©Operative Dentistry, 2014, **39-3,** 308-316

Accuracy of Ceramic Restorations Made Using an In-office Optical Scanning Technique: An *In Vitro* Study

P Tidehag • K Ottosson • G Sjögren

Clinical Relevance

The findings in the present study suggest that in-office digital impressions and subsequent computer-aided design/computer-aided manufacturing (CAD/CAM) fabrication of ceramic crowns could result in marginal and internal fit similar to that of hot-pressed all-ceramic crowns.

SUMMARY

The present in vitro study concerns determination of the pre-cementation gap width of all-ceramic crowns made using an in-office digital-impression technique and subsequent computer-aided design/computer-aided manufacturing (CAD/CAM) production. Two chairside video camera systems were used: the Lava Oral scanner and Cadent's iTero scanner. Digital scans were made of a first molar typodont tooth that was suitably prepared for an all-ceramic crown. The digital impressions were sent via the Internet to commercial dental laboratories, where the crowns were made. Also, an impression of the typodont tooth was made, poured, and scanned in order to evaluate the pre-cementation gap of crowns produced from scanning stone dies. These methods and systems were evaluated by creating replicas of the intermediate space using an addition-cured silicone, and the gap widths were determined using a measuring microscope. Hot-pressed leucite-reinforced glass-ceramic crowns were selected as a reference. The mean value for the marginal measuring points of the control was 170 µm, and the values for all the evaluated crowns ranged from 107 to 128 µm. Corresponding figures for the internal measuring points were 141-210 µm and 115-237 µm, respectively. Based on the findings in the present study, an in-office digital-impression technique can be used to fabricate CAD/CAM ceramic single crowns with a marginal and internal accuracy that is on the same level as that of a conventional hot-pressed glass-ceramic crown. In the pre-

*Per Tidehag, DDS, PhD, Faculty of Medicine, Umeå University, Umeå, Sweden.

Kristina Ottosson, DDS, Faculty of Medicine, Umeå University, Umeå, Sweden.

Göran Sjögren, DDS, professor, Faculty of Medicine, Umeå University, Umeå, Sweden.

*Corresponding author: Umeå, SE-901 87, Sweden; e-mail: Per.Tidehag@odont.umu.se

DOI: 10.2341/12-309-L

sent study, however, slight differences could be seen between the two types of ceramic crowns studied with respect to the internal fit obtained.

INTRODUCTION

The marginal and internal fit of dental restorations, such as inlays and crowns, is crucial for the clinical outcome of dental restorations. During the past few decades various impression and die materials have been used in dentistry,[1-3] and marginal and internal fit has been determined using a variety of measuring techniques: cementing on extracted teeth or replicas and subsequent slicing of the restorations and the teeth/replicas,[4-6] direct measurement with light microscope,[7,8] or replica technique with polyvinylsiloxane impression materials.[9-10]

Currently, most impression materials have to be sent by mail and/or courier to dental laboratories despite the possible risk of the impressions being disease carriers as disinfection of impression materials is problematic.[11,12] To avoid the use of impression materials, attempts to determine the shape of preparations for dental restorations using various mechanical and/or optical systems were presented in the 1970s,[13] but as far as we know, they were not routinely used in clinical practice. Later, around the middle of the 1980s, a system for electronically designing and milling ceramic restorations was introduced in dentistry.[14] This system used a three-dimensional (3D) miniature video camera to stereo-photogrammetrically scan the cavity preparation and make a 3D pattern of the tooth preparation, which could then be stored in a chairside microprocessor unit and, in combination with a numerically controlled miniature three-axis milling device, the restorations could be milled from prefabricated ceramic blocks.[14] Because it was a completely new way of producing dental restorations, the precision of the final restorations was questioned and was of particular interest. Thus, several studies addressing the internal and marginal fit of these restorations were presented; these stated, among other things, that the properties of the luting agents used, the shape of the preparation and the restoration, and the location of the measuring points could influence the outcome.[6,8-14] Recently, a number of improved versions of 3D miniature video cameras, in combination with improved microprocessors, have been introduced in dentistry. Examples of such systems are the Cerec AC (Sirona Dental Systems GmbH, Bensheim, Germany), E4D CADCAM system (Ivoclar AG, Schaan, Lichtenstein), Cadent's iTero (Cadent Inc, Carlstadt, NJ, USA), and Lava Chairside Oral Scanner C.O.S. (3M ESPE, St Paul, MN, USA).[15]

