Determination of Accuracy of CAD/CAM All-ceramic Restorations Fabricated from Different Digitizing and Finishing Methods

การหาความเที่ยงตรงในงานบูรณะฟันเซรามิกล้วนแคดแคมจากวิธีการได้มาซึ่งภาพและวิธีการตบแต่งชิ้นงานขั้นสุดท้ายที่แตกต่างกัน

Nattakorn Yingyongyos (ณัฐกร ยิ่งยงยศ)* Dr.Niwut Juntavee (ดร.นิวัตร จันทร์เทวี)**
Dr.Supaporn Chatrchaiwiwatana (ดร.สุภาภรณ์ ฉัตรชัยวิวัฒนา)***

ABSTRACT

The objective of this study was to evaluate the accuracy in terms of marginal and internal fit of CAD/CAM all-ceramic crowns fabricated with CEREC® 3 system from different digitizing (direct and indirect technique) and finishing methods (polishing and glazing). Forty-eight crowns were established by combining two different digitizing methods with two different finishing methods. Twelve crowns from each of 4 groups were evaluated. The fit of crowns was made by replicas technique. The results shown that the digitizing and finishing methods were not have any significant effect on the marginal gap. The internal gap of the crown was affected by the different digitizing methods, the internal gap of indirect technique is greater than direct technique. From this study, the marginal and internal gap of the crown were in the range of clinical acceptability.

บทคัดย่อ

วัตถุประสงค์ของการศึกษานี้เพื่อประเมินความเที่ยงตรงในแง่ของความแนบสนิทบริเวณขอบและความแนบสนิทภายในของงานบูรณะฟันเซรามิกล้วนแคดแคมที่สร้างด้วยระบบซีเรค 3 จากการได้มาซึ่งภาพ (วิธีตรงและวิธีอ้อม) และการตบแต่งชิ้นงานขั้นสุดท้าย (การขัดและการเคลือบมัน) ที่แตกต่างกัน โดยใช้ครอบฟัน 48 ชิ้น แบ่งเป็น 4 กลุ่ม กลุ่มละ 12 ชิ้น ตามปัจจัยร่วมสองอย่างข้างต้น ความแนบสนิทได้มาด้วยวิธีเรพลิกา จากการศึกษาพบว่าการได้มาซึ่งภาพและการตบแต่งชิ้นงานขั้นสุดท้ายส่งผลอย่างไม่มีนัยสำคัญต่อความแนบสนิทบริเวณขอบ ในขณะที่วิธีการได้มาซึ่งภาพที่แตกต่างกันส่งผลอย่างมีนัยสำคัญต่อความแนบสนิทภายใน โดยการได้มาซึ่งภาพแบบวิธีอ้อมจะมีค่าของความแนบสนิทภายในมากกว่าวิธีตรง และจากการศึกษานี้ค่าความแนบสนิทบริเวณขอบและความแนบสนิทภายในของครอบฟันมีค่าอยู่ในช่วงที่รับได้ในทางคลินิก

Key Words: Accuracy, CAD/CAM all-ceramic restorations, Digitizing and finishing methods
คำสำคัญ: ความเที่ยงตรง งานบูรณะฟันเซรามิกล้วนแคดแคม การได้มาซึ่งภาพและวิธีการตกแต่งชิ้นงานขั้นสุดท้าย

** Student, Master of Science in Prosthodontics Department, Faculty of Dentistry, Khon Kaen University*

*** Associate Professor, Department of Prosthodontiscs, Faculty of Dentistry, Khon Kaen University*

**** Associate Professor, Department of Oral Biology, Faculty of Dentistry, Khon Kaen University*

Introduction

Recently, all-ceramic restorations have become the materials of choice for esthetically pleasing indirect restorations. This is because they have excellent biocompatibility, mechanical properties and have no metal that block the light transmission, so natural tooth structure can be better resembled in terms of color and translucency (Nakamura et al., 2003).

The CAD/CAM technology was introduced to the dental community more than 20 years ago. Nowadays, there is a variety of CAD/CAM systems available for the fabrication of all types of indirect restorations. The CEREC® 3 system (Sirona Dental Systems GmbH, Bensheim, Germany) is one of the CAD/CAM systems currently in use. Using this system, inlays, onlays, veneers, and crowns can be fabricated at the chair-side during a single-visit procedure. Therefore, procedures can be performed without intermediate appointments, thus decreasing cost, time and the chance of contamination during the provisional phase (Seo et al., 2009).

