Dental Materials Journal 2017; 36(4): 387–393

SEM evaluation of the precision of fit of CAD/CAM zirconia and metal-ceramic posterior crowns

Rocio ORTEGA, Esther GONZALO, Miguel GOMEZ-POLO, Carlos LOPEZ-SUAREZ and Maria J. SUAREZ

Department of Buccofacial Prostheses, Faculty of Odontology, University Complutense, Pza Ramon y Cajal s/n, 28040 Madrid, Spain
Corresponding author, Maria J. SUAREZ; E-mail: mjsuarez@ucm.es

The purpose of this study is to evaluate the precision of fit of posterior crowns made from three commercial CAD/CAM zirconia ceramics and conventional metal-ceramic technique. The external and internal marginal fit of the crowns was evaluated using direct SEM-based measurements. The data were subjected to Kruskal-Wallis, multicomparison *post hoc* analysis and Wilcoxon rank sum tests (α=0.05). Significant differences were observed for the external (p<0.002) and the internal (p<0.0001) marginal evaluation among the groups. No differences were observed between the buccal and lingual surfaces for the external (p=0.34) and internal (p=0.55) evaluations. No differences were showed between the external and internal measurements (p=0.37). The accuracy of fit was within the range of clinical acceptance. The lowest discrepancies corresponded to the NobelProcera group for external (39.3±11.81 µm) and internal (41.09±7.54 µm) marginal fit. The results confirmed that destructive methods are not required to assess the marginal fit of dental prosthetic crowns.

Keywords: Zirconia, CAD/CAM, External marginal fit, Internal marginal fit, Measurement techniques

INTRODUCTION

Fixed prostheses are a reliable and predictable dental procedure, whose good long-term performance has been well documented by any number of studies. Inasmuch as they have been in use for many years, metal-porcelain crowns are the type of fixed prostheses that have been clinically tested most thoroughly[1,2]. Nonetheless, increasingly demanding esthetic expectations, together with the application of computer aided design-computer aided machining (CAD/CAM) systems to dentistry, have driven the development of metal-free crowns made with new materials. Among the most prominent of these new substances for copings is zirconium oxide, whose physical properties are more suitable than other materials used in metal-free crowns such as feldspar and aluminous ceramics[3,4].

Marginal fit is one of the most important criteria for good long-term performance in fixed prostheses restorations. Poor seals may give rise to a series of biological, periodontal, esthetic or mechanical complications, which may present singly or jointly[5-7]. However, no consensus has yet been reached on the clinically acceptable dimension of the interface, ranging the values reported in the literature from 50–200 µm[7-9], and most researchers continue to use the criteria established by McLean and von Fraunhofer[10]. Several studies demonstrated that the final adaptation of the restorations depends on several factors such as finish line, manufacturing technique, porcelain firing and cementing[9,11-13]. Different methods are used to analyze the marginal fit of the restorations, but there is an absence of standardization in the methodology[14]. Direct visual observation and interphase probing is the simplest method although the least reliable[14]. Based on previous studies, external and internal methods are used to measure of the marginal fit and both may be performed direct or indirectly[15]. Scanning electron microscopy (SEM) is a conservative technique with high magnifying power that provides very precise measurements of the marginal discrepancy and quality of fit. Nonetheless, SEM is also subject to certain limitations, for it requires pre-scanning sample preparation (fixation, carbon coating) and the accuracy of the measurements depends on the viewing angle[15]. Because of the large variations in marginal fit observed for different zirconia systems it is important to investigate the precision of fit of these restorations and to evaluate them comparatively based on clinically acceptable thresholds under standardized conditions.

Consequently, in this study we prepared CAD/CAM zirconia and conventional metal-ceramic crowns for the premolar region and investigated the fit of these crowns. To this end, three types of commercial zirconia that are widely used in clinical dental settings and a chrome-cobalt (Cr-Co) alloy were selected. The objectives of the current study were to evaluate: (1) the precision of fit of CAD/CAM zirconia and metal-ceramic posterior crowns; (2) the differences between buccal and lingual surfaces; and (3) the external and internal marginal fit values obtained by SEM. The established null hypotheses were that no differences would be found in the marginal precision of fit among the groups, and that no differences would be observed between buccal and lingual surfaces and between the external and internal precision of fit.