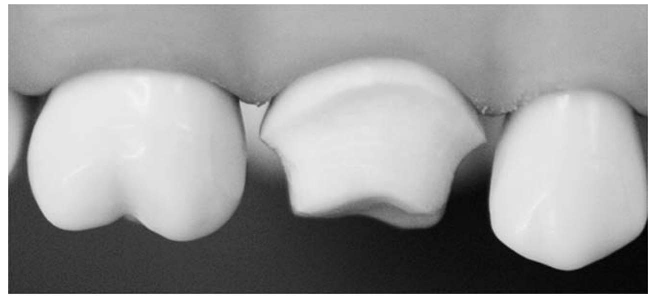

Figure 1. *Shape of the prepared maxillary right first phantom Frasaco molar with a ~1.5-mm chamfer preparation placed in a Frasaco phantom model.*

These systems are said to be improvements on the earlier types of equipment intended for digitalizing dental preparations[15] and should thus produce better internal and marginal fit for the restorations. The aim of the present work was, therefore, to determine the marginal and internal pre-cementation space in ceramic crowns made using two of the recently introduced systems and to compare the results with ceramic crowns made after taking impressions with an addition-cured silicone and using conventional die stone models, wax copings, and subsequent press casting.

METHODS AND MATERIALS

The internal and marginal fit was determined for two different types of all-ceramic crowns, which were made using two types of digital impression systems: the Lava Chairside Oral Scanner C.O.S. and Cadent's iTero systems.

A ~1.5-mm chamfer preparation was made for an all-ceramic crown on a maxillary right first phantom Frasaco molar (Frasaco GmbH, Tettnang, Germany) placed in a maxillary Frasaco model (Figure 1). The maxillary Frasaco model was placed in a Frasaco phantom head (Figure 2), and digital impressions, using the Lava or the Cadents iTero scanning systems, were made of the prepared phantom molar and the surrounding area and the opposing teeth, in accordance with the manufacturer's instructions. The digital impressions were then sent via the Internet to two different commercial dental laboratories experienced in fabricating the relevant types of crowns. One laboratory produced nine iTero all-ceramic crowns, and the other laboratory produced nine Lava all-ceramic crowns. In the following text

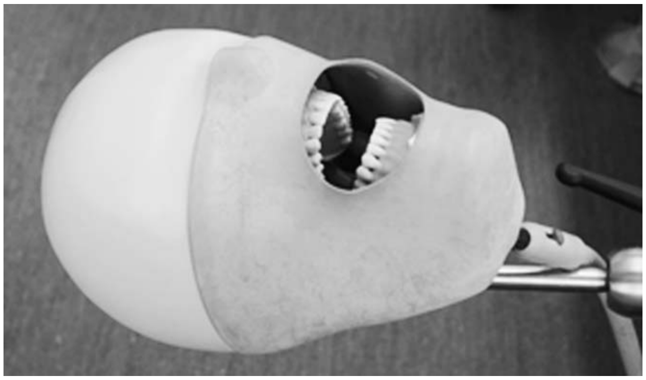

Figure 2. *A phantom Frasaco model placed in a Frasaco phantom head.*

those crowns are referred to as ”iTero Oral” and ”Lava Oral,” respectively.

In addition, to study the effect on the marginal and internal gap width of producing Lava and iTero crowns after scanning die stone models made from impressions of the prepared molar and the surrounding and opposing areas, addition-cured silicone impressions were made (Provil Novo Light body, batch number 310309, and Provil Novo Medium, batch number 320079, Heraeus Kulzer GmbH, Hanau, Germany). These silicone impressions were then sent to two different commercial dental laboratories experienced in the technique. Thereafter, one dental laboratory did the scans for the Lava crowns and another for the iTero crowns. The scanned files were used to produce nine Lava and nine iTero crowns, respectively. In the following text these crowns are designated “iTero Die Stone” and “Lava Die Stone”.

Hot-pressed leucite-reinforced glass-ceramic crowns (Empress, Ivoclar Vivadent AG, Schaan, Lichtenstein) were selected as the reference. After taking impressions of the prepared molar and the surrounding and opposing areas with an addition-cured silicone (Provil Novo Light body, batch number 310309, and Provil Novo Medium, batch number 320079), nine Empress crowns were made by one of the authors (KO) and a dental technician at the Department of Odontology, Umeå University, who was specially trained in the Empress technique using conventional die stone models (Vel-Mix Die Stone, Type IV, Kerr Dental Laboratory Products, Orange, CA, USA), wax copings, and subsequent press casting.