In some situations, the dentists cannot scan the prepared teeth directly in the patient's mouth because of their unsuitable angle of the teeth or some dental clinics are not equipped the CEREC® 3 system. Still, dentists can make the restorations by this system too. They need to take impression for making stone model and send them to the lab, where the optical impression is done on the stone models and the restoration can be computerized designed and fabricated. In CEREC® 3 system, "direct technique" is the method that the restorations were made by scanning the prepared teeth directly in the patient's mouth. On the other hand, "indirect technique" is the method that the restorations were made by scanning the stone models. There are a lots of systems for indirect technique such as CEREC® inLab and CEREC® *Scan.* CEREC® *Scan* consists of a milling unit and a built-in laser that was specially designed for dentists who prefer the indirect technique.

Finished restoration provide three benefits of dental care: oral health, function, and esthetics. The ideal surface for ceramic restorations is a polished and glazed surface. The way to obtain a smooth, glossy surface on dental porcelain is by glazing in a porcelain oven or after minor adjustments of the surface, the porcelain can be polished using a series of coarse to fine abrasive rubber wheels (containing silicon carbide or aluminum oxide), followed by a fine-particle-size diamond paste with a brush or felt wheel.

Dentists have expressed a number of concerns about CEREC-generated restorations since their introduction, regarding the adaptation and marginal fit of the milled restoration (Fasbinder, 2006).

Although CAD/CAM all-ceramic restorations are widely used, there is a lack of information about how the fit is affected by digitizing and finishing procedures. The adequacy of the fit of all-ceramic restorations has been questioned.

Objectives of the study

The purpose of this study was to evaluate the accuracy in terms of marginal and internal fit of CAD/CAM all-ceramic crowns fabricated with CEREC® 3 system from different digitizing (direct and indirect technique) and finishing methods (polishing and glazing).

Methodology

This study was an analytical laboratory study. Forty-eight crowns were established by combining two different digitizing methods (direct and indirect technique) with two different finishing methods (polishing and glazing). Twelve crowns from each of 4 groups (Group DP: Direct technique + polishing, Group DG: Direct technique + glazing, Group IP: Indirect technique + polishing, and Group IG: Indirect technique + glazing) were evaluated. Measurement of specimens were performed on a metal die (Figure 1).

Figure 1 Metal die

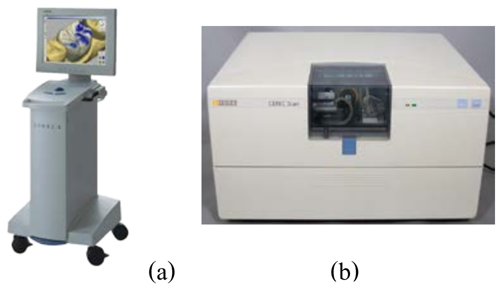
A mandibular right first molar plastic tooth (Frasaco GmbH, Tettnang, Germany) were use in this experiment. It was placed in a lower dental model (Standard working model A3 28, Frasaco GmbH, Tettnang, Germany). It was prepared for a single all-ceramic crown. The prepared tooth was sprued and invested with phosphate-bonded investment (CERAMVEST® HI-SPEED and EXPANSOR-B liquid, Protechno, Girona, Spain) according to manufacturers' instruction. The sprue was cut and the metal die were contoured and finished with aluminum oxide stones (Lab Series Pink, Shofu Inc, Kyoto, Japan) and then polished using rubber cups and points (Shofu Inc, Kyoto, Japan).

The master metal die was placed in the lower dental model and duplicated 24 times using a putty and light body silicone impression materials (elite® HD$^+$ Putty Normal Set and light body, Zhermack, New Jersey, USA) with perforated trays. Twenty-four stone dies were fabricated from the impression in type VI stone plaster (Kerr Classic Vel Mix, KerrLab, Kerr, Orange,Canada) mixed in accordance to the manufacturers' instructions in a vacuum (Vaccuum Power Mixwe Plus, Whipmix, Kentucky, USA).

Use a trimmer to trim all of the areas not requires for the scanning operation. The proper stone model shown in Figure 2.

Figure 2 Stone model

Forty-eight all-ceramic crowns were fabricated with CEREC® 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany) (Figure 3), CEREC® 3D software version 2.10 (Sirona Dental Systems GmbH, Bensheim, Germany) in accordance with two different techniques: direct and indirect technique.