Color figures can be viewed in the online issue, which is available at J-STAGE.

Received Sep 4, 2016: Accepted Nov 17, 2016
doi:10.4012/dmj.2016-305 JOI JST.JSTAGE/dmj/2016-305

MATERIALS AND METHODS

Fabrication of the experimental model

For this *in vitro* study, the mandibular first premolar was selected as abutment. In order to fabricate a master model, the abutment was designed (AutoCAD 2011, Autodesk, San Rafael, CA, USA) with 5 mm in height, a occlusal diameter of 5 mm, a 1-mm-wide chamfer circumferentially finish line and a 6º angle of convergence of the axial walls, simulating clinical conditions. Forty solid steel specimens were machined in stainless steel (316L UNS S3 Alloy, Masteel, Birmingham, UK) in the Physical Science Faculty (University Complutense of Madrid, Spain) (Fig. 1).

The specimens were randomly divided into 4 groups (n=10 each, according to the results of power analysis) categorized according to the material of the restorations: MC (metal-ceramic), P (NobelProcera Zirconia Crowns, Nobel Biocare, Zurich, Switzerland), L (Lava Zirconia, 3M ESPE, Seefeld, Germany) and YZ (VITA In-Ceram YZ, VITA Zahnfabrik, Bad Säckingen, Germany). The specimens were used as working dies. Table 1 displays the coping materials and manufacturers.

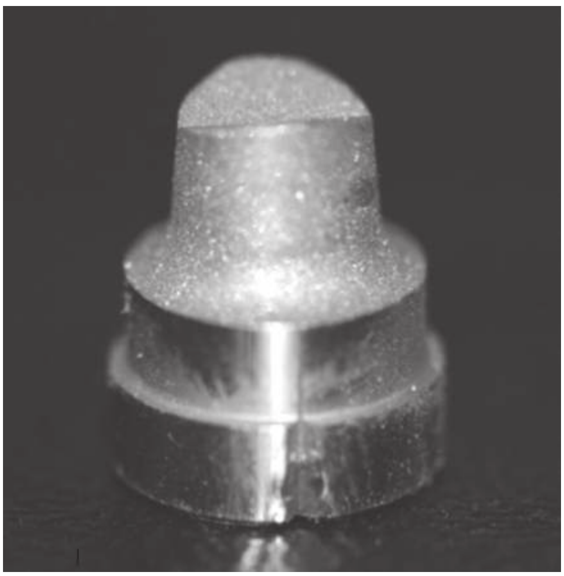

Fig. 1 Standardized steel specimen simulating prepared abutment.

Fabrication of the restorations

The zirconia crowns were prepared according to the manufacturers' specifications by an experienced technician who was accustomed to the specific CAD/CAM system. The process of fabricating the zirconia cores consisted of scanning and digitizing the steel dies with the corresponding scanners: Procera Forte (Nobel Biocare) for NobelProcera Zirconia, Lava Scan (3M ESPE) for Lava Zirconia and InEos (Sirona Dental, Bensheim, Germany) for VITA In-Ceram YZ restorations, as previously described[9]. The cores of the three zirconia systems were prepared with a wall thickness of 0.5 mm, and a cement gap of 50 µm. Once the designs were complete, the files were sent to the corresponding milling machine (NobelProcera, Nobel Biocare; Lava, 3M ESPE; InLab, Sirona; respectively) to manufacture the pre-sintered zirconia blocks. The copings were then fully sintered in their correponding furnace. A porcelain layering material (0.5 mm thickness) was built up on the zirconia cores according to each manufacturer's recommendations: NobelRondo (Nobel Biocare), Lava Ceram (3M ESPE) and VITA VM9 (VITA Zahnfabrik) respectively. The thickness of the core and the veneering porcelain was verified at different locations with a digital micrometre (Mitutoyo, Tokyo, Japan) accurate to 0.01 mm.