After all the crowns were produced, replicas of the intermediate space between the inner surface of the crowns and the prepared Frasaco tooth surface were

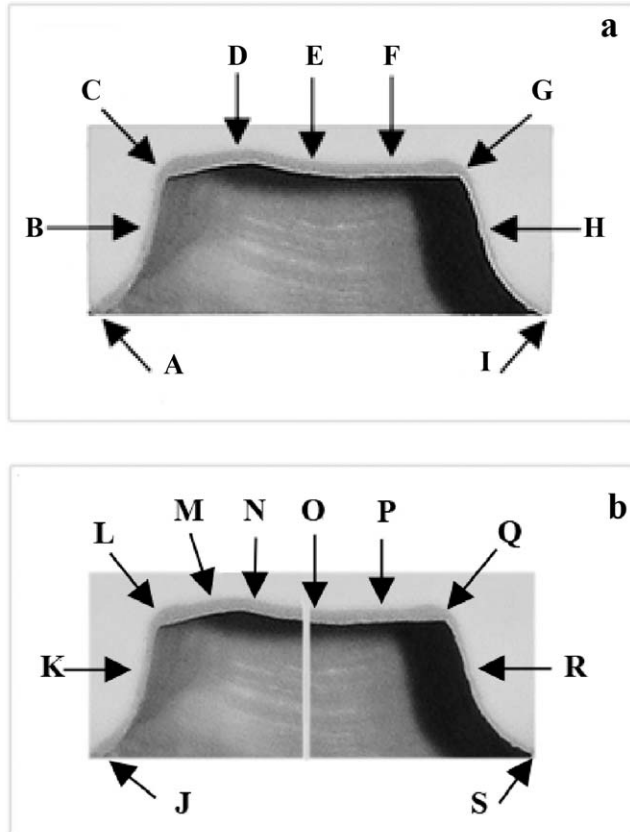

Figure 3. *Example of an addition silicone replica of the marginal width. The letters indicate the selected measuring points. Darker shade = light body; lighter shade = medium body. (a): Denotes the letters of the measuring points in the mesiodistal direction; (b): Denotes the letters of the measuring points in the buccolingual direction.*

taken with an addition-cured silicone (Provil Novo, Heraeus Kulzer GmbH). The crowns were filled with the addition-cured silicone light-body impression material (Provil Novo Light, batch number 310309, color green), placed on the prepared Frasaco tooth, and held in position using finger pressure for 4 minutes at room temperature. After the light-body impression material had polymerized, the crowns were removed and the thin film of the impression material that dressed the outside of the prepared Frasaco tooth or the inside of the crown was covered by a medium-body impression material (Provil Novo Medium, batch number 320079) that differed in color (yellow) from the light-body material. After polymerization, the light-body and the medium-body impression materials were removed en bloc. Three persons made the replicas: one person made 20 of the Lava Oral replicas, another person made 23, and a third person made two. Because the medium-body impression material joined the light-body replicas in one piece, they could be cut with a scalpel in two directions: one corresponding to the mesiodistal (Figure 3A) and one to the buccolingual (Figure 3B). That is, the replicas were divided into four pieces, and because the light-body and the medium-body impression materials were different colors (green and yellow, respectively), the discrepancy between the master model and the frameworks representing the cement space could be distinguished (Figure 3a,b). The gap width was then measured using a Leitz UWM-DigS measuring microscope (Esselte Leitz GmbH & Co KG, Stuttgart, Germany) at 19 preselected locations (Figure 3a,b) on each half of the sectioned replicas at 20× magnification, giving a total of 38 measuring points for each crown. The gap width was measured as the thickness of the light-body impression material at the measuring points in Figure 3a,b. The same person carried out all the measurements without knowing the identity of the specimens.

Statistical Analysis

The values were statistically analyzed using an independent *t*-test at a significance level of $p<0.05$ after Bonferroni correction $p<0.01$. The data were analyzed using SPSS statistical software, version 20 (Statistical Package for Social Science, SPSS Inc, Chicago, IL, USA).

