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The Marginal Fit of CAD/CAM Monolithic Ceramic and Metal-Ceramic Crowns

Yolanda Freire, DDS, Esther Gonzalo, DDS, PhD, Carlos Lopez-Suarez, DDS, PhD, & Maria J. Suarez, MD, DDS, PhD

Department of Buccofacial Prostheses, Faculty of Odontology, University Complutense of Madrid, Madrid, Spain

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Correspondence
Maria J Suarez, MD, DDS, PhD, Department of Buccofacial Prostheses, University Complutense of Madrid (UCM), Pza Ramon y Cajal s/n, 28040 Madrid, Spain.
E-mail: mjsuarez@odon.ucm.es.

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Abstract

Purpose: Studies on the marginal fit of monolithic restorations are limited. This study aimed to evaluate the marginal fit among monolithic zirconia, monolithic lithium disilicate, and conventional metal-ceramic crowns and to compare the buccal and lingual surfaces.
Materials and Methods: Thirty standardized stainless steel master dies were fabricated (height: 5 mm; convergence: 6°; chamfer: 1 mm). The dies were randomly divided into three groups (n = 10 each) according to the material used to construct the crowns: group 1 (LM): Lava Plus; group 2 (DM): IPS e.max CAD; and group 3 (MC): Metal-ceramic. The crowns were luted in a standard manner onto the stainless steel master dies using conventional glass ionomer cement. The vertical marginal gap of the restorations was evaluated under a scanning electron microscope (SEM) at 500x magnification. One-way ANOVA, Tukey´s HSD test, and Student's paired t test were used to assess the marginal discrepancy among the groups. The cutoff value for statistical significance was set at $\alpha = 0.05$.
Results: Significant differences among the three groups ($p = 0.0001$) were recorded. DM group showed the lowest discrepancies (27.95 ± 9.37 μm). Significant differences were observed for the buccal ($p = 0.007$) and lingual ($p = 0.0001$) surfaces between the DM group and the other groups.
Conclusions: The accuracy of fit achieved for the three groups was within the range of clinical acceptance. IPS e.max CAD showed the lowest discrepancies.

Metal-ceramic crowns are currently the most commonly used crowns for fixed prostheses,[1] but when esthetics are a priority, ceramic crowns are the best choice because they are visually appealing and are also a biocompatible material.[2,3] Marginal fit, esthetics, and fracture resistance are considered to be the most important criteria for the clinical quality and success of ceramic crowns.[4,5] Inaccuracy in the marginal adaptation of ceramic crowns can reduce longevity and lead to other adverse effects, such as dissolving of the luting material, microleakage, and plaque retention, which can then cause secondary caries, pulpitis, and periodontal disease.[4,6,7] However, despite its importance, no consensus exists regarding the maximum acceptable marginal gap size. In the scientific literature, large variations are present in the acceptable value ranges reported, but most authors agree that 120 μm is the maximum marginal gap that is clinically acceptable for a good long-term prognosis,[4,8,9] a value based on criteria established by McLean and von Franhoufer.[10]

Since ceramic crowns were introduced, many changes in their composition have been made to improve their properties.[2] A number of different types of ceramic systems are available for clinical use, but the most common are lithium disilicate and zirconia.

The zirconia-based ceramics contain yttrium cation-doped tetragonal zirconia polycrystals (Y-TZP) that have a particular quality known as "transformation toughening." This gives them excellent mechanical properties for use in the fabrication of frameworks for fixed dental prostheses (FDPs).[1,3] Lithium disilicate is a relatively new and popular material for esthetic restorations; however, its clinical behavior over medium-term lengths of time is not yet clear.[11]

Ceramic restorations are typically coated with feldspathic ceramic to achieve a natural appearance,[1] but some issues with this coating have been noted, including one main problem that involves the bond between the core and the veneer, which leads to chipping of the veneer ceramic.[2] This disadvantage is associated with a multistep manufacturing process, and several factors may be involved, such as residual tensile stresses following veneering, differences in the toughness between the core and the veneer, and the bond between the core and veneer.[2,12] Monolithic crowns were developed to solve these problems, although a major esthetic drawback exists for these monolithic restorations.

