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Marginal Fit Evaluation of CAD/CAM All Ceramic Crowns Obtained by Two Digital Workflows: An In Vitro Study Using Micro-CT Technology

Ibrahim Salim Duqum, DDS, MS,[1] Christian Brenes, DDS, MS,[2] Gustavo Mendonca, DDS, MSc, PhD,[3] Thiago Almedia Prado Naves Carneiro, DDS, MSc, PhD,[4] & Lyndon F. Cooper, DDS, PhD[5]

[1]Division of Comprehensive Oral Health- Prosthodontics, Adams School of Dentistry, University of North Carolina at Chapel Hill, Chapel Hill, NC
[2]Department of General Dentistry, Dental College of Georgia at Augusta University, Augusta, GA
[3]Biologic & Materials Sciences, Division of Prosthodontics, University of Michigan, Ann Arbor, MI
[4]Department of Occlusion, Fixed Prostheses, and Dental Materials, School of Dentistry, Universidade Federal de Uberlândia, Uberlândia, Minas Gerais, Brazil
[5]Associate Dean for Research, College of Dentistry, University of Illinois at Chicago

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Correspondence
Ibrahim Duqum, DDS, MS, University of North Carolina at Chapel Hill, Adams School of Dentistry – Comprehensive Oral Health-Prosthodontics, Chapel Hill, North Carolina, 337 Brauer Hall, CB # 7450, Chapel Hill, NC 27599. Email: Ibrahim_duqum@unc.edu

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Abstract

Purpose: To evaluate the marginal fit of CAD/CAM all ceramic crowns made from lithium disilicate and zirconia using two different fabrication protocols (model and model-less).

Materials and Methods: Forty anterior all ceramic restorations (20 lithium disilicate, 20 zirconia) were fabricated from digital impressions using a CEREC Bluecam scanner. Two different digital workflows were used: a fully digital model-less approach and a printed model digital approach. The crowns were cemented on the respective prepared typodont teeth and marginal gap was evaluated using Micro-CT. Each specimen was analyzed in sagittal and trans-axial orientations, allowing evaluation of the marginal fit (vertical and horizontal) on each surface. Logarithmic transformation was used with a significance of 0.05. After that a reliability analysis was performed by re-measuring four randomized selected images for each specimen and performing intraclass correlations to determine any systematic bias in the measurements.

Results: Vertical measurements in the lingual, distal and mesial views had an estimated marginal gap ranging from 101.9 to 133.9 µm for lithium disilicate crowns and 126.4 to 165.4 µm for zirconia. No significant differences were found between model and model-less techniques.

Conclusions: Both workflows are valid protocols for the fabrication of monolithic ceramic restorations. The use of a printed model did not improve the marginal fit of lithium disilicate or zirconia crowns.

Both materials are also clinically acceptable, no matter which workflow was used to obtain the restoration.

Introduction

Dental crown restorations have been used for decades to restore compromised, heavily restored teeth, and for esthetic and functional improvements. The fabrication process of these restorations has been traditionally performed using elastomeric impression materials after tooth preparation followed by fabrication of a master cast with a die preparation. In the conventional workflow, the crown or the crown coping is produced by the lost wax technique, and where a compatible ceramic veneer is applied by layering or pressing.[1] Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology expanded the choices of contemporary ceramic materials and presents a viable alternative for the fabrication of dental restorations. The increased demand of contemporary ceramic material use is due to the excellent biocompatibility, strength, esthetics and reduced fabrication cost. Although emerging evidence indicates that all-ceramic restorations are viable alternatives to metal ceramic restorations, there is a need for a systematic comparisons of the marginal fit of full coverage CAD/CAM restorations and processing techniques.[2] Multiple recent studies examined the marginal fit of ceramic restorations fabricated using digital impression systems.[3-10] Many of these studies, compared the marginal fit using digital and conventional impressions and concluded that both protocols result in clinically acceptable marginal adaptation for the fabrication of indirect all ceramic dental restorations.[3,4,6,7,11,12] Nonetheless, another