(a) (b)

Figure 3 (a) CEREC®3, (b) CEREC® scan milling unit

After completion of all metal and stone dies, the surface were powdered with antireflection powder: titanium dioxide powder (CEREC® Optispray, Sirona Dental Systems GmbH, Bensheim, Germany) to facilitate the scanning process.

For direct technique group: Twenty-four all-ceramic crowns were fabricated by scanning the metal dies in the lower dental model. Optical impressions were taken from CEREC® 3 intraoral camera (Figure 4) and milled from CEREC® *scan* milling machine.

Figure 4 Optical impression

For indirect technique group: Twenty-four all-ceramic crowns were fabricated by scanning each stone models that were fixed on the model holder in the right position (Figure 5). Scanning and milling were taken from CEREC® *scan* milling machine.

Figure 5 Scanning the stone model

After scanning, the data was stored and designed using CEREC® 3D software version 3.85). After designing each crown the information was sent to the CEREC® *scan* milling unit, which utilized cylindrical diamond and tapered burs (CEREC® Cone-shaped Cylinder Diamond 1.6; D-3329, CEREC® Taper Diamond 1.2; D64625, Sirona Dental Systems GmbH, Bensheim, Germany).The crowns were fabricated from ceramic block (Vitablocs® Mark II, size 12 x 14 x 18 mm^3, shade 3M3C,Vita Zahnfabrik, Germany) (Figure 6). There were no corrections or adjustments for the fit of the crowns.

Figure 6 The milled crown before finishing

A total of 48 crown specimens were created, 24 crowns for each of the two conditions: direct and indirect technique. The crowns from each digitizing technique were randomly divided into 2 groups of 12, for which 12 polishing or 12 glazing.

Polishing procedures (Figure 7): the crowns were polished with ceramic polishing system (Optra®Fine, Ivoclar Vivadent, Schann, Liechtenstein) using conta-angle handpiece (Trend WD-56, W&H, Logne, Germany) as advice by the manufacturer. Polishing was performed by the same investigator.

Glazing procedure (Figure 8): the crowns were autoglazed in the porcelain furnace (Programmat® P100 Furnace, Ivoclar Vivadent, Schann, Liechtenstein) at temperature according to the manufacturer's instruction.

Figure 7 Polishing

Figure 8 Glazing

Finally, 48 crowns were divided into four groups of 12 by combining two different digitizing methods (direct and indirect technique) with two different finishing methods (polishing and glazing).

- Group DP: 12 crowns with direct technique and polishing
- Group DG: 12 crowns with direct technique and glazing
- Group IP: 12 crowns with indirect technique and polishing

- Group IG: 12 crowns with indirect technique and glazing

The metal die was embedded in plastic ring with pink self-cured acrylic resin. The plastic ring was fixed to the base of the the Universal Testing Machine (Lloyd®, LR30/k, Leicester, England). In this study, all restorations were seated on the metal dies by the Universal Testing Machine.

Replicas were made of the intermediate space between the inner surface of the restoration and die surface. To obtain the gap of the restoration. A light body silicone (elite® HD+ Light Body Fast Set, Zhermack, New Jersey, USA) was injected onto the internal surface of each of the crown specimens. The crown specimens was seated on the metal die, and a constant load of 50 N was applied on the occlusal surface parallel to the long axis of the tooth of the crown using the Universal Testing Machine at a crosshead speed of 10 mm/min for 10 minutes. After polymerization of the light body silicone, excess silicone was removed from around the crown using a blade. The crown was removed, leaving a thin film of light body silicone adhering to the crown. Representing the discrepancy between restoration and die. For the purpose of stabilization, a regular body silicone (elite® HD+ Regular Body Normal Set, Zhermack, New Jersey, USA) was applied, adhering with the light body film dressing the cavity. This procedure made it possible to removed and handle the intermediate replica of the light body silicone.

Each replica specimens (Figure 9) were segmented with the razor blades (Super Thin®, Gillette, Massachusetts, USA) through the center of the replica in buccolingually direction, addition cross-section were obtained bilaterally at 1 mm interval for a total of five buccolingually sections (Figure 10). The positions for sectioning were measure with ruler and marked with permanent pen. The marginal and internal gaps between crown and die were then measured.

According to Holmes et al., the perpendicular measurement from the internal surface to the restoration to the axial wall of the preparation is the internal gap, and the same measurement at the margin is the marginal gap (Holmes et al., 1989).