The aim of this study was to evaluate the marginal gaps among monolithic zirconia, monolithic lithium disilicate, and conventional metal-ceramic restorations and to analyze the differences between buccal and lingual surfaces. The null hypothesis stated that no differences would be found among materials or between surfaces in terms of marginal discrepancies.

Materials and methods

Experimental model

Thirty standardized machined stainless steel specimens were fabricated to simulate a first mandibular molar. The manufacturing process of the dies began with the design of the technical characteristics (AutoCAD 2011; Autodesk, San Rafael, CA). The dies were designed to simulate clinical conditions with a 1-mm-wide chamfer, a circumferential finish line, and a 6° angle of convergence of the axial walls. Beginning with solid stainless steel 316L Alloy (UNS S3 1603) rods, the dies were manufactured using the EMCO Turn 342 numerical control lathe (EMCO Group, Hallein, Austria), which is governed by SINUMERIK (Siemens AG, Munich, Germany). The edges of the dies were then rounded and smoothed. All processing occurred in the Mechanical Workshop of the Physical Science Faculty (University Complutense of Madrid, Spain). The specimens were randomly assigned to one of three groups ($n = 10$), and the groups were categorized according to the material of the restoration: group 1 (LM) Lava Plus (3M ESPE, Seefeld, Germany); group 2 (DM): IPS e.max CAD (Ivoclar Vivadent, Schäan, Liechtenstein); and group 3 (MC): Metal-ceramic (control group).

Restoration fabrication

To fabricate the Lava Plus restorations, the surfaces of the dies were first coated with a titanium oxide powder (Occlusal Spray; Yeti Dentalprodukte GmbH, Engen, Germany). Then, the dies were scanned in a Lava Scan ST (3M ESPE) extraoral scanner, and the data were entered into specific design software (Lava TM System 3.01; 3M ESPE). The restorations were designed by choosing the anatomy for a first mandibular molar from the library included in the software. The design was enlarged by 20% to offset postsintering shrinkage. Manufacturing was performed using the Lava Form (3M ESPE) milling unit after selection of the pre-sintered zirconia blocks (Lava Plus; 3M ESPE). Thereafter, the specimens were dried and introduced in the Lava Therm (3M ESPE) sintering furnace at 1500°C for 4 hours.

The manufacturing process for the lithium disilicate restorations (IPS e.max CAD) was similar to the Lava Plus system in regard to the scanning and design process, but it was not necessary to enlarge the design. Once the design was completed, the data were transferred to the milling software (Zenotec CAM 3.2; Wieland Dental, Pforzheim, Germany). The milling process was conducted in the Wieland Zenotec (Wieland Dental) milling unit, and the vitrification process was performed in the Programat P510 furnace (Ivoclar Vivadent). An internal space of 50 μm for the cement was programmed in both ceramic groups.

The first step in the preparation of the metal-ceramic restorations was the wax-up of the copings onto the dies, which were previously varnished with two layers of die-spacer (Space-It; TAUB Products, Jersey City, NJ) (50 μm). Then, the dies were placed into a cylinder coated with phosphate graphite-free investment (Vestofix; DFS Diamond GMBH, Riedenburg, Germany), placed into the preheating furnace (Jelrus Infinity L30; Whip Mix, Dortmund, Germany) with a heating rate of 2 to 5°C/min, and heated to 900 to 950°C. Following this process, the dies were placed into the vacuum-pressure casting machine for induction heating (MIE 200; Ordenta, Arganda del Rey, Spain) and cast with a cobalt-based alloy (Ugirex C; UginDentaire, Seyssins, France). After divesting, the castings were cleaned using airbone-particle abrasion with aluminium-oxide powders (50 μm), and the veneering ceramic (VITA VM13; VITA Zahnfabrik, Bad Säckingen, Germany) was applied.