The metal-ceramic group was vacuum cast by using a base-metal alloy of chrome-cobalt (Kera C, Eisenbacher Dentalwaren ED, Woerth, Germany), and manufactured using the conventional lost-wax casting technique. The dies were varnished with three layers of die spacer (total thickness, 50 µm). Before casting the frameworks, wax patterns were prepared and invested with a commercial phosphate graphite free investment plaster (Vestofix, DFS Diamon, Riedenburg, Germany). The casting was performed using induction and a centrifugal vacuum/pressure casting machine (CL-IG, Heraeus Kulzer Japan, Tokyo, Japan). After divesting, the castings were cleaned using airbone-particle abrasion with aluminium-oxide powders (50 µm) and veneered with compatible hand-layered feldsphatic ceramic (Omega 900, VITA Zahnfabrik).

All the crowns were cemented on their respective stainless-steel master dies using conventional glass ionomer cement (Ketac-Cem Easymix, 3M-ESPE) mixed following the manufacturer's specifications, at room temperature (18–24ºC) and relative humidity (50±10%). The cement was applied to the axial walls

Table 1 Coping materials assessed in the study

Group	Material type	Brand	Manufacturer
MC	Chrome-cobalt alloy	Kera C	Eisenbacher Dentalwaren ED, Woerth, Germany
P	Zirconia	NobelProcera Zirconia	Nobel Biocare, Zurich, Switzerland
L	Zirconia	Lava Zirconia	3M ESPE, Seefeld, Germany
YZ	Zirconia	VITA In-Ceram YZ 2000	VITA Zahnfabrik, Bad Säckingen, Germany

of the restorations and a constant seating force of 10 N was applied with a USAG 820/70 torque wrench (SWK Utensilerie, Milan, Italy) for 10 min.

Measurement of the marginal fit

Marginal fit was assessed by measuring the external (EMG) and internal (IMG) vertical marginal gaps (or the vertical distance between the crown margin and the preparation cavosurface angle as previously described[16]) under a scanning electron microscope (SEM) (JSM-6400, JEOL, Tokyo, Japan) with a magnification factor of ×500. Prior to SEM evaluation, samples were gold coated under vacuum (K550X, Emitech Quorum Technologies, Kent, UK) to render them electrically conductive. Due to the morphology of the crowns, the samples were mounted on a customized metallic support at an angle of 25 degrees in order to situate the interface perpendicularly to the optical axis of the microscope, thus guaranteeing repeatable projection angles[17,18]. To standardize the marginal analysis, the measuring areas were previously marked with an indelible marking pen (Lumocolor permanent, Staedtler Mars, Nürnberg, Germany) at the same point in the middle of the buccal and lingual surfaces for each crown[7-9]. The data were captured and the images digitized using the software INCA suite 4.04 (Oxford Instruments Analytical, Oxford, UK). Previous studies[9,17-20] were considered regarding the number of measurements, therefore to increase the number of measurements per specimen, the images were edited using design software (Adobe Photoshop CS6, Adobe Systems, San Jose, CA, USA) to produce lines that were parallel to the original, and up to 29 lines per side were added on each SEM image. To increase the reliability of measurements, each line was measured three times and their average values were taken[17]. The SEM analysis was blindly performed by a specialized operator. Thus, 60 measurements were taken per crown (30 per surface).

After the external marginal fit measurements were taken, the samples were embedded in a thermally polymerized resin (TAAB, TAAB Laboratories, Berkshire, UK) and sectioned longitudinally across the middle of the vestibular and lingual surfaces to analyze the internal marginal fit, with a cutting machine (EXTEC Labcut 150, Extec, Enfield, CT, USA; and Precision Diamond Wire Saw Well 3242, Well Diamond Wire Saws, Le Locle, Switzerland). The sectioned specimens were polished in a grinding machine (PT 251, Metasinex, Nordrhein-Westfalen, Germany). Marginal accuracy of the sectioned samples was measured similarly to the EMG using SEM (JSM-6400).

Statistical analysis

The mean values and the standard deviations (SD) per group for the vertical marginal fit parameter were calculated. The Kruskal-Wallis and subsequently the *post hoc* test for multiple comparisons were used for comparisons among the different groups. The Wilcoxon signed rank test, was conducted to compare buccal and lingual surfaces for each group analyzed. The significance level was set to $\alpha=0.05$. All data analyses were made with S.A.S. 9.2 (SAS Institute, Cary, NC, USA) statistical software.