RESULTS

The results and statistical analyses are summarized in Tables 1 and 2. Statistical analysis (section A of Table 2) of all the measuring points, that is, measuring points A-S in Figure 3, revealed that the gap width was significantly wider ($p<0.001$) for the Empress crowns (control) than for the Lava Oral crowns, whereas there were no significant differences between Empress and Lava Die Stone, iTero Oral, and iTero Die Stone. The Lava Oral crowns showed a significantly ($p<0.01$) smaller gap width than the other groups.

Comparison of the marginal measuring points, that is, measuring points A, I, J, and S in Figure 3, showed that the marginal gap width was significantly ($p<0.01$) wider for Empress than for all the other groups (section B in Table 2).

For the proximal measuring points, that is, measuring points B, H, K, and R in Figure 3, there were no significant differences between the Empress and the other groups tested, whereas the gap width for the iTero Die Stone was significantly ($p<0.001$) wider than for the iTero Oral. For the Lava Die Stone, the proximal gap width was significantly wider ($p<0.001$) than for the iTero Oral crowns (section E in Table 2).

At the proximal-occlusal measuring points, that is, measuring points C, G, L, and Q in Figure 3, there were no significant differences between Empress and the other groups tested. The gap width for the iTero Oral crowns was significantly wider than for Lava Oral ($p<0.01$). No statistically significant differences were seen among the other groups of crowns studied for the proximal-occlusal measuring points (section D of Table 2).

The occlusal gap width, that is, measuring points D, E, F, M, N, O, and P in Figure 3, was significantly wider for the iTero Oral crowns than for the Empress, Lava Oral, and iTero Die Stone crowns ($p<0.001$). The Lava Die Stone crowns exhibited a significantly ($p<0.001$) wider occlusal gap width than the Empress, Lava Oral, and iTero Die Stone crowns (section E of Table 2).

DISCUSSION

The purpose of the present study was to evaluate the accuracy of ceramic crowns produced by means of in-office scanning of the preparation and subsequent computer-aided design/computer-aided manufacturing (CAD/CAM) production technologies. Today, dental CAD/CAM technology has expanded well beyond the initial version of the Cerec system introduced in the middle of the 1980s, and a number of CAD/CAM restorative technologies are currently on the market.[15] To evaluate the ability of the recently introduced in-office scanning and CAD/CAM restorative technologies to produce all-ceramic crowns with acceptable marginal and internal fit, two such systems, 3M ESPE Lava COS and Cadents iTero, were used. To copy the clinical situation as closely as possible, a digital impression of the scanned preparation was sent via the Internet to commercial dental laboratories trained in the technique of manufacturing this type of ceramic crown. In addition, the present study evaluated the marginal and internal fit of crowns made after the preparation was scanned from die stone models constructed from polyvinyl-siloxane impressions of the prepared phantom Frasaco model. Hot-pressed leucite-reinforced glass-ceramic crowns (IPS Empress) were used as a control. The IPS Empress crowns were selected for this purpose because this type of all-ceramic crown has been in clinical use for a long time.[16,17]

In the present work, replicas of the space between the inner surface of the crowns and the prepared

Table 1: *Summary of the Gap Widths at the Various Measuring Points*

	Empress	Lava Oral	Lava Die Stone	iTero Oral	iTero Die Stone
A. All measuring points (μm) (n=342 measuring points for each group)					
Mean±SD	183±90	162±65	177±60	181±72	174±60
Minimum	0	0	38	59	49
Maximum	597	331	327	346	420
Median	177	154	184	181	175
95% CI					
Lower	174	155	174	173	168
Upper	193	169	181	184	181
B. Marginal measuring points (μm) (n=72 measuring points for each group)					
Mean±SD	170±94	107±47	113±48	128±59	115±37
Minimum	0	32	38	59	49
Maximum	398	223	267	288	215
Median	145	97	47	59	37
95% CI					
Lower	148	96	102	114	106
Upper	192	118	124	141	123
C. Proximal measuring points (μm) (n=72 measuring points for each group)					
Mean±SD	141±75	130±55	149±44	115±40	160±52
Minimum	0	0	81	60	76
Maximum	367	265	286	243	334
Median	121	128	139	111	157
95% CI					
Lower	124	118	139	106	148
Upper	159	143	159	125	172
D. Proximal-occlusal measuring points (μm) (n=72 measuring points for each group)					
Mean±SD	210±116	176±54	189±48	201±46	195±57
Minimum	60	53	88	123	78
Maximum	597	293	327	310	393
Median	188	163	188	191	182
95% CI					
Lower	183	164	178	190	182
Upper	237	189	200	212	209
E. Occlusal measuring points (μm) (n=126 measuring points for each group)					
Mean±SD	200±65	203±54	224±32	237±50	204±47
Minimum	75	109	148	149	122
Maximum	359	331	294	346	420
Median	205	204	223	224	190
95% CI					
Lower	189	193	218	228	196
Upper	212	212	229	246	213