All the crowns were luted in a standard manner onto the stainless-steel master dies using conventional glass ionomer cement (Ketac-Cem Esaymix; 3M ESPE), mixed following the manufacturer's specifications, at room temperature (18 to 24°C) and relative humidity ($50 \pm 10\%$). The cement was applied to the axial walls of the restorations, and a constant seating force of 10 N was applied with a USAG 820/70 torque wrench (SWK Utensilerie S.R.L., Milan, Italy) for 10 minutes.

The marginal accuracy of the restorations was evaluated by measuring the vertical marginal gap between the crown margin and the cavosurface angle of the preparation under a scanning electron microscope (SEM) (JSM 6400; JEOL Tokyo, Japan) at 500× magnification. Before the SEM evaluation, the specimens were coated with 24 kt, 19.32 g/m^3 density gold by a Q15RS metallizer (Quorum Technologies, Sussex, UK) to avoid electron beam distortion. The SEM evaluations were performed in the ICTS National Electron Microscopy Centre (University Complutense of Madrid).

The JEOL 6400 SEM produces increases in magnification of 15 to 30,000×, with 3.5 nm of resolution and a variable voltage of 0.5 to 40 kV. Image acquisition was accomplished using the Link Pentafet energy dispersal detector (Oxford Instruments, Abingdom, UK). The images were transferred to a personal computer with software (INCA Suite 4.04; Oxford Instruments) that captured and digitalized the images.

The specimens were positioned in a base perpendicular to the optical axis of the microscope. The marginal fit was measured for each restoration at a point in the middle of the buccal and lingual surfaces that was marked with an indelible marking pen (Lumocolor permanent; Staedler Mars, Nuernberg, Germany). Once the specimen was brought into focus, a 500× photograph

Table 1 Groups, brands, manufacturers, mean marginal gap values, and standard deviation (SD)

				Marginal gap (μm)	
Group	Brand	Manufacturer	n	Mean	SD
LM	Lava Plus	3M ESPE, Seefeld, Germany	10	58.05	16.6
DM	IPS e.max CAD	Ivoclar Vivadent, Schäan, Liechtenstein	10	27.95	9.37
MC	UgirexC VITAVM 13	UginDentaire, Seyssins, France VITA Zahnfabrik, Bad Säckingen, Germany	10	57.42	19.28

LM: monolithic zirconia. DM: monolithic lithium disilicate. MC: metal-ceramic

Table 2 One-way ANOVA results for the marginal discrepancy among groups

ANOVA Source of variation	SS	df	MS	F	*p*-Value
Between groups	5915.511	2	2957.756	18.902	0.0001
Within groups	4224.806	27	156.474		
Total	10140.371	29			

SS: Sum of squares; df: degrees of freedom; MS: mean square; F: F-distribution.

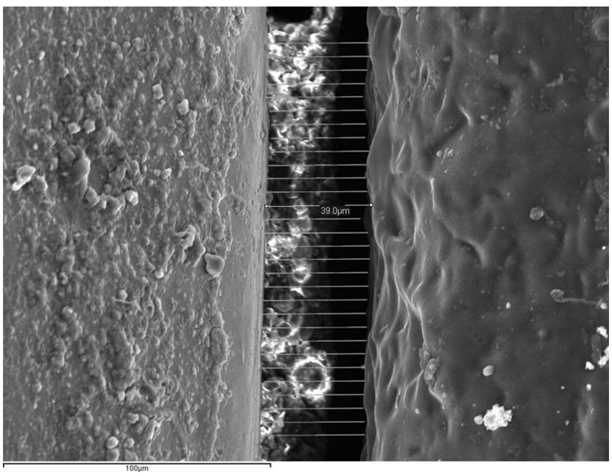

Figure 1 SEM image (500×), showing the marginal gap of an IPS emax CAD specimen (left: steel abutment, right: ceramic).