RESULTS

All groups evaluated showed marginal discrepancy values below 120 µm, regardless of the evaluation method (Figs. 2–4). The NobelProcera group exhibited the lowest values, and similar external and internal marginal discrepancies (EMG=39.3±11.81 µm and IMG=41.09±7.54 µm), thus demonstrating its superior fit, while the metal-ceramic group exhibited the largest variation of all the groups (EMG=83.91±25.85 µm and IMG=101.5±35.01 µm) (Fig. 2). The Kruskall Wallis test indicated that significant differences were observed ($p<0.002$) in the external marginal discrepancy between NobelProcera and the other three groups. Likewise, statistically significant differences ($p<0.0001$) were observed for the internal marginal gaps among the groups, showing *post hoc* test differences between the metal-ceramic and the zirconia groups.

The mean and SD of the precision of fit for buccal and lingual surfaces are reported in Tables 2 and 3. When differences between both surfaces were analyzed for all groups ($n=40$), the Wilkoxon signed rank test revealed no significant differences for the external ($p=0.33$) and internal ($p=0.54$) marginal gap. Comparing both surfaces in each group, again no significant differences were observed.

With regards to the mean values between the difference of the external and internal marginal fit, the groups for which the greatest differences were observed were MC (−17.6±38.71 µm), followed by Lava (12.79±29.88 µm). The difference for the Procera and YZ groups, by contrast, was minor (−1.77±11.17 and −3.46±37.12 µm, respectively). No significant differences in marginal discrepancies between the EMG and the IMG values

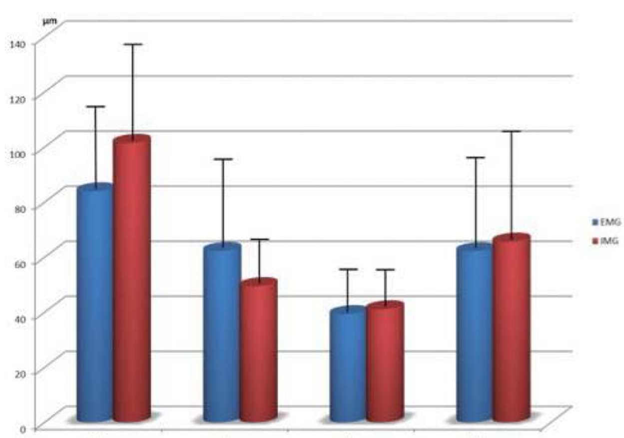

Fig. 2 Mean and standard deviation values of the external and the internal marginal gap of the crown specimens.

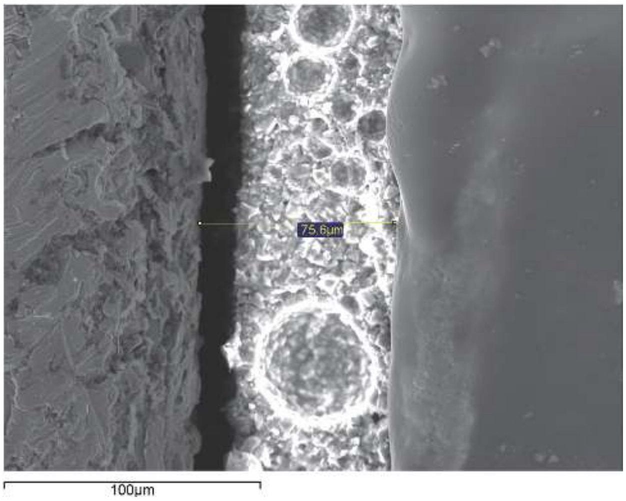

Fig. 3 SEM photograph (×500 magnification) showing the external marginal gap of an In-Ceram YZ specimen.