Abbreviations: SD, standard deviation; CI, confidence interval.

tooth were made, using a polyvinyl siloxane addition-cured silicone, to determine the gap widths. This technique was selected as it has been determined that using light-body addition-cured polyvinyl-siloxane impression materials for the replica technique is a reliable and commonly accepted method for evaluating clinical accuracy.[18-24] In addition, it has been shown that the gap-width values obtained using this technique are similar to those obtained after luting with glass-ionomer cement.[19] Other techniques for determining gap widths of dental restorations are using a light

Table 2: *Summary of the Statistical Analysis*[a]

	Empress	Lava Oral	Lava Die Stone	iTero Oral	iTero Die Stone
A. Statistical analysis of all measuring points (n=342)					
Empress	–				
Lava Oral	***	–			
Lava Die Stone	NS	***	–		
iTero Oral	NS	***	NS	–	
iTero Die Stone	NS	**	NS	NS	–
B. Statistical analysis of the marginal measuring points (n=72)					
Empress	–				
Lava Oral	***	–			
Lava Die Stone	***	NS	–		
iTero Oral	**	NS	NS	–	
iTero Die Stone	***	NS	NS	NS	–
C. Statistical analysis of the proximal measuring points (n=72)					
Empress	–				
Lava Oral	NS	–			
Lava Die Stone	NS	NS	–		
iTero Oral	NS	NS	***	–	
iTero Die Stone	NS	NS	NS	***	–
D. Statistical analysis of the proximal-occlusal measuring points (n=72)					
Empress	–				
Lava Oral	NS	–			
Lava Die Stone	NS	NS	–		
iTero Oral	NS	**	NS	–	
iTero Die Stone	NS	NS	NS	NS	–
E. Statistical analysis of the occlusal measuring points (n=126)					
Empress	–				
Lava Oral	NS	–			
Lava Die Stone	***	***	–		
iTero Oral	***	***	NS	–	
iTero Die Stone	NS	NS	***	***	–

[a] *NS (not significant):* $p>0.01$; ** $p<0.01$; *** $p<0.001$
(independent t*-test and Bonferroni corrections).*

microscope directly after the restoration is placed on the prepared tooth or die stone[8] or luting the restorations on extracted teeth and then sectioning the crowns and teeth to determine the gap width.[8] When using light microscopy directly, only the marginal gap width can be determined,[8] and when using a number of prepared teeth and then sectioning the crowns/teeth, the gap width could be influenced by such factors as the design of the prepared teeth.[25-28] It should be noted, however, that with the replica technique used in the present study the crowns were filled with light-body impression material and held in place with finger pressure. This could have resulted in a variable force applied on the crowns, but the experimental setup imitates the way crowns are usually placed in patients.

In the present study all the crowns produced using scanning and CAD/CAM production, irrespective of type or whether they were made via die stone models or directly from the prepared tooth, exhibited marginal fit that was smaller than for the control. At the proximal and proximal-occlusal measuring points, no significant differences could be seen compared with the control, whereas occlusally the control exhibited a significantly smaller gap width than the iTero Oral and Lava Die Stone crowns. It should be noted that the controls were manually produced using the lost wax technique and die spacer, whereas Lava and iTero were digitally produced crowns. Because it is difficult to exactly reproduce the die spacer thickness and manually produce the crowns, this can be one of the reasons for the discrepancy in gap widths and the error distribution observed between the manually and digitally produced crowns (Table 1).