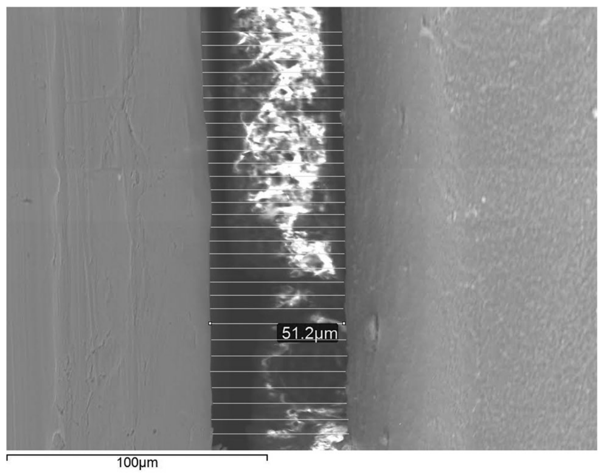

Figure 2 SEM image (500×), showing the marginal gap of a Lava Plus specimen (left: steel abutment, right: ceramic).

was obtained, and then a second image was produced using the INCA software, which included a measurement expressed in microns.

To increase the number of measurements per specimen, the images were edited using design software (Adobe Photoshop CS6; Adobe Systems, San Jose, CA) to produce lines parallel to the original, and up to 29 lines per side were added (Figs 1 and 2). Therefore, 60 measurements per specimen, and 30 per surface, were recorded. The 60 measurements per specimen were measured on a scale of 1:300 (Faber Castell, Stein, Germany), and all data were entered into a Microsoft Excel spreadsheet (Microsoft Corp, Redmond, WA).

The statistical analysis was performed with SPSS 22.0 software (IBM Corp, Armonk, NY). The Kolmogorov-Smirnov test was used to confirm that the data were normally distributed. The mean values and the standard deviations per group were calculated for each group and surface. One-way ANOVA was used to assess the marginal discrepancy among the groups, and Tukey's HSD test was used for post hoc comparisons. Student's paired *t* tests were used to compare lingual and buccal surfaces. The cutoff value for statistical significance was set at $\alpha = 0.05$.

Results

Table 1 displays the mean marginal discrepancy values for the experimental groups. The overall mean marginal discrepancy was 47.80 ± 18.6 μm. For the buccal surface, the mean value was 50.25 ± 21.56 μm, and the mean value for the lingual surface was 45.37 ± 21.56 μm.

ANOVA revealed that the marginal discrepancy, independent of the surface, was significantly different among the three groups ($p = 0.0001$) (Table 2). Tukey's test indicated that the

Table 3 Tukey's HSD test for marginal discrepancy among groups

Restoration type	Restoration type	Mean difference	Standard error	*p*	95% Confidence interval Lower bound	Upper bound
LM	DM	30.099	5.594	0.0001	16.228	43.969
	MC	.632	5.594	0.993	−13.238	14.337
DM	LM	−30.099	5.594	0.0001	−43.969	−16.228
	MC	−29.467	5.594	0.0001	−43.337	−15.596
MC	DM	29.467	5.594	0.0001	15.596	43.337
	LM	−.632	5.594	0.993	−14.502	13.238

LM: monolithic zirconia; DM: monolithic lithium disilicate; MC: metal-ceramic; p-value: significance $p < 0.05$.

values for the IPS e.max CAD group (Fig 1) were significantly smaller than those of the other groups ($p = 0.0001$). No differences were observed between the Lava Plus (Fig 2) and metal ceramic groups ($p = 0.993$) (Table 3).

Means and standard deviations (SDs) for the buccal and lingual surfaces are shown in Table 4. Significant differences were observed for the buccal ($p = 0.007$) and lingual ($p = 0.0001$) surfaces among the groups. Tukey's test indicated that the IPS e.max CAD group had a significantly better marginal fit than the Lava Plus ($p = 0.018$) and metal-ceramic groups ($p = 0.012$) for the buccal surface. For the lingual surface, the results obtained were similar to those found for the buccal surface. The IPS e.max CAD group had significantly smaller values than the Lava Plus ($p = 0.0001$) and metal-ceramic ($p = 0.0001$) groups. No differences were observed between the Lava Plus and metal-ceramic groups for the buccal ($p = 0.988$) or lingual surfaces ($p = 0.919$).