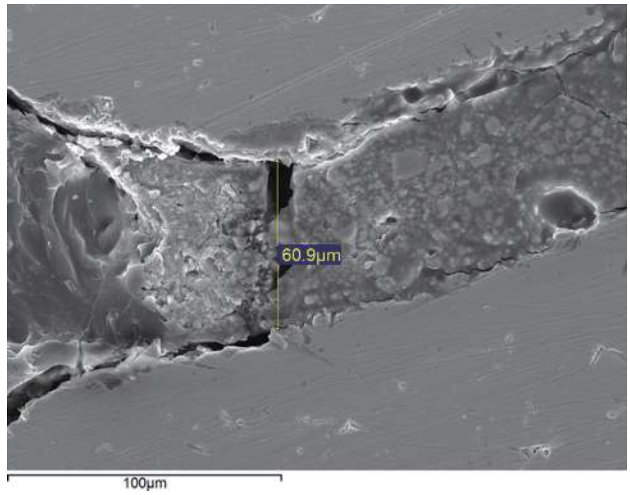

Fig. 4 SEM photograph (×500 magnification) showing the internal marginal gap of a Lava specimen.

Table 2 Mean(±SD) (micrometers) values of the external marginal gap for both surfaces (buccal and lingual)

Group	*n*	Buccal	Lingual	*p*
MC	10	100.50 (±36.47)	92.20 (±25.33)	0.48
L	10	62.28 (±29.82)	62.24 (±32.00)	1.00
P	10	33.35 (±17.68)	45.27 (±24.90)	0.55
YZ	10	61.61 (±28.63)	62.72 (±35.55)	0.92
Total	40	60.72 (±28.15)	63.11 (±29.44)	0.33

Table 3 Mean (±SD) (micrometers) values of the internal marginal gap for both surfaces (buccal and lingual)

Group	*n*	Buccal	Lingual	*p*
MC	10	99.45 (±33.11)	103.5 (±31.66)	0.60
L	10	48.43 (±18.56)	50.52 (±16.18)	0.91
P	10	43.71 (±13.34)	38.46 (±16.04)	0.37
YZ	10	68.98 (±30.01)	62.28 (±30.24)	0.23
Total	40	65.14 (±23.75)	63.69 (±23.53)	0.55

were showed (p=0.37) among the four analyzed groups.

DISCUSSION

The precision of fit is an important factor to ensure the success of the restorations, and an inadequate adaptation of the restorations may be detrimental for the tooth and the periodontal supporting tissue[15]. This research attempts to compare the accuracy of fit of three different CAD/CAM zirconia systems and conventional metal-ceramic tecbnique, and vertical gap was measured to permit comparison with previous studies[8,9,15,17,18,21-23]. The data obtained in the study support the partial rejection of the null hypothesis because differences in marginal fit were shown among the groups, however no differences were observed between external and internal marginal discrepancy values. The clinically acceptable threshold remains controversial although, most authors agree that a marginal gap below 120 µm is clinically acceptable for cast crowns and all-ceramic crowns[9-12,21]. In the present study, the mean marginal gap of the metal-ceramic cowns was 84–101 µm and in the zirconia crowns was of 39–66 µm, therefore the values were within clinically acceptable limits. This is an important finding since the marginal adaptation is an important criterion for the success of ceramic restorations in the long-term. The measurements were performed after cementation to approximate the clinical situation, and although each crown was fabricated with different methods, the results indicated that the predetermined internal space of 50 µm in all crowns is adequate for the luting agent, as previously reported[9,23)]. By comparing the precision of fit, statistically significant differences was observed among the CAD/CAM experimental groups. Procera group exhibited the lowest marginal gap when compared to the other groups, as previously reported[7-9,15,23)]. Kim *et al.*[24)] reported that during the CAD/CAM process, the possibility of increasing the marginal discrepancies is present at every step. The differences in the results of the study could be explained by the differences in the scanners used. The precision of the digitizing method for the Procera group, using a mechanical scanner, might explain these results as previously reported[7,9,23,25)]. The metal-ceramic group demonstrated differences with respect to the internal marginal fit of zirconia groups. This confirmed that the CAD/CAM technique provided more precision than the conventional metal-ceramic technique[9,23)].

In this *in vitro* evaluation, no differences were observed between the buccal and the lingual surfaces. Previous studies have reported similar results[8,11,23)], however other authors have found significant differences between surfaces[9,26)], therefore additional studies are needed to clarify this aspect.

