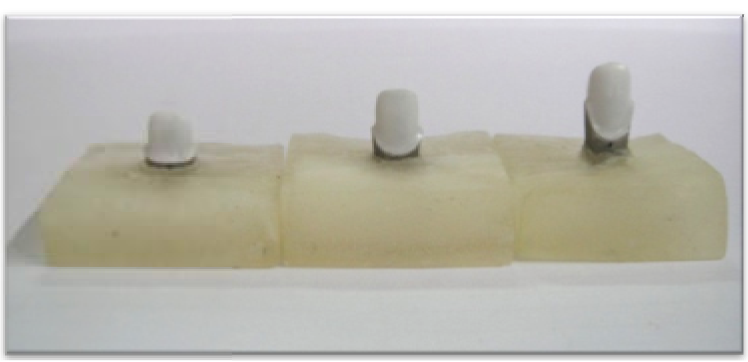

Figure 6. Labial view of three metal abutments in square shaped acrylic resin

2. The metal abutments were labeled with measurement points; on the labial and lingual sides, the labels were marked at the most apical finishing line point, whilst on the mesial and distal sides, the labels were marked at the most coronal finishing line point.
3. This was then followed by random seating of the specimens on their respective metal abutments using a digital caliper micrometer (Mitutoyo, Japan), as shown in Figure 7.

Figure 7. Seating of the specimens using a digital caliper micrometer

4. Measurements of the marginal gap were carried out using a stereomicroscope (ML 9300 MEIJI, CANON, Japan) and a camera (EOS 100, CANON, Japan) under 45x power magnification, as shown in Figure 8.

Figure 8. The stereomicroscope with the digital camera

5. The magnified images were measured and calculated the marginal gap from the margin of the prepared tooth to the margin of the casting parallel to the vertical line in micrometers, illustrated in Figure 9, at 4 sites which are mesial, distal, labial and lingual sites using a computer software (Image-pro® plus, The proven solution™ version 4.5.11.22).

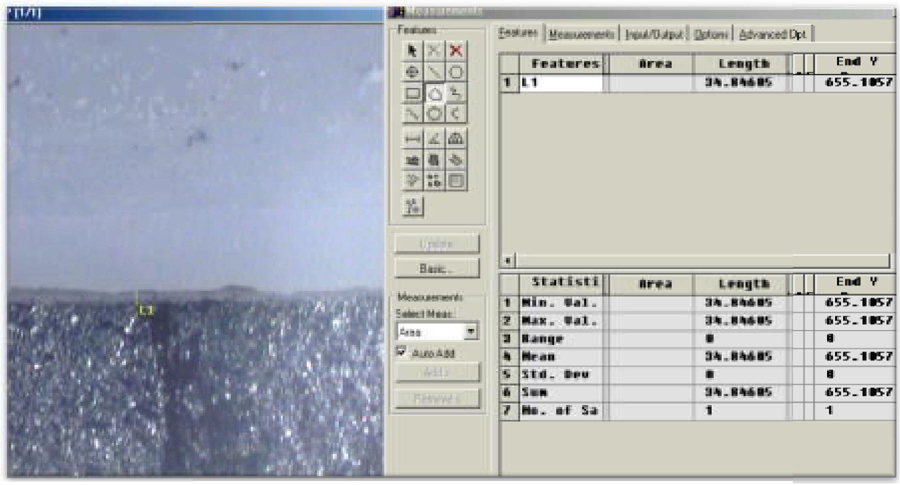

Figure 9. Marginal gap measurement using the Image-pro® plus software

Data collection

Each measurement was repeated three times, with all of these measurements being carried out by an individual investigator; this was subsequently followed by the calculation of the mean of the data.

Statistical Analysis

1. Data were analyzed using the SPSS program version 17.0. A one-sample Kolmogorov-Smirnov Test was used to test whether the data were normally distributed.

2. Three-way ANOVA test was used to determine statistic significant of abutment finishing line curvatures, ceramic systems and sites of measurement.
3. To compare the marginal gaps of different degrees of abutment finishing line curvature and ceramic systems, the mean marginal gaps of all sites of measurement (La, Li, M and D) were combined for each specimen. Two-way ANOVA test was used to determine statistic significant of abutment finishing line curvatures and ceramic systems.
    a. For each finishing line curvature and ceramic system, one-way ANOVA tests were performed to identify the significance of two factors separately.
    b. Levene test was used to test a homogeneity of variance. For variables with equal variances, Bonferroni tests were used as the post hoc test. On the other hand, Tamhane' s T2 tests were used when the variances of data were not equal.
4. For each ceramic system (Cercon, IPS e.max and Lava), two-way ANOVA tests were used to indicate statistic significant of abutment finishing line curvatures and sites of measurement at p-value = 0.05.
    a. One-way ANOVA tests were performed separately in each abutment finishing line curvature and site of measurement to verify the significance of both factors. A homogeneity of variance was tested by using Levene test.
    b. Bonferroni and Tamhane' s T2 tests were performed to be the post hoc test in the same aforementioned conditions.