However, it is still not known what gap distance is clinically optimal or what effect the selection of the location of the measuring points has. McLean and Fraunhofer[29] conclude that 120 μm is the maximum tolerable marginal opening, but previous studies reported mean gap widths ranging from 9 to 215 μm in dental restorations and a gap width of 420 μm at the marginal measuring point and 850 μm at the occlusal measuring point.[30-34] In a previous study of heat-pressed Empress crowns cemented to dies with zinc phosphate cement the marginal gap widths reported range between 26 and 548 μm.[35] In a recently presented study using Lava COS and Cerec intraoral scanning systems (Sirona, Bensheim, Germany), the gap widths determined using silicone replicas ranged between 0 and 552 μm.[36] That is, in the previous studies[30-36] there was a huge spread in the gap widths, which supports the findings in the present study. Thus, the results obtained in the present study are within the ranges reported in previous studies, although the values reported for the Empress crowns were obtained for crowns luted to dies with zinc phosphate cement and sectioned before measuring the gap width.[35] It should be noted, however, that conditions in the studies varied and there is no standardized method for determining the accuracy of dental crowns, making comparison difficult. Most of the studies referred to earlier[30-36] include restorations produced by means of conventional impression techniques or scanning from die stone models, and in a survey of the literature, only one article was found that addressed the internal and marginal fit of ceramic crowns made using in-office scanning of the preparation and subsequent CAD/CAM production.[36] One interesting finding in the previous study of Lava crowns[36] was that the values were almost identical to those obtained in the present study, with the exception of those for the marginal fit. Possible explanations for the divergent gap width determined in the three studies could be that the there were slight differences in convergence angle and/or in the finishing margin design of the prepared teeth and/or differences in preparation depth.[25-28]

Regarding the internal fit, internal discrepancies may weaken the ceramic crowns, so the marginal and internal fits are among the important criteria for the long-term success of ceramic restorations. For example, because the space between the tooth and the restoration exposes the luting material to the oral environment, a wide gap discrepancy may cause cement solubility, plaque accumulation, marginal leakage, and crown failures. Inadequate marginal fit is also said to be the most significant factor in the development of caries.[37] Today the recommended method for many types of all-ceramic restorations, such as IPS Empress, is adhesive luting using resin composite, which may be less soluble in oral fluids than conventional zinc phosphate and glass-ionomer cements.[38,39] However, it should be emphasized that restorations made of oxide ceramics may be luted with conventional zinc oxide phosphate or glass-ionomer cements.[40-42] In this context it should be noted that glass-ionomer and zinc oxide phosphate cements exhibit higher solubility than resin composite.[38,39] In addition, the clinical experience of those types of cements is mainly based on metal or porcelain-fused-to-metal restorations, and mean values for the marginal fit of such crowns have been reported to range between 31 and 72 μm.[43-45] More long-term follow-up studies are, therefore, necessary to determine the optimal internal and marginal fit of all-ceramic dental restorations.

CONCLUSION

All the crowns in the present study made via scanning and subsequent CAD/CAM production showed marginal fit that was less than that of the control. At the proximal and proximal-occlusal measuring points, however, there were no significant differences between the studied crowns and the control. Occlusally, the gap width for iTero Oral and Lava Die Stone was wider than for the control. Thus, based on the findings of the present study, an in-office digital-impression technique can be used in vitro to fabricate CAD/CAM ceramic single crowns with a marginal and internal accuracy that is on the same level as that of a conventional hot-pressed glass-ceramic crown. In the present study, slight differences could be seen between the two types of ceramic crowns studied with respect to internal fit. However, it should be noted that the gaps determined in the present study are almost two times higher than those reported for cast metal or porcelain-fused-to-metal crowns and that the present study is an in vitro comparison study. More studies are, therefore, necessary to validate the ability of in-office digital-impressions in clinical situations.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 26 April 2013)