Seven landmark were defined (Figure 11) and marked with permanent pen.

P1 and P7 is represents the marginal gap and P2,P3,P4,P5,P6 are represent the internal gaps (P1 and P7: marginal gap, P2 and P6: mid-axial internal gap, P3 and P5: axio-occlusal internal gap, P4: occlusal internal gap)

Figure 9 The replicas

Figure 10 The replicas after section

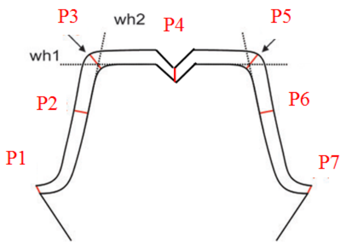


Figure 11 Sites of marginal and internal gap evaluation

Measurements were performed using a polarizing microscope (Nikon Polarizing Microscope ECLIPSE LV100POL, Nikon) at a magnification of ×50 by a single operator. The polarizing microscope was connected to a digital camera and the program NIS-Elements AR 3.1 was used for measurement. Measurements of the film thickness were performed at seven locations for each section, totaling 35 measurement for each replicas. Cross-section of a replica shown in Figure 12

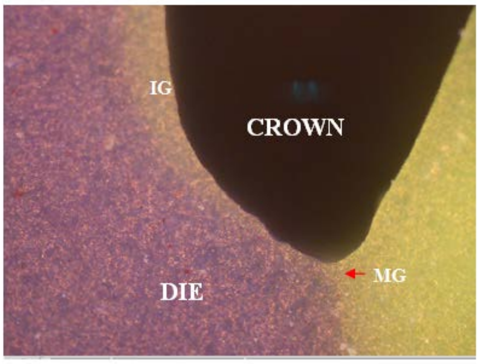


Figure 12 Cross-section of a replicas

Statistic analysis of the marginal and internal gap was carried out using SPSS 11.5 (SPSS Inc., Illinois, Chicago, USA)

The mean of each marginal and internal gap of each group were compared using a two-way ANOVA to verify whether significant difference existed from the effect of digitizing and finishing methods for making all-ceramic crown with CEREC® 3. The confidence level of 0.95 (alpha = 0.05) was used to interpret the data.

Results

1. The effects of the digitizing and finishing methods on the marginal gap

The mean values and standard deviations of the marginal gap were shown in Table 1 and the bar graphs of them are shown in Figure 13. The highest mean and standard deviation of the marginal gap was obtained with group IG (73.73±4.54 μm), following by group IP (73.15±6.67 μm), group DG (67.06±8.45 μm) and group DP (61.33±4.54 μm).

Table 1 Summary of the mean and standard deviation of the marginal gap (in μm)

Group		Mean	SD	N
Digitizing	Finishing			
Direct	Polishing	61.33	4.54	120
Direct	Glazing	67.06	8.45	120
Indirect	Polishing	73.15	6.67	120
Indirect	Glazing	73.73	9.67	120

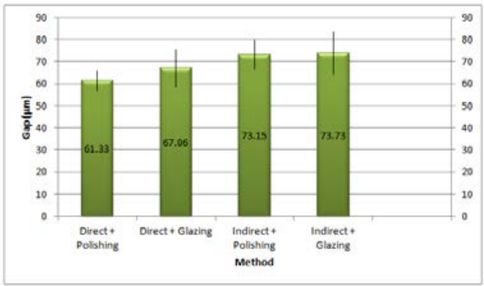


Figure 13 Bar graph of the mean and standard deviations of the marginal gap (in μm)

Two-way ANOVA revealed that there were no significant difference in ditizing methods, finishing methods and between the interaction of digitizing and finishing methods at p-value < 0.05 (Table 2)

Tale 2 The Two-way ANOVA of the marginal gap

Dependent Variable: GAP

Source	df	Mean Square	F	sig
Corrected model	3	4078.458	.801	.494
Intercept	1	2273255.360	446.685	.000
Digitize	1	10251.134	2.014	.156
Finish	1	1193.064	.234	.628
Digitize * Finish	1	791.175	.155	.694
Error	476	5089.165		
Total	480			
Corrected Total	479			

2. The effects of the digitizing and finishing methods on the internal gap

The mean values and standard deviations of the internal gap (landmark P2+P3+P4) were shown in Table 3 and the bar graphs of them are shown in Figure 14. The highest mean and standard deviation of the internal gap was obtained with group IP (153.20±16.32 µm), following by group IG (148.38±24.11 µm), group DG (140.92±21.34 µm) and group DP (139.65±18.43 µm).