When differences in marginal discrepancy between surfaces were analyzed for all groups (n = 30), a paired *t* test revealed no differences ($p = 0.222$). A paired *t* test indicated that the IPS e.max CAD group exhibited different values between surfaces ($p = 0.025$), with the lingual surface having the smallest mean value. No differences were found between surfaces in either in the Lava Plus ($p = 0.97$) or metal-ceramic groups ($p = 0.7$).

Table 4 Mean and standard deviation (SD) values of the marginal gap (μm) for the buccal (B) and lingual (L) surfaces for each group

Group	Surface	n	Mean	SD
LM	B	10	57.96	21.22
	L	10	58.15	17.71
DM	B	10	33.59	12.62
	L	10	22.32	10.25
MC	B	10	59.20	20.46
	L	10	55.64	13.82
TOTAL	B	30	50.25	21.56
	L	30	45.37	21.56

Discussion

This study evaluated the marginal adaptation of two monolithic systems and compared them to conventional metal-ceramic restorations. The results supported rejection of the null hypothesis for the vertical marginal discrepancy of the groups and for the comparison between the surfaces, because significant differences were observed in those comparisons.

These monolithic systems are the latest generation of ceramic crowns, and they present superior mechanical and esthetic properties.[12,13] Marginal adaption is an important factor in terms of clinical quality and success.[3-5,8,14,15] The definition of marginal adaptation was described in 1989 by Holmes et al.[16] In the present study, the vertical marginal gap was evaluated and defined as the vertical marginal misfit measured in parallel to the path of draw of the restoration.[16]

The marginal fit of ceramic crowns has been widely studied, but the results have shown large variations among the different ceramic systems.[3,6] A few studies compare the marginal fits of different monolithic crowns. Therefore, our comparisons were made with previous studies that evaluated the marginal fits of both materials, hand-layered-veneered zirconia and lithium disilicate.

Baig et al[17] reported better marginal adaptation for lithium disilicate crowns than for zirconia crowns, which is consistent with the findings of this study; However, other studies[18,19] have demonstrated better marginal gaps in zirconia restorations. Furthermore, Subasi et al[20] did not show significant differences between the two materials, and Asavapanumas and Leevailoj[21] found that the lithium disilicate marginal gap values were between those of two zirconia systems.

Regarding the zirconia-ceramic group, in the present study, the mean marginal gap values were similar to those reported by Ortega et al,[22] but lower than values observed by other authors for crowns[19,21] and FDPs.[4,8,15] Lopez-Suarez et al[23] reported higher values for the same monolithic zirconia system, but they used FDPs as experimental restorations. IPS e.max CAD crowns showed the lowest mean marginal openings in the current study, which could be explained by the precision of the digitization system and the mechanized technique used. Most previous studies have analyzed IPS e.max Press, and all results were within ranges considered clinically acceptable.[18,21,24,25] Guess et al found no differences when they compared the marginal fit of heat-pressed and CAD/CAM lithium disilicate onlays.

The major drawbacks of comparing the results of different studies include the absence of a standardized methodology[3,8,22] and that many factors can influence the results.[3,4] One of these factors is the different measurement methodologies used. Although various protocols have been proposed to analyze marginal precision, no guidelines exist regarding how to perform gap measurements;[8,22,26,27] therefore, variability exists in the results obtained from the different techniques used to record the data.[3,4,8,22,28] In the present study, marginal adaptation was evaluated by direct viewing on an SEM to obtain external measurements. This technique has the advantages of being noninvasive, allowing the placement of restorations in a base to standardize measurements,[8] and examination under high power magnification, a factor crucial for the accuracy of this method. Furthermore, this technique reduces the chance of error accumulation due to the preparation of a replica.[29] Another factor that influences the discrepancies between studies is the presence or absence of cementation. Cementation may affect marginal adaptation due to potential differences in factors such as luting agent viscosity and seating forces.[17] Cementation increases the marginal gap,[24] but examination without cementation does not replicate the actual situation in clinical practice;[3,17] therefore, our study measurements were performed on cemented crowns. Furthermore, it is important to consider the role of the dental technician in the fabrication of the restorations, as that could influence the results.[3,4] Therefore, in our study, the same technician fabricated all restorations.