REFERENCES

1. Hansson O, & Eklund J (1984) A historical review of hydrocolloids and an investigation of the dimensional accuracy of the new alginates for crown and bridge impressions when using stock trays *Swedish Dental Journal* **8(2)** 81-95.
2. Chee WW, & Donovan TE (1992) Polyvinyl siloxane impression materials: a review of properties and techniques *Journal of Prosthetic Dentistry* **68(5)** 728-732.
3. Donovan TE, & Chee WW (2004) A review of contemporary impression materials and techniques *Dental Clinics of North America* **48(2)** 445-470.
4. Grenade C, Mainjot A, & Vanheusden A (2011) Fit of single tooth zirconia copings: comparison between various manufacturing processes *Journal of Prosthetic Dentistry* **105(4)** 249-255.
5. Belser UC, MacEntee MI, & Richter WA (1985) Fit of three porcelain-fused-to-metal marginal designs in vivo: a scanning electron microscope study *Journal of Prosthetic Dentistry* **53(1)** 24-29.
6. Sjögren G (1995) Marginal and internal fit of four different types of ceramic inlays after luting. An in vitro study *Acta Odontologica Scandinavia* **53(1)** 24-28.
7. Eden GT, Franklin OM, Powell JM, Ohta Y, & DicksonG (1979) Fit of porcelain fused-to-metal crown and bridge castings *Journal of Dental Research* **58(12)** 2360-2368.
8. Hickel R, & Kunzelmann KH (1990) The influence of cavity preparation on the width of marginal gaps in Cerec inlays *Deutsche Zahnarztliche Zeitung* **45(10)** 675-677.
9. Mörmann WH, & Krejci I (1992) Computer-designed inlays after 5 years in situ: clinical performance and scanning electron microscopic evaluation *Quintessence International* **23(2)** 109-115.
10. Molin M, & Karlsson S (1993) The fit of gold inlays and three ceramic inlay systems. A clinical and in vitro study *Acta Odontologica Scandinavia* **51(4)** 201-206.
11. Blair FM, & Wassell RW (1996) A survey of the methods of disinfection of dental impressions used in dental hospitals in the United Kingdom *British Dental Journal* **180(10)** 369-375.
12. Bergman B (1989) Desinfection of prosthodontic impression materials: a literature review *International Journal of Prosthodontics* **2(6)** 537-542.
13. Young JM, & Altschuler BR (1977) Laser holography in dentistry *Journal of Prosthetic Dentistry* **38(2)** 216-225.
14. Mörmann WH, Brandestini M, Lutz F, & Barbakow F (1989) Chairside computer-aided direct ceramic inlays *Operative Dentistry* **20(5)** 329-339.
15. Kachalia PR, & Geissberger MJ (2010) Dentistry a la carte: in-office CAD/CAM technology *Journal of the California Dental Association* **38(5)** 323-330.
16. Sjögren G, Lantto R, Granberg Å, Sundström B-O, & Tillberg A (1999) Clinical examination of leucite-reinforced glass ceramic crowns (Empress) in general practices. A retrospective study *International Journal of Prosthodontics* **12(2)** 122-128.
17. Höland W, Schweiger M, Frank M, & Rheinberger V (2000) A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramic *Journal of Biomedical Material Research* **53(4)** 297-303.
18. Kokubo Y, Tsumita M, Kano T, Sakurai S, & Fukushima S (2011) Clinical marginal and internal gaps of zirconia all-ceramic crowns *Journal of Prosthodontic Research* **55(1)** 40-43.
19. Rahme HY, Tehini GE, Adib SM, Ardo AS, & Rifai KT (2008) In vitro evaluation of the "replica technique" in the measurement of the fit of Procera crowns *Journal of Contemporary Dental Practice* **9(2)** 25-32.
20. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult von Steyern P, & Fukushima S (2005) Clinical marginal and internal gaps of Procera AllCeram crowns *Journal of Oral Rehabilitation* **32(7)** 526-530.
21. Kokubo Y. Nagayama Y. Tsumita M. Ohkubo C, Fukushima S, & Vult von Steyern P (2005) Clinical marginal and internal gaps of In-Ceram crowns fabricated using the GN-I system *Journal of Oral Rehabilitation* **32(10)** 753-758.
22. Tsumita M, Kokubo Y, Ohkubo C, Nagayama Y, Sakurai S, & Fukushima S (2007) Clinical evaluation of marginal and internal gaps of zirconia-based 3-unit CAD/CAM fixed partial dentures *Prosthodontic Society* **6(2)** 114-119.
23. Obana J, Miyata T, Kouta M, Kawasaki F, Aoyama S, & Yanagibashi M (1975) New application of injection type silicone impression material to prosthodontic field. Part II: fitness test for crowns and bridges *Tsurumi University Dental Journal* **1(1)** 63-68.
24. Kohorst P, Brinkmann H, Dittmer MP, Borchers L, & Stiesch M (2010) Influence of the veneering process on the marginal fit of zirconia fixed dental prostheses *Journal of Oral Rehabilitation* **37(4)** 283-291.
25. Shih A, Flinton R, Vaidyanathan J, & Vaidyanathan T (2011) Effect of margin design and processing steps on marginal adaptation of captek restorations *ISRN Dentistry* **2011(2011)** Article ID 810565, doi:10.5402/2011/810565
26. Chan DC, Wilson AH Jr, Barbe P, Cronin RJ Jr, Chung C, & Chung K (2005) Effect of preparation convergence on retention and seating discrepancy of complete veneer crowns *Journal of Oral Rehabilitation* **32(1)** 58–64.
27. Iwai T, Komine F, Kobayashi K, Saito A, & Matsumura H (2008) Influence of convergence angle and cement space on adaptation of zirconium dioxide ceramic coping *Acta Odontologica Scandinavia* **66(4)** 214–218.
28. Azar MS, Lehmann KM, Dietrich H, Weibrich G, Schmidtmann I, & Scheller H (2011) Effect of preparation depth differences on the marginal fit of zirconia crown copings: an in vitro study *International Journal of Prosthodontics* **24(3)** 264-266.