Up to date, there is a lack of consensus relating to marginal adaptation of various crowns systems due to differences in testing methods and experimental protocols employed[27)]. In the present study, marginal adaptation was evaluated by direct viewing with external and internal measurements and although various protocols have been proposed to analyze the marginal gap, no general guideline exists on how to perform gap measurements[9,15,27-29)]. Several direct and indirect methods are available for analyzing the marginal and internal adaptation of fixed prosthodontics restorations. Some methods include perfilometry[14)] and microfiltration with dyes, whose main drawback is the subjectivity inherent in using semi-quantitative measuring scales[17,18,30)]. Direct viewing with external measurements has the advantage of being noninvasive and is, therefore, useful to determine the precision of fit of the restorations[7,15,29)]. Several studies investigating the internal marginal fit are based on measurements of sectioned teeth, and although extremely accurate, these measurements result in the destruction of the restoration and consequently are of little use in clinical practice[15,20)]. Most methods for evaluating the internal marginal fit, however, involve the use of an intermediate material to create a replica of the interface. One such material is fluid silicone[24,25,28,31)], which may be subsequently weighed to calculate the gap or whose thickness is measured, by cross-sectional measurements of the replica material, examined under microscope or photographed for analysis using image management software, to ascertain the space occupied by the cement[22,24,26,32-34)]. This type of evaluation has inherent errors, such as cut being oblique and resulting in the introduction of error into the measurement[34)]. Jahangiri and Estafan[35)] corroborated the validity of the methods involving elastomeric materials to measure internal fit and supplement the measurements with mathematical analysis to determine both the volume and mean thickness of the space.

Some controversy has arisen around the measurement instruments, thus an optical microscope[20,24,28,31)], digital micrometer[36)], laser microscope[33)], or image analysis system[7-9,11,15,20,33)], have been proposed as an alternative to SEM[15,17-19,23,37)]. While some authors have found the precision obtained with an optical microscope and SEM to be similar[37)], other authors could not demonstrate which was the best method[15)]. Borba *et al.*[21)] found that the X-ray microtomography can be recommended as a useful tool for the marginal and internal fit evaluation of the restorations, and this technique is recommended for further research on marginal adaptation. Nonetheless, further *in vitro* studies on the marginal fit should be performed to determine the best measurement instrument. In the present study, SEM was used, and although it is difficult to repeat the measurements from an identical angle[20)], nevertheless, this aspect could be minimized by two factors: the use of experimental restorations, which had a better-defined and more regular margin and are thus easier to align with the focal plane of the microscope, and the positioning of the restorations in relation to a base to ensure that the measurements were always taken at the same points[7,9,15,17,18)].

Although several investigators analyzed the marginal and internal adaptation of restorations, studies concerning comparative analysis among measurement methods are very limited and the current state of research does not allow for a proper comparison of the various systems in terms of marginal fit[38)]. Some studies employed two different methods to evaluate the external ant internal marginal fit of the restorations, but no comparisons were done between the measurements[21,33,36)]. Ucar *et al.*[32)] compared direct and indirect methods (sectioned crowns/silicone weight) and have showed that both methods are acceptable and show similar results. The present study compared two direct SEM-based measurements to evaluate the marginal gap, and no differences were found between external and internal measurements. Since no previous comparative studies on the two techniques analyzed in the study were found in the literature, the present results could not be compared to other authors' observations. The results are important because demonstrate that it is not necessary to section the samples for the internal measurement of the marginal fit, and that the direct external measurement is enough and accurate to analyze the marginal fit of the restorations.

There were some limitations in the present study. The sample numbers were small, although power analysis indicated that 10 samples per group were sufficient. All copings were produced and tested under ideal conditions, which may not reflect conditions in daily clinical practice. However, standardized metallic dies were used in this study to accurately control the variables of preparation dimensions and other subsequent variables related to impression and pouring techniques[7,9,39]. The crowns were cemented under the same conditions and seating force and in the clinical condition, there will be a chance not to seat evenly when cementing. Another limitation of the study was that a different dental laboratory technician fabricated each group of crowns, however, in the present study, the internal surface of zirconia copings was not adjusted by the technician, avoiding that the proficiency of the technician could influence the results[17], although this does not reflect the clinical situation. The study includes measuring only the vertical marginal fit and this might no represent the precision of fit of the whole specimen[23,29].