Table 3 Summary of the mean and standard deviation of the internal gap (in µm)

Group		Mean	SD	N
Digitizing	Finishing			
Direct	Polishing	139.65	18.43	300
Direct	Glazing	140.92	21.34	300
Indirect	Polishing	153.20	16.32	300
Indirect	Glazing	148.38	24.11	300

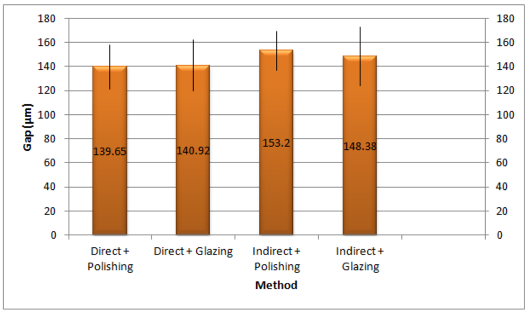


Figure 14 Bar graph of the mean and standard deviations of the internal gap (in µm)

The statistical evaluation using the two-way ANOVA analysis to verify whether significant difference existed from the effect of digitizing and finishing methods for making all-ceramic crown with CEREC® 3 at p-value < 0.05 was shown in Table 4. Two-way ANOVA revealed that there was significant difference in digitizing methods at p-value < 0.05, but there were no significant difference in finishing methods and interaction of digitizing and finishing methods at p-value > 0.05.

Tale 4 The Two-way ANOVA otf the marginal gap

Dependent Variable: GAF

Source	df	Mean Square	F	sig
Corrected model	3	12272.271	1.483	.217
Intercept	1	25417399.60	3071.695	.000
Digitize	1	33094.848	4.000	.046
Finish	1	946.413	.114	.735
Digitize * Finish	1	2775.551	.335	.563
Error	1196	8274.715		
Total	1200			
Corrected Total	1199			

Discussion and Conclusions

This study assessed the marginal and internal fit of single crowns made on metal die of prepared mandibular right first molar acrylic tooth model. Several investigators have used metal die to measure the fit (Baig et al., 2010). With a metal die, the advantages are namely standardize preparation and lack of wear during the manufacturing process and measurement (Lee et al., 2008). The dies had a occlusal surface with the entire circumferential margin, which simulate clinical tooth preparation.

The results shown that the digitizing and finishing methods were not have any significant effect on the marginal gap (Table 2). In the internal gap, there was a significant difference due to digitizing methods at p-value < 0.05, but there were no significant difference due to finishing methods and interaction of digitizing and finishing methods at p-value > 0.05.

Crowns are fabricated using indirect technique, and therefore changed in size of the impression or the model materials may affect the crown's fit. With the

CEREC® 3 CAD/CAM system used in this study, the crown is designed on a computer, using data from 3-D image abutment taken by a CCD camera. This is why, unlike with the indirect technique, the CEREC® 3 system does not required taking conventional impressions or making plaster model; therefore, there is no reason for changes in size because of instability of the impression or model-making materials.

The gap is less accurate in the internal regions than at the marginal area in all group confirms findings of earlier studies (Reich et al., 2005).

Since CAD/CAM techniques involve scanning, software and machining procedures, each single step could contribute to the overall fit of the crown (Bornemann et al., 2002). Bornemann et al. used three-dimensional procedures for analysis of internal fit of restorations. Because of the finite scanning resolution of the measuring system, edges may appear slightly rounded. This can lead to wide gap at the incisal/occlusal edges. The "rounded edge" phenomena have been described for the CEREC® intraoral camera (Pfeiffer, 1999).

The point clouds obtained in scanning are transformed into a smooth, continuous surface by the software. This can also lead to some internal inaccuracy (Luthardt et al., 2002).

The grinding process and the preparation design may also affect the internal adaptation. The narrowest possible diameter of the preparation is determined by the smallest diameter of the bur used for machining the internal surface. Thus, in structures smaller than the narrowest bur diameter, more internal substance may be removed than necessary. This may also result in larger internal gaps than mandatory for a good fit (Tinschert et al., 2004).