29. McLean JW, & Fraunhofer von JA (1971) The estimation of cement film thickness by an in vivo technique *British Dental Journal* **131(3)** 107-111.

30. Boening KW, Wolf BH, Schmidt AE, Kästner K, & Walter MH (2000) Clinical fit of Procera AllCeram crowns *Journal of Prosthetic Dentistry* **84(4)** 419-424.

31. Fleming GJ, Dobinson MM, Landini G, & Harris JJ (2005) An in-vitro investigation of the accuracy of fit of Procera and Empress crowns *European Journal of Prosthodontics and Restorative Dentistry* **13(3)** 109-114.

32. Martínez-Rus F, Suárez MJ, Rivera B, & Pradíes G (2011) Evaluation of the absolute marginal discrepancy of zirconia-based ceramic copings *Journal of Prosthetic Dentistry* **105(2)** 108-114.

33. Grenade C, Mainjot A, & Vanheusden A (2011) Fit of single tooth zirconia copings: comparison between various manufacturing processes *Journal of Prosthetic Dentistry* **105(4)** 249-255.

34. Kokubo Y, Tsumita M, Kano T, Sakurai S, & Fukushima S (2011) Clinical marginal and internal gaps of zirconia all-ceramic crowns *Journal of Prosthodontic Research* **55(1)** 40-43.

35. Fleming GJ, Dobinson MM, Landini G, & Harris JJ (2005) An in-vitro investigation of the accuracy of fit of Procera and Empress crowns *European Journal of Prosthodontics and Restorative Dentistry* **13(3)**:109-114.

36. Brawek PK, Wolfart S, Endres L, Kirsten A, & Reich S (2013) The clinical accuracy of single crowns exclusively fabricated by digital workflow—the comparison of two systems *Clinical Oral Investigations* Prepublished Jan 31, 2013. doi 10.1007/s00784-013-0923-5

37. Larsson TD (2012) The clinical significance of marginal fit *Northwest Dentistry* **91(1)** 22-29.

38. Hamouda IM (2011) Effects of various beverages on hardness, roughness, and solubility of esthetic restorative materials Journal of Esthetic and Restorative Dentistry **23(5)** 315-322.

39. Yanikoğlu N, & Yeşil Duymuş Z (2007) Evaluation of the solubility of dental cements in artificial saliva of different pH values *Dental Material Journal* **26(1)** 62-67.

40. Roediger M, Gersdorff N, Huels A, & Rinke S (2010) Prospective evaluation of zirconia posterior fixed partial dentures: four-year clinical results *International Journal of Prosthodontics* **23(2)** 141-148.

41. Sorrentino R, Galasso L, Tetè S, De Simone G, & Zarone F (2012) Clinical evaluation of 209 all-ceramic single crowns cemented on natural and implant-supported abutments with different luting agents: a 6-year retrospective study *Clinical Implant Dentistry and Related Research* **14(2)** 184-197.

42. Ortorp A, Kihl ML, & Carlsson GE (2012) A 5-year retrospective study of survival of zirconia single crowns fitted in a private clinical setting *Journal of Dentistry* **40(6)** 527-530.

43. Belser UC, Mac Entee MI, & Richter WA (1985) Fit of three porcelain-fused-to-metal marginal designs in vivo: a scanning electron microscopy study *Journal of Prosthetic Dentistry* **53(1)** 24-29.

44. Pettenò D, Schierano G, Bassi F, Bresciano ME, & Carossa S (2000) Comparison of marginal fit of 3 different metal-ceramic systems: an in vitro study *International Journal of Prosthodontics* **13(5)** 405-408.

45. Holden JE, Goldstein GR, Hittelman EL, & Clark EA (2009) Comparison of the marginal fit of pressable ceramic to metal ceramic restorations *Journal of Prosthodontics* **18(8)** 645-648.