CHAPTER IV

RESULTS

The marginal gaps were measured on a total of 108 copings, comprising of 36 copings for each of the ceramic systems (Cercon, IPS e.max and Lava™), further divided into the three types of abutment finishing line curvature (1mm, 3mm and 5mm). Based upon the one-sample Kolmogorov-Smirnov test, the results were found to be normally distributed. The three-way ANOVA results in Table I indicated significant effects for finishing line curvature, ceramic system and site of measurement.

Table I. Three-way ANOVA results of significant effects among abutment finishing line curvature, ceramic system and site of measurement.
Dependent Variable: Total marginal gap

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Cu	182354.927	2	91177.463	88.232	<.001
Ce	1201174.149	2	60087.074	58.146	<.001
S	78114.406	3	26038.135	36.246	<.001
Cu * Ce	5527.497	4	1381.852	1.924	.106
Cu * S	49789.106	6	8298.184	11.551	<.001
Ce * S	15909.034	6	2651.506	3.691	.001
Cu * Ce * S	8832.534	12	736.045	1.025	.452

R Squared = .413

df, Degree of freedom

Cu, Abutment finishing line curvature

Ce, Ceramic system

S, Site of measurement

The significance of finishing line curvature and ceramic system

The two-way ANOVA results in Table II indicated significant effects for both finishing line curvature (p-value <.001) and ceramic system (*p*-value <.001); however, no interactions were found between the two factors (*p*-value = .214).

Table II. Two-way ANOVA results of significant effects between abutment finishing line curvature and ceramic system. Dependent Variable: Total marginal gap

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Curvature	45588.732	2	22794.366	97.605	<.001
Ceramic system	30043.537	2	15021.769	64.323	<.001
Curvature * Ceramic	1381.852	4	345.463	1.479	.214

R Squared = .413

df, Degree of freedom

For each of the three ceramic systems, significant differences were observable in the total marginal gaps between the three degrees of finishing line curvature, as shown in Table III and Figure 10.

Table III. Total marginal gaps of coping margins

Ceramic System	Finishing Line Curvature 1mm (µm)		3mm (µm)		5mm (µm)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Cercon	38.30	6.85 [A,a]	60.18	9.74 [B,d]	76.59	23.01 [B,g]
IPS e.max	52.22	10.66 [C,b]	81.79	16.20 [D,e]	106.44	18.48 [E,h]
Lava™	69.99	6.77 [F,c]	99.19	15.32 [G,f]	128.34	20.79 [H,i]

The statistically significant differences in the marginal gaps are indicated by different capital (lower case) letters for different degrees of finishing line curvature (different ceramic systems) using one-way ANOVA tests followed by Tamhane T2 post-hoc tests.

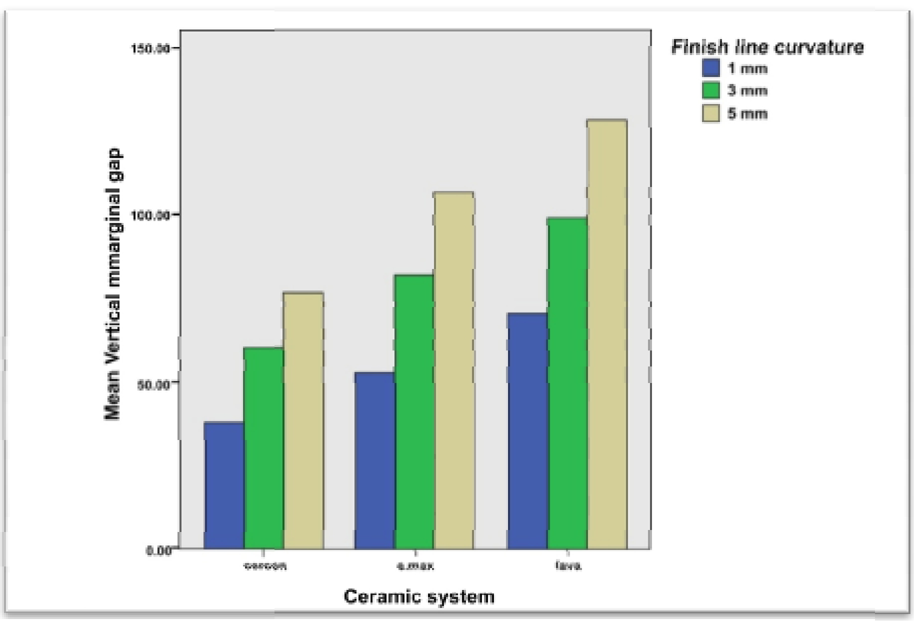

Figure 10. Histrograms showing total marginal gaps (µm) of three systems of all-ceramic coping

For each ceramic system, the greater the finishing line curvature, the larger the marginal gaps observed for all finishing line curvature groups (1 mm < 3 mm < 5 mm). However, no significant differences were remarkable in the marginal gaps between the 3 mm and 5 mm finishing line curvatures of the Cercon copings (Table III).

As regards the finishing line curvature, statistically significant differences were found between the mean marginal gaps of the Cercon, IPS e.max and Lava™ systems, with the Lava™ system exhibiting greater marginal gap widths than both the IPS e.max and Cercon systems. However, no significant differences were observable between the marginal gaps of the IPS e.max and Lava™ systems for the 5mm finishing line curvature (Table III).

The significance of finishing line curvature and site of measurement for each ceramic system

Comparisons were carried out between the marginal gaps of the four measurement locations in order to verify the significant sites of the crown margin. As shown in Table IV, the two-way ANOVA results in Panels A (Cercon) and C (Lava™) revealed significant differences in the marginal gaps for different finishing line curvatures (p-value <.001) and measurement sites (p-value <.001), whilst also showing interaction between the two factors (p-value <.001); however, the results in Panel B (IPS e.max) show no significant effects for different measurement sites (p-value = 0.070) or interactions between the two factors (p-value = 0.058).

Table IV. Two-way ANOVA results of significant effects between finishing line curvature and site of measurement of difference all ceramic systems. Dependent Variable: Marginal gap

Source	Panel A: Cercon			Panel B: IPS e.max			Panel C: Lava™		
	df	F	*P*	*df*	F	*P*	*df*	F	*P*
Curvature	2	29.037	<.001	2	40.228	<.001	2	61.366	<.001
Site	3	32.261	<.001	3	2.412	.070	3	14.328	<.001
Curvature * Site	6	7.918	<.001	6	2.098	.058	6	4.648	<.001
	R Squared = .605			R Squared = .432			R Squared = .595		

df, Degree of freedom.

For the Cercon (Panel A) and Lava™ (Panel C) systems, the marginal gaps at the labial and lingual sites were found to be much greater than those at the mesial and distal sites; however, no significant differences were observable between any of the measurement sites in the IPS e.max system (Panel B), as shown in Table V. These results revealed statistically significant differences in the marginal gaps of all-ceramic copings for different abutment finishing line curvatures; thus, the null hypothesis of this study was rejected.

Table V. One-way ANOVA results on marginal gaps of crown margins for each ceramic system

Ceramic System	Finishing Line Curvature 1mm (µm)		3mm (µm)		5mm (µm)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Panel A: Cercon						
Labial	36.40	9.57 [a]	77.24	24.17 [c]	128.35	53.71 [e]
Lingual	50.72	13.90 [b]	87.70	34.87 [c]	90.80	34.95 [e]
Mesial	30.24	7.63 [a]	36.59	15.09 [d]	44.77	11.14 [f]
Distal	35.82	13.04 [a]	39.19	15.85 [d]	42.42	17.27 [f]
Panel B: IPS e.max						
Labial	47.82	16.77 [g]	87.31	40.98 [h]	132.61	57.27 [i]
Lingual	52.09	18.32 [g]	88.66	13.67 [h]	108.99	37.15 [i]
Mesial	56.82	8.67 [g]	72.02	29.13 [h]	100.09	36.67 [i]
Distal	52.16	14.44 [g]	79.18	26.48 [h]	84.07	15.16 [i]
Panel C: Lava™						
Labial	79.17	17.54 [j]	91.16	18.41 [l]	162.23	30.04 [n]
Lingual	75.69	11.38 [j, k]	130.09	6.88 [m]	140.52	31.54 [n, o]
Mesial	62.43	18.79 [k]	86.46	17.11 [l]	110.93	38.34 [o, p]
Distal	62.68	14.79 [k]	89.05	36.39 [l]	99.70	42.70 [p]

The different lower case letters indicate statistically significant differences in the marginal gaps for different measurement sites based upon one-way ANOVA tests followed by Bonferroni and Tamhane T2 post hoc tests

CHAPTER V
DISCUSSION

The major finding of this study is 'the greater the finishing line curvature, the wider the marginal gap', a result which is in line with those of the prior studies carried out by Tao and Han (9) and Tao et al (10); however, statistically significant differences were observable between the marginal gaps for the different finishing line curvatures of the Cercon copings, which clearly contradicts the findings of Tao and Han (9).

One possible explanation for such a difference between the findings of the Tao and Han study and the present study may be the greater number of samples used in our study. Another likely reason is the possible distinctions between the method of measurement, such as the type of machine and the measurement magnification. In the present study, the marginal gaps were measured using a stereomicroscope under 45x power magnification, which was a greater magnification than that used in the Tao and Han study (9). Furthermore, a 30 µm die spacer was applied to the fabrication processes of the three ceramic systems in the present study, which again differs from the fabrication technique adopted in the prior study (9).

There are a number of factors which can give rise to discrepancies in the sharper degree of abutment finishing line curvature groups for ceramic copings; for example, the greater volume of ceramics in a sharper degree finishing line curvature could be related to the larger amount of shrinkage which occurs during the firing (IPS e.max) or sintering (Cercon and Lava^{TM}) fabrication process, thereby creating a greater marginal discrepancy for that group (42).

Furthermore, the different margin levels relating to the sharper degree abutment finishing line curvature copings requires much greater accuracy of the longer line of the crown margin than the equal margin level of crown margin copings. Thus, as compared to the other groups, the abutment finishing line curvature group with the sharpest degree should also exhibit the highest level of marginal openings.

To mimic the clinical situation, the all-ceramic copings were measured the marginal gaps on their respective metal abutments. Thus, the marginal discrepancies may be the result of distortion of impression material or stone die material. However, in this study, the impression procedure and stone mixing were performed in the ratio recommended by manufacturer to decrease shrinkage of materials and one impression was poured only one time in order not to be damaged from previous removal of the stone die.

In the present study, regardless of finishing line curvature, the Cercon group was found to exhibit a lower mean marginal gap width (38.30-76.59 µm) than the IPS e.max group (52.22-106.44 µm). In a recent study undertaken by Korkut et al., the Cercon group (43.02 µm) was similarly found to exhibit a lower mean marginal gap than the IPS e.max group (47.51 µm) (43); however, the in-vitro studies carried out by Ural et al. (44) reported a greater mean marginal gap for the Cercon group (77.10 µm) as compared to the IPS e.max group (61.94 µm).

The Lava™ and Cercon copings were fabricated using the CAD-CAM technique, but there were differences in the scanners used on these two ceramic brands. A laser scanner (Cercon brain) was used for the Cercon copings, which were scanned in a direction, whereas an optical 3D (Scanner ST) scanner was used for the Lava™ coping, based upon a triangulation scanning approach with a fringe pattern. Thus, different results were obtained for the two types of CAD-CAM ceramic copings in our study.

A comparison between the mean marginal gaps at the four measurement locations (labial, lingual, mesial and distal) showed that the Cercon and Lava™ copings (CAD-CAM technique) exhibited much greater marginal gaps at both the labial and lingual sites than those at the mesial and distal sites. As noted earlier, the greater volume of ceramics in the labial and lingual sites could be due to a significant amount of sintering shrinkage leading to a greater marginal discrepancy than that found at the proximal sites (42, 45).

No significant differences were found in the marginal gap at the different measurement sites for the heat-press ceramic (IPS e.max) copings. The outcome of distortion of restorations from the heat-press or lost-wax technique used in the fabrication of IPS e.max copings can be attributable to several factors, such as die spacer thickness (46), the 0.4 per cent shrinkage of the wax pattern (42), or the 0.2 per cent thermal shrinkage of the ceramic coping after casting (47). In the present study, it was expected that the respective setting and thermal expansion of the phosphate-bonded investment, at approximately 0.3 per cent and 0.2 per cent, would compensate for this thermal shrinkage (42). The contraction and expansion of various materials used in the fabrication process has been developed in all directions; thus, no significant differences were observable in the marginal misfits of the IPS e.max copings at the different measurement sites.

McLean and von Fraunhofer concluded that 120 µm was the maximum acceptable marginal opening (ranging from 100-120 µm) (7). According to the findings of the present study, the mean marginal gaps of the 1mm and 3mm finishing line curvature for the Cercon and IPS e.max ceramics met the acceptable criterion (ranging from 36.40-88.66 µm), as did the 1 mm finishing line curvature for the Lava™ ceramics; however, the mean marginal gaps of the 5 mm finishing line curvatures of the Cercon and IPS e.max ceramics and those of the 3 mm and 5mm finishing line curvatures for the Lava™ ceramics failed to meet this criterion (ranging from 42.42-162.23 µm).

In a prior related study (9), no significant differences were found between the marginal gap widths of the ceramic copings and the veneered ceramic crowns, and indeed, Sulaiman et al. reported that the marginal gaps of the ceramic copings were the same as the overall fit of a veneered crown (42). The present study was therefore carried out without veneering material with the overall aim of reducing the potential errors attributable to the greater number of steps that are involved in the crown fabrication process.

The direct view method was used to carry out the repeat seating of the specimens on their respective master dies without destruction (48). Since Ural et al. reported increased marginal discrepancies as a result of the cementation process which they attributed to hydrostatic pressure (44), the direct view method was considered more appropriate for use in the present study.

CONCLUSIONS

Within the limitations of this study, we draw the following conclusions from our analysis: (i) a 5 mm finishing line curvature coping in all-ceramic systems exhibited the greatest marginal gap values, with lower respective values being exhibited for the 3 mm and 1 mm finishing line curvatures; (ii) the lowest marginal gap for all levels of finishing line curvature was exhibited by the Cercon copings, with Lava™ demonstrating greater marginal gaps than both the IPS e.max and Cercon copings; (iii) the marginal gaps found in the Cercon and Lava™ copings at both the labial and lingual sites are much greater than those found at the mesial and distal sites; however, no significant differences were observable for each of the measurement sites of the IPS e.max copings.

Implication of the Result of this Study

As regards the clinical implications, this study has revealed that greater increases in marginal gaps are to be expected for sharper degrees of finishing line curvature abutment; thus, any preparations which conform to higher degrees of abutment finishing line curvature in labio-lingual gingival recession should be avoided. Furthermore, the porcelain margin design should be considered to decrease the marginal gap with veneering material for sharper degrees of finishing line curvature abutment.

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APPENDICES

Appendix A. Marginal gap width of each ceramic specimen

Cercon Number	Vertical marginal gap width (µm) of 1 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	39.49	62.72	38.58	44.14	46.23
2	37.17	44.14	23.23	34.85	34.85
3	41.82	39.49	30.2	26.46	34.49
4	27.88	25.55	27.88	23.43	26.19
5	58.08	62.72	27.88	48.78	49.37
6	27.88	58.07	32.52	21.11	34.90
7	27.88	48.78	30.2	37.17	36.01
8	34.85	46.46	23.23	58.08	40.66
9	44.14	37.17	39.49	55.75	44.14
10	32.52	44.14	20.91	24.85	30.61
11	23.23	72.02	23.23	31.11	37.40
12	41.82	67.37	45.55	24.14	44.72
Mean	36.40	50.72	30.24	35.82	38.30
SD	9.57	13.90	7.63	13.04	6.85

Cercon Number	Vertical marginal gap width (µm) of 3 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	120.8	65.05	32.52	23.23	60.40
2	76.66	95.25	41.82	44.34	64.52
3	65.05	99.89	25.55	42.02	58.13
4	76.66	62.73	23.23	58.08	55.18
5	88.28	67.37	25.55	18.58	49.95
6	99.89	55.73	69.69	51.11	69.11
7	69.69	62.72	44.14	33.43	52.50
8	27.87	81.31	20.91	41.31	42.85
9	81.31	67.37	32.52	34.85	54.01
10	74.34	83.63	60.4	65.25	70.91
11	97.57	144.03	30.2	11.61	70.85
12	48.78	167.26	32.52	46.46	73.76
Mean	77.24	87.70	36.59	39.19	60.18
SD	24.17	34.87	15.09	15.85	9.74

Cercon Number	Vertical marginal gap width (µm) of 5 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	183.52	62.52	42.52	75.55	91.03
2	102.22	74.14	52.72	55.75	71.21
3	120.8	144.03	63.23	38.08	91.54
4	125.45	63.43	60.91	32.52	70.58
5	27.88	61.11	34.85	32.52	39.09
6	104.54	61.11	35.55	31.82	58.26
7	104.54	95.25	32.52	20.91	63.31
8	197.46	164.94	58.58	58.58	119.89
9	153.32	106.86	39.49	23.23	80.73
10	99.89	61.11	35.55	37.37	58.48
11	225.34	109.18	37.17	65.55	109.31
12	95.25	85.95	44.14	37.17	65.63
Mean	128.35	90.80	44.77	42.42	76.59
SD	53.71	34.95	11.14	17.27	23.01

IPS e.max Number	Vertical marginal gap width (µm) of 1 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	41.82	37.17	59.49	62.72	50.30
2	48.78	44.14	56.15	42.82	47.97
3	34.85	39.49	38.78	41.82	38.74
4	25.55	48.78	64.34	44.14	45.70
5	32.52	48.78	41.82	65.05	47.04
6	76.66	62.95	64.54	46.46	62.65
7	72.02	72.02	55.25	51.11	62.60
8	46.46	44.14	57.17	34.85	45.66
9	58.08	67.37	54.14	76.66	64.06
10	25.55	27.88	64.85	30.2	37.12
11	53.43	39.49	60.2	62.72	53.96
12	58.07	92.92	65.05	67.37	70.85
Mean	47.82	52.09	56.82	52.16	52.22
SD	16.77	18.32	8.67	14.44	10.66

IPS e.max Number	Vertical marginal gap width (µm) of 3 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	76.66	74.34	27.88	125.45	76.08
2	72.02	78.98	44.14	57.88	63.26
3	60.4	62.72	51.11	85.95	65.05
4	167.26	104.94	72.02	76.66	105.22
5	44.14	104.14	55.75	123.12	81.79
6	78.98	83.63	97.57	48.78	77.24
7	83.63	81.31	85.95	93.12	86.00
8	37.17	87.17	106.86	64.03	73.81
9	58.08	95.05	44.14	60.4	64.42
10	144.03	94.03	125.45	96.55	115.02
11	137.06	109.38	85.95	46.26	94.66
12	88.28	88.27	67.37	72.01	78.98
Mean	87.31	88.66	72.02	79.18	81.79
SD	40.98	13.67	29.13	26.48	16.20

IPS e.max Number	Vertical marginal gap width (µm) of 5 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	88.28	137.06	83.63	95.25	101.06
2	51.11	95.25	95.25	88.28	82.47
3	171.91	44.14	118.48	70.2	101.18
4	167.26	167.16	83.63	83.63	125.42
5	127.77	90.6	151	99.89	117.32
6	134.74	102.22	144.03	88.78	117.44
7	99.89	146.35	34.85	51.11	83.05
8	157.97	146.35	153.32	85.95	135.90
9	276.45	81.31	76.66	88.28	130.68
10	111.51	137.17	62.72	62.72	93.53
11	102.22	90.6	111.51	98.78	100.78
12	102.22	69.69	85.95	95.95	88.45
Mean	132.61	108.99	100.09	84.07	106.44
SD	57.27	37.15	36.67	15.16	18.48

Lava™ Number	Vertical marginal gap width (μm) of 1 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	67.37	69.69	76.46	69.69	70.80
2	85.95	62.72	48.78	77.37	68.71
3	85.95	74.14	69.49	90.09	79.92
4	102.21	79.18	69.69	67.37	79.61
5	90.6	80.83	51.82	79.18	75.61
6	67.34	98.68	48.78	41.82	64.16
7	81.31	76.66	77.37	44.14	69.87
8	83.63	51.11	57.17	62.72	63.66
9	51.11	77.14	74.14	50.2	63.15
10	55.75	80.2	48.78	51.11	58.96
11	109.18	80.15	54.14	60.4	75.97
12	69.69	77.82	72.52	58.08	69.53
Mean	79.17	75.69	62.43	62.68	69.99
SD	17.54	11.38	11.79	14.79	6.77

Lava™ Number	Vertical marginal gap width (µm) of 3 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	92.92	133.63	106.86	78.98	103.10
2	58.08	135.72	76.66	78.98	87.36
3	127.77	136.75	77.88	174.23	129.16
4	72.02	118.28	65.05	46.46	75.45
5	83.63	134.74	101.82	76.66	99.21
6	95.25	130.72	66.46	58.08	87.63
7	74.34	128.27	95.25	78.98	94.21
8	85.95	118.48	58.08	78.98	85.37
9	92.92	124.53	90.91	60.4	92.19
10	104.34	127.77	108.28	92.92	108.33
11	109.18	132.61	97.57	99.89	109.81
12	97.57	139.58	92.72	144.03	118.48
Mean	91.16	130.09	86.46	89.05	99.19
SD	18.41	6.88	17.11	36.39	15.32

Lava^{TM} Number	Vertical marginal gap width (µm) of 5 mm finishing line curvature group				
	Labial	Lingual	Mesial	Distal	Mean
1	155.65	95.25	69.69	55.75	94.09
2	106.86	148.68	102.22	69.69	106.86
3	174.23	141.71	92.92	174.23	145.77
4	146.35	181.2	116.15	164.94	152.16
5	125.45	102.22	113.83	58.08	99.90
6	174.23	160.29	181.2	55.75	142.87
7	155.65	144.03	48.78	74.34	105.70
8	188.17	102.22	106.86	139.38	134.16
9	169.58	164.61	132.42	78.98	136.40
10	141.71	192.81	83.63	106.86	131.25
11	213.72	118.48	174.23	88.28	148.68
12	195.14	134.74	109.18	130.09	142.29
Mean	162.23	140.52	110.93	99.70	128.34
SD	30.04	31.54	38.34	42.70	20.79

Appendix B. The one-sample Kolmogorov-Smirnov results of normal distribution of data

One-Sample Kolmogorov-Smirnov Test			
Ceramic system	Degree of finish line curvature	Site of measurement	Asymp. Sig. (2-tailed)
Cercon	1 mm	Labial	0.959
		Lingual	0.974
		Mesial	0.884
		Distal	0.830
	3mm	Labial	0.972
		Lingual	0.607
		Mesial	0.333
		Distal	0.979
	5mm	Labial	0.789
		Lingual	0.772
		Mesial	0.784
		Distal	0.364

One-Sample Kolmogorov-Smirnov Test			
Ceramic system	Degree of finish line curvature	Site of measurement	Asymp. Sig. (2-tailed)
IPS e.max	1 mm	Labial	0.998
		Lingual	0.502
		Mesial	0.652
		Distal	0.8110
	3mm	Labial	0.491
		Lingual	0.995
		Mesial	0.989
		Distal	0.984
	5mm	Labial	0.908
		Lingual	0.770
		Mesial	0.950
		Distal	0.502
Lava^{TM}	1 mm	Labial	0.985
		Lingual	0.480
		Mesial	0.576
		Distal	0.997
	3mm	Labial	0.994
		Lingual	0.967
		Mesial	0.801
		Distal	0.321
	5mm	Labial	1.000
		Lingual	0.977
		Mesial	0.747
		Distal	0.786

Appendix C. Three-way ANOVA results of significant effects among abutment finishing line curvature, ceramic system and site of measurement.

Dependent Variable : Total marginal gap

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	460701.563[a]	35	13162.902	18.323	.000
Intercept	2711613.478	1	2711613.478	3774.672	.000
Curvature	182354.927	2	91177.463	126.923	.000
Site	78114.406	3	26038.135	36.246	.000
Ceramic	120174.149	2	60087.074	83.644	.000
Curvature * Site	49789.106	6	8298.184	11.551	.000
Curvature * Ceramic	5527.407	4	1381.852	1.924	.106
Site * Ceramic	15909.034	6	2651.506	3.691	.001
Curvature * Site * Ceramic	8832.534	12	736.045	1.025	.425
Error	284474.791	396	718.371		
Total	3456789.833	432			
Corrected Total	745176.355	431			

a. R Squared = .618 (Adjusted R Squared = .585)

Appendix D. Two-way ANOVA results of significant effects between abutment finishing line curvature and ceramic system.