Despite the variety of methodologies available, certain aspects have yet to be clarified and more studies are needed to compare the reliability of the instruments and the techniques used to measure the marginal fit in ceramic crowns and to conclusively determine the ideal technique for measuring marginal gap. It is also important to establish a standardized method to analyze the marginal fit of fixed prosthodontics restorations.

CONCLUSIONS

Within the limitations of this study, it was concluded that the vertical external and internal marginal adaptations values observed were within the clinically acceptable range (120 μm). The NobelProcera group presented the best mean marginal adaptation. No differences were observed between buccal and lingual measurements or between external and internal measurements.

AKNOWLEDGMENTS

The study was supported by Research Grant between the University Complutense of Madrid and 3M España (No. 26-2005), and Nobel Biocare Ibérica (No. 322-2005), through the last author. The authors are grateful for the contribution of the ceramic material by Vita Zahnfabrik and to the Dident, Poveda, and Prótesis dental laboratories for their technical advice and for manufacturing the crowns. The authors also thank Dr. Ricardo GARCÍA, from the Center for Data Processing, Computing Service for Research Support of the University Complutense of Madrid, for his assistance with the statistical analysis. The authors reported no conflicts of interest related to this study.

REFERENCES

1) Walton TR. An up to 15-year longitudinal study of 515 metal-ceramic FPDs: Part 1. Outcome. Int J Prosthodont 2002; 15: 439-445.
2) Layton D. A critical appraisal of the survival and complication rates of tooth-supported all-ceramic and metal-ceramic fixed dental prostheses: the application of evidence-based dentistry. Int J Prosthodont 2011; 24: 417-427.
3) Peláez J, Cogolludo P, Serrano B, L Lozano JF, Suárez MJ. A prospective evaluation of zirconia posterior fixed dental prostheses: Three-year clinical results. J Prosthet Dent 2012; 107: 373-379.
4) Raidgrodski AJ, Hillstead MB, Meng GK, Chung KH. Survival and complications of zirconia-based fixed dental prostheses: a systematic review. J Prosthet Dent 2012; 107: 170-177.
5) Sorensen JA. A rational comparison of plaque-retaining properties of crown systema. J Prosthet Dent 1989; 62: 264-269.
6) Knoernschild KL, Campbell SD. Periodontal tissue responses after insertion of artificial crowns and fixed partial dentures. J Prosthet Dent 2000; 84: 492-498.
7) Martínez-Rus F, Suárez MJ, Rivera B, Pradíes G. Evaluation of the marginal accuracy of zirconia-based all-ceramic crown systems. J Prosthet Dent 2011; 105: 108-114.
8) Gonzalo E, Suárez MJ, Serrano B, L Lozano JF. Marginal fit of zirconia posterior fixed dental prostheses. Int J Prosthodont 2008; 21: 98-99.
9) Gonzalo E, Suárez MJ, Serrano B, L Lozano JF. Precision of fit of zirconia and metal-ceramic posterior fixed partial dentures before and after cementation. J Prosthet Dent 2009; 102: 378-384.
10) McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971; 131: 107-110.
11) Suárez MJ, González de Villaumbrosia P, Pradíes G, Lozano JF. Comparison of the marginal fit of Procera All Ceram crowns with two finish lines. Int J Prosthodont 2003; 16: 229-232.
12) Quintas AF, Oliveira F, Bottino MA. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: an in vitro evaluation. J Prosthet Dent 2004; 92: 250-257.
13) Li RW, Chow TW, Martinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: State of the art. J Prosthodont Res 2014; 58: 208-216.
14) Mitchell CA, Pintado MR, Douglas WH. Nondestructive, in vitro quantification of crown margins. J Prosthet Dent 2001; 85: 575-584.
15) Gonzalo E, Suarez MJ, Serrano B, Lozano JF. Comparative analysis of two measurement methods for marginal fit in metal-ceramic and zirconia posterior FPDs. Int J Prosthodont 2009; 22: 374-377.
16) Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of margin fit. J Prosthet Dent 1989; 62: 405-408.
17) Oyagüe RC, Sánchez-Turrión A, L Lozano JF, Suárez MJ. Vertical discrepancy and microleakage of laser-sintered and vacuum-cast implant-supported structures luted with different cement types. J Dent 2012; 40: 123-130.
18) Castillo R, Lynch D, S Turrión A, L Lozano JF, Torres-Lagares D, Suárez MJ. Misfit and microleakage of implant-supported crown copings obtained by laser sintering and casting techniques, luted with glass-ionomer, resin cements and acrylic/urethane-based agents. J Dent 2013; 41: 90-96.
19) Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in-vitro testing. J Prosthet Dent 2000; 83: 40-49.