The number of measurements per specimen is another factor that varies greatly among studies. In the literature, the number of measurements ranged from four to more than 100 sites per restoration.[30] Approximately 50 measurements per specimen would allow a consistent estimation of the misfit,[26,30] and although it has been suggested that a larger sample size produces more consistent data,[29] previous studies analyzing marginal adaptation have used a larger number of measurements per specimen (>50) to compensate for smaller sample sizes.[8,22,23,29,31] In this study, 60 measurements per specimen were obtained to ensure accurate results, and the measurements were always performed by the same technician.

Few studies have compared discrepancies between surfaces (buccal or lingual), and the results of these studies are controversial. Several previous studies[6,15,22,23] have found no differences between surfaces; however, other studies[4,32] have reported differences between these surfaces, as we showed in the current study in the monolithic lithium disilicate group. Further studies are needed to clarify this discrepancy.

In the present study, the marginal fits for both monolithic systems were below 100 μm; therefore, the results were in the clinically acceptable range, according to previous studies.[3-9,15,22,23,28,31,32] Currently, CAD/CAM systems have shown high precision in their marginal adaptation; therefore, the range of clinically acceptable limits may need to be reviewed.

The present study had some limitations. The crowns were fabricated under standardized conditions, which may not reflect conditions in clinical practice, and the fit could be influenced by tooth preparation, the impression technique, and cementation. Further studies are needed to analyze the factors that affect the marginal gap of monolithic restorations, including the finish line design, the impression technique, and the luting agent used. In addition, clinical studies are needed to validate these results.

Conclusions

Considering the limitations of this in vitro study, the following conclusions can be drawn:

1. The vertical marginal adaptation values exhibited an acceptable marginal fit of less than 100 μm.
2. The monolithic lithium disilicate group demonstrated the best marginal adaptation.

The results were influenced by the location of the measurements. It is important to establish a standardized method to evaluate the marginal fit of fixed prosthodontic restorations in the future.

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References

1. Rodriguez V, Castillo-Oyagüe R, Lopez-Suarez C, et al: Fracture load before and after veneering posterior zirconia fixed dental prostheses. J Prosthodont 2016;25:550-556
2. Pelaez J, Cogolludo PG, Serrano B, et al: A four-year prospective clinical evaluation of zirconia and metal-ceramic posterior fixed dental prostheses. Int J Prosthodont 2012;25:451-458
3. Martínez-Rus F, Suárez MJ, Rivera B, et al: Evaluation of the absolute marginal discrepancy of zirconia-based ceramic copings. J Prosthet Dent 2011;105:108-114
4. Gonzalo E, Suarez MJ, Serrano B, et al: A comparison of the marginal vertical discrepancies of zirconium and metal ceramic posterior fixed dental prostheses before and after cementation. J Prosthet Dent 2009;102:378-384
5. Biscaro L, Bonfiglioli R, Soattin M, et al: An in vivo evaluation of fit of zirconium-oxide based ceramic single crowns, generated with two CAD/CAM systems, in comparison to metal ceramic single crowns. J Prosthodont 2013;22:36-41
6. Suarez MJ, González de Villaumbrosia P, Pradíes G, et al: Comparison of the marginal fit of procera all ceram crowns with two finish lines. Int J Prosthodont 2003;16:229-232
7. Rinke S, Fornefett D, Gersdorff N, et al: Multifactorial analysis of the impact of different manufacturing processes on the marginal fit of zirconia copings. Dent Mater J 2012;1:601-609
8. Gonzalo E, Suarez MJ, Serrano B, et al: Comparative analysis of two measurement methods for marginal fit in metal-ceramic and zirconia posterior FPDs. Int J Prosthodont 2009;22:374-377
9. Euan R, Figueras-Álvarez F, Cabratosa-Termes J, et al: Comparison of the marginal adaptation of zirconium dioxide crowns in preparations with two different finish lines. J Prosthodont 2012;21:291-295
10. McLean JW, von Fraunhofer JA: The estimation of cement film thickness by an in vivo technique. Br Dent J 1971;131:107-111
11. Pieger S, Salman A, Bidra AS: Clinical outcomes of lithium disilicate single crowns and partial fixed dental prostheses: a systematic review. J Prosthet Dent 2014;112:22-30
12. Guess PC, Zavanelli RA, Silva NR, et al: Monolithic CAD/CAM lithium disilicate versus veneered Y-TZP crowns: comparison of failure modes and reliability after fatigue. Int J Prosthodont 2010;23:434-442