Dependent Variable : Total marginal gap

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	77014.121[a]	8	9626.765	41.222	.000
Intercept	677903.369	1	677903.369	2902.771	.000
Curvature	45588.732	2	22794.366	97.605	.000
Ceramic	30043.537	2	15021.769	64.323	.000
Curvature * Ceramic	1381.852	4	345.463	1.479	.214
Error	23120.125	99	233.537		
Total	778037.615	108			
Corrected Total	100134.245	107			

a. R Squared = .769 (Adjusted R Squared = .750)

Appendix E. One-way ANOVA results to identify the significance of abutment finishing line curvature factor and ceramic system factor separately

One-way ANOVA results for each ceramic system to identify the significance abutment finishing line curvature. Dependent Variable: Total marginal gap

Test of Homogeneity of Variances

Ceramic system	Levene Statistic	df1	df2	Sig.
Cercon	20.110	2	141	.000*
IPS e.max	10.906	2	141	.000*
Lava™	24.677	2	141	.000*

*. The mean difference is significant at the 0.05 level.

ANOVA

Total marginal gap

		Sum of Squares	df	Mean Square	F	Sig.
Cercon	Between Groups	35428.388	2	17714.194	14.818	.000*
	Within Groups	168555.774	141	1195.431		
	Total	203984.162	143			
IPS e.max	Between Groups	70744.090	2	35372.045	37.359	.000*
	Within Groups	133499.730	141	946.807		
	Total	204243.820	143			
Lava^{TM}	Between Groups	81709.856	2	40854.928	42.650	.000*
	Within Groups	135064.368	141	957.903		
	Total	216774.224	143			

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Total marginal gap : Tamhane tests

Ceramic system	Degree of finish line curvature		Sig. at 95% Confidence Interval
Cercon	1mm	3mm	.000*
	1mm	5mm	.000*
	3mm	5mm	.156
IPS e.max	1mm	3mm	.000*
	1mm	5mm	.000*
	3mm	5mm	.004*
Lava^{TM}	1mm	3mm	.000*
	1mm	5mm	.000*
	3mm	5mm	.001*

*. The mean difference is significant at the 0.05 level.

One-way ANOVA results for each abutment finishing line curvature to identify the significance of ceramic system. Dependent Variable: Total marginal gap

Test of Homogeneity of Variances

Degree of finish line curvature	Levene Statistic	df1	df2	Sig.
1 mm	.623	2	141	.538
3 mm	.279	2	141	.757
5 mm	.863	2	141	.424

ANOVA

Total marginal gap

		Sum of Squares	df	Mean Square	F	Sig.
1 mm	Between Groups Within Groups Total	24234.467 30253.641 54488.108	2 141 143	12117.233 214.565	56.474	.000*
3 mm	Between Groups Within Groups Total	36670.426 126796.774 163467.200	2 141 143	18335.213 899.268	20.389	.000*
5 mm	Between Groups Within Groups Total	64796.663 280069.457 344866.120	2 141 143	32398.332 1986.308	16.311	.000*

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Total marginal gap : Bonferroni

Degree of finish line curvature	Ceramic system		Sig. at 95% Confidence Interval
1mm	Cercon	IPS e.max	.000*
	Cercon	Lava™	.000*
	IPS e.max	Lava™	.000*
3mm	Cercon	IPS e.max	.002*
	Cercon	Lava™	.000*
	IPS e.max	Lava™	.015*
5mm	Cercon	IPS e.max	.004*
	Cercon	Lava™	.000*
	IPS e.max	Lava™	.052

*. The mean difference is significant at the 0.05 level.

Appendix F. Two-way ANOVA results of significant effects between finishing line curvature and site of measurement of difference all ceramic systems.

For Cercon system

Tests of Between-Subjects Effects

Dependent Variable : Marginal gap of Cercon

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	123455.662[a]	11	11223.242	18.397	.000*
Intercept	490331.389	1	490331.389	803.737	.000*
Curvature	35428.388	2	17714.194	29.037	.000*
Site	59043.079	3	19681.026	32.261	.000*
Curvature * Site	28984.195	6	4830.699	7.918	.000*
Error	80528.499	132	610.064		
Total	694315.551	144			
Corrected Total	203984.162	143			

a. R Squared = .605 (Adjusted R Squared = .572)

b. * .The mean difference is significant at the 0.05 level

Test of Homogeneity of Variances

Degree of finish line curvature	Levene Statistic	df1	df2	Sig.
1 mm	2.481	3	44	.073
3 mm	2.268	3	44	.094
5 mm	6.342	3	44	.001*

*. The mean difference is significant at the 0.05 level.

ANOVA
Marginal gap of Cercon

		Sum of Squares	df	Mean Square	F	Sig.
1 mm	Between Groups Within Groups Total	2747.196 5641.621 8388.817	3 44 47	915.732 128.219	7.142	.001*
3 mm	Between Groups Within Groups Total	24544.762 25066.989 49611.751	3 44 47	8181.587 569.704	14.361	.000*
5 mm	Between Groups Within Groups Total	60735.316 49819.889 110555.205	3 44 47	20245.105 1132.270	17.880	.000*

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Marginal gap of Cercon : Bonferroni

Degree of finish line curvature	Ceramic system		Sig. at 95% Confidence Interval
1mm	Labial	Lingual	.020*
	Labial	Mesial	1.000
	Labial	Distal	1.000
	Lingual	Mesial	.000*
	Lingual	Distal	.014*
	Mesial	Distal	1.000
3mm	Labial	Lingual	1.000
	Labial	Mesial	.001*
	Labial	Distal	.002*
	Lingual	Mesial	.000*
	Lingual	Distal	.000*
	Mesial	Distal	1.000
5mm	Labial	Lingual	.295
	Labial	Mesial	.001*
	Labial	Distal	.001*
	Lingual	Mesial	.005*
	Lingual	Distal	.003*
	Mesial	Distal	.999

*. The mean difference is significant at the 0.05 level.

For IPS e.max system

Tests of Between-Subjects Effects

Dependent Variable: Marginal gap of IPS e.max

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	88178.280[a]	11	8016.207	9.117	.000*
Intercept	925086.491	1	925086.491	1052.090	.000*
Curvature	70744.090	2	35372.045	40.228	.000*
Site	6363.541	3	2121.180	2.412	.070
Curvature * Site	11070.648	6	1845.108	2.098	.058
Error	116065.540	132	879.284		
Total	1129330.312	144			
Corrected Total	204243.820	143			

a. R Squared = .432 (Adjusted R Squared = .384)

b. * .The mean difference is significant at the 0.05 level

Test of Homogeneity of Variances

Degree of finish line curvature	Levene Statistic	df1	df2	Sig.
1 mm	2.364	3	44	.084
3 mm	3.079	3	44	.037*
5 mm	3.269	3	44	.030*

*. The mean difference is significant at the 0.05 level.

ANOVA
Marginal gap of IPS e.max

		Sum of Squares	df	Mean Square	F	Sig.
1 mm	Between Groups	486.362	3	162.121	.720	.545
	Within Groups	9904.746	44	225.108		
	Total	10391.108	47			
3 mm	Between Groups	2160.343	3	720.114	.843	.478
	Within Groups	37579.543	44	854.081		
	Total	39739.885	47			
5 mm	Between Groups	14787.485	3	4929.162	3.162	.034*
	Within Groups	68581.252	44	1558.665		
	Total	83368.737	47			

*. The mean difference is significant at the 0.05 level.

There were no significant differences in the marginal gaps of the 1 mm and 3 mm finish line curvature groups. Therefore, Tamhane tests were only performed for 5 mm finish line curvatures group.

Multiple Comparisons

Marginal gap of IPS e.max : Tamhane

Degree of finish line curvature	Ceramic system		Sig. at 95% Confidence Interval
5 mm	Labial	Lingual	.816
	Labial	Mesial	.517
	Labial	Distal	.083
	Lingual	Mesial	.993
	Lingual	Distal	.259
	Mesial	Distal	.702

For Lava™ system

Tests of Between-Subjects Effects

Dependent Variable : Marginal gap of Lava™

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	128893.472[a]	11	11717.588	17.600	.000*
Intercept	1416369.746	1	1416369.746	2127.437	.000*
Curvature	81709.856	2	40854.928	61.366	.000*
Site	28616.820	3	9538.940	14.328	.000*
Curvature * Site	18566.797	6	3094.466	4.648	.000*
Error	87880.752	132	665.763		
Total	1633143.970	144			
Corrected Total	216774.224	143			

a. R Squared = .595 (Adjusted R Squared = .561)

b. * .The mean difference is significant at the 0.05 level

Test of Homogeneity of Variances

Degree of finish line curvature	Levene Statistic	df1	df2	Sig.
1 mm	1.498	3	44	.228
3 mm	4.149	3	44	.011*
5 mm	.919	3	44	.439

*. The mean difference is significant at the 0.05 level.

ANOVA

Marginal gap of Lava™

		Sum of Squares	df	Mean Square	F	Sig.
1 mm	Between Groups Within Groups Total	2729.755 8743.961 11473.716	3 44 47	909.918 198.726	4.579	.007*
3 mm	Between Groups Within Groups Total	15408.852 22036.286 37445.137	3 44 47	5136.284 500.825	10.256	.000*
5 mm	Between Groups Within Groups Total	29045.010 57100.505 86145.515	3 44 47	9681.670 1297.739	7.460	.000*

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Marginal gap of Lava™

Degree of finish line curvature	Ceramic system		Sig. at 95% Confidence Interval
1mm (Bonferroni)	Labial	Lingual	1.000
	Labial	Mesial	.034*
	Labial	Distal	.038*
	Lingual	Mesial	.156
	Lingual	Distal	.173
	Mesial	Distal	1.000
3mm (Tamhane)	Labial	Lingual	.000*
	Labial	Mesial	.988
	Labial	Distal	1.000
	Lingual	Mesial	.000*
	Lingual	Distal	.015*
	Mesial	Distal	1.000
5mm (Bonferroni)	Labial	Lingual	.882
	Labial	Mesial	.007*
	Labial	Distal	.001*
	Lingual	Mesial	.302
	Lingual	Distal	.048*
	Mesial	Distal	1.000

*. The mean difference is significant at the 0.05 level.

BIOGRAPHY

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