For a good longterm prognosis, the clinically acceptable marginal gap limit is considered to be in the range of 120–200 µm (Shokry, 2010). From this study, the marginal and internal gap of the crowns fabricated with CEREC® 3 system were in the range of clinical acceptability.

There were some limitation of this study, marginal and internal fit made on metal die. The discrepancies may have been different from the values found in this study if a natural molar tooth was used instead, because of different morphology and shape. In addition, the results may have differed if the fixed partial dentures had been examined rather than single crown.

This study used only one ceramic block (Vitablocs® Mark II,Vita, Zahnfabrik, Germany) and one CAD/CAM system (CEREC® 3 systerm, Sirona, Bensheim, Germany) to fabricate all restorations, if another material is used, this research may or may not confirm the results.

Within the limitation of this study, the following conclusions were drawn:

1. The marginal gap of the crown was not affected by the different digitizing and finishing methods.
2. The internal gap of the crown was affected by the different digitizing methods, the internal gap of indirect technique is greater than direct technique.
3. The marginal and internal gap of the crown were not affected by the different finishing methods.
4. The gap is less accurate in the internal regions than at the marginal area in CEREC®3 CAD/CAM system.
5. Marginal and internal gap of the crown fabricated with CEREC® 3 system were in the range of clinical acceptability.

Acknowledgements

I would like express my heartfelt to my advisor, Associate Professor Dr. Niwut Juntavee, for his guidance and support. His encouragement, kindness, remarkable patience, considerateness, and caring as a patient made me succeed walking through this thesis. Everything from him will always be appreciated.

I would like to express my sincere appreciation to co-advisor, Associate Professor Dr. Supaporn Chatrchaiwiwatana for her enormous help with data analysis and precious comments throughout this thesis.

I am very grateful to thanks all staff and the postgraduate students of Prosthodontics department at Khon Kaen University for kind helps during my education.

My thanks go to my parents for their love, support, encouragement, considerateness, and patience throughout my life, I feel very lucky and proud for having parents like them.

References

Baig, MR., Tan, KB., and Nicholis Ji. 2010. Evaluation of the marginal fit of zirconia ceramic computer-aided machine (CAM) crown system. J Prosthet Dent. 104(4): 216-227.

Bornemann, G., Lemelson, S., and Luthardt, R. 2002. Innovative method for the analysis of the internal 3D fitting accuracy of Cerec-3 crowns. Int J Conput Dent. 5(2-3): 177-182.

Fasbinder, DJ. 2006. Clinical performance of chairside CAD/CAM restorations. J Am Dent Assoc. 137 suppl: 22s-31s.

Holmes, JR., Bayne , SC., Holland, GA., and Sulik, WD. 1989. Considerations in measurement of marginal fit. J Prosth Dent. 62(4): 405-408.

Lee, KB., Park, CW., Kim, KH., and Kwon, TY. 2008. Marginal and internal fit of all-ceramic crowns fabricated with two different CAD/CAM systems. Dent Mater J. 27(3): 422-426.

Luthardt, R., Weber, A., Rudolph, H., Schone, C., and Quaas, S. 2002. Design and production of dental prosthetic restorations: basis research on dental CAD/CAM technology. 5(2-3): 165-176.

Nakamura, T., Dei, N., Wakabayashi, K., and Kojima, T. 2003. Marginal and internal fit of cerec 3 CAD/CAM all-ceramic crowns. Int J Prosthdont. 16(3): 244-248.

Pfeiffer, J. 1999. Dental CAD/CAM technologies: the optical impression (II). Int J Comput Dent. 2(1): 65-72.

Reich, S., Wichman, M., Nikenke, E., and Proeschel, P. 2005. Clinical fit of all-ceramic three unit fixed partial dentures, generated with three different CAD/CAM systems. Eur J Oral Sci. 113(2): 174-179.

Seo, D., Yi, Y., and Roh, B. 2009. The effect of preparation designs on the marginal and internal gaps in Cerec 3 partial ceramic crowns. J Dent. 37(5): 374-382.

Shokry, TE., Attia, M., Mosleh, I., Elhosary, M., Hamza, T., and Shen, C. 2010. Effect of metal selection and porcelain firing on the marginal accuracy of titanium-based metal ceramic restorations. J Prosthet Dent. 103(1): 45-52.

Tinschert, J., Natt, G., and Hassenpflug, S., and Spiekermann, H. 2004. Status of current CAD/CAM technology in dental medicine. Int J Comput Dent 7(1): 25-45.