13. Zhang Y, Lee JJW, Srikath R, et al: Edge chipping and flexural resistance of monolithic ceramics. Dent Mater 2013;29:1201-1208
14. Contrepois M, Soenen A, Bartala M, et al: Marginal adaptation of ceramic crowns: a systematic review. J Prosthet Dent 2013;110:447-454
15. Gonzalo E, Suarez MJ, Serrano B, et al: Marginal fit of zirconia posterior fixed partial dentures. Int J Prosthodont 2008;21:398-399
16. Holmes JR, Bayne SC, Holland GA, et al: Considerations in measurement of margin fit. J Prosthet Dent 1989;62:405-408
17. Baig MR, Tan KB, Nicholls JI: Evaluation of the marginal fit of a machined (CAM) crown system. J Prosthet Dent 2010;104:216-227
18. Yuksel E, Zaimoglu A: Influence of marginal fit and cement types on microleakage of all-ceramic crown systems. Braz Oral Res 2011;23:261-266
19. Pimenta MA, Frasca LC, Lopes R, et al: Evaluation of marginal and internal fit of ceramic and metallic crown copings using x-ray microtomography (micro-CT) technology. J Prosthet Dent 2015;114:223-228
20. Subasi G, Orturk N, Inana O, et al: Evaluation of marginal fit of two all- ceramic copings with two finish lines. Eur J Dent 2012;6:163-168
21. Asavapanumas C, Leevailoj C: The influence of finish line curvature on the marginal gap width of ceramic copings. J Prosthet Dent 2013;109:226-233
22. Ortega R, Gonzalo E, Gomez-Polo M, et al: Marginal and internal discrepancies of posterior zirconia-based crowns fabricated with three different CAD/CAM systems versus metal-ceramic. Int J Prosthodont 2015;28:509-511
23. Lopez-Suarez C, Gonzalo E, Pelaez J, et al: Marginal vertical discrepancies of monolithic and veneered zirconia and metal-ceramic three-unit posterior fixed dental prostheses. Int J Prosthodont 2016;29:256-258
24. Borges GA, Faria JS, Agarwal AM, et al: In vitro marginal fit of three all-ceramic crown systems before and after cementation. Oper Dent 2012;37:641-569
25. Anadioti E, Aquilino SA, Gratton DG, et al: 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. J Prosthodont 2014;23:610-617
26. Gassino G, Barone Monfrin S, Scanu M, et al: Marginal adaptation of fixed prosthodontics: a new in vitro 360-degree external examination procedure. Int J Prosthodont 2004;17:218-223
27. Laurent M, Scheer P, Dejou J, et al: Clinical evaluation of the marginal fit of cast crowns-validation of the silicone replica method. J Oral Rehabil 2008;35:116-122
28. Groten M, Girthofer S, Pröbster L: Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro: J Oral Rehabil 1997;24:871-881
29. Nawafleh NA, Mack F, Evans J, et al: Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: a literature review. J Prosthodont 2013;22:419-428
30. Groten M, Axmann D, Probster L, et al: Determination of the minimum number of marginal gap measurements required for practical in vitro testing. J Prosthet Dent 2000;83:40-49
31. Lee KB, Park CW, Kim KH, et al: Marginal and internal fit of all-ceramic crowns fabricated with two different CAD/CAM systems. Dent Mater J 2008;27:422-426
32. Boening KW, Wolf BH, Schmidt AE, et al: Clinical fit of Procera Allceram crowns. J Prosthet Dent 2000;84:419-424