20) Gassino G, Barone Monfrin S, Scanu M, Spina G, Preti G. Marginal adaptation of fixed prosthodontics: A new in vitro 360-degree external examination procedure. Int J Prosthodont 2004; 17: 218-223.
21) Borba M, Cesar PF, Griggs JA, Della Bona A. Adaptation of all-ceramic fixed partial dentures. Dent Mater 2011; 27: 1119-1126.
22) Miura S, Inagaki R, Kasahara S, Yoda M. Fit of zirconia all-ceramic crowns with different cervical margin designs, before and after porcelain firing and glazing. Dent Mater J 2014; 33: 484-489.
23) Ortega R, Gonzalo E, Gomez-Polo M, Suarez MJ. 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.
24) Kim JH, Kim KB, Kim WC, Lee IH, Kim JH. Influence of various gypsum materials on precision of fit of CAD/CAM fabricated zirconia copings. Dent Mater J 2015; 34: 19-24.
25) Kokubo Y, Tsumita M, Kano T, Sakurai S, Fukushima S. Clinical marginal and internal gaps of zirconia all-ceramic crowns. J Prosthodont Res 2011; 55: 40-43.
26) Boening KW, Wolf BH, Schmidt AE, Kästner K, Walter MH. Clinical fit of procera all-ceramic crowns. J Prosthet Dent 2000; 84: 419-424.
27) Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: a literature review. J Prosthodont 2013; 22: 419-428.
28) Luthardt RG, Bornemann G, Lemelson S, Walter MH, Hüls A. An innovative method for evaluation of the 3-D internal fit of CAD/CAM crown fabricated after direct optical versus indirect laser scan digitizing. Int J Prosthodont 2004; 17: 680-685.
29) Koç E, Öngül D, Şermet B. A comparative study of marginal fit of copings prepared with various techniques on different implant abutments. Dent Mater J 2016; 35: 447-453.
30) Alani AH, Toh CG. Detection of microleakage around dental restorations: a review. Oper Dent 1997; 22: 173-185.
31) Lee KB, Park CW, Kim KH, Know TY. Marginal and internal fit of all-ceramic crowns fabricated with two different CAD/CAM systems. Dent Mater J 2008; 27: 422-426.
32) Ucar Y, Akova T, Akyil MS, Brantley WA. Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: Laser-sintered Co-Cr crowns. J Prosthet Dent 2009; 102: 253-259.
33) Komine F, Iwai T, Kobayashi K, Matsumura H. Marginal and internal adaptation of zirconium dioxide ceramic copings and crowns with different finish line designs. Dent Mater J 2007; 26: 659-664.
34) Coli P, Karlsson S. Fit of new pressure-sinterized zirconium dioxide copins. Int J Prosthodont 2004; 17: 59-64.
35) Jahangiri L, Estafan D. A method of verifying and improving internal fit of all-ceramic restorations. J Prosthet Dent 2006; 95: 82-83.
36) Milan FM, Consani S, Correr Sobrinho L, Sinhoreti MA, Sousa-Neto MD, Knowles JC. Influence of casting methods on marginal and internal discrepancies of complete cast crowns. Braz Dent J 2004; 15: 127-132.
37) Groten M, Girthofer S, Pröbster L. Marginal fit consistency of copy-milled all-ceramic crows during fabrication by light and scanning electron microscopic analysis in vitro. J Oral Rehabil 1997; 24: 871-881.
38) Contrepois M, Soenen A, Bartala M, Laviole O. Marginal adaptation of ceramic crowns: a systematic review. J Prosthet Dent 2013; 110: 447-454.
39) Gomez-Cogolludo P, Castillo-Oyagüe R, Lynch CD, Suarez-Garcia MJ. Effect of electric arc, gas oxygen torch and induction melting techniques on the marginal accuracy of cast base-metal and noble metal-ceramic crowns. J Dent 2013; 41: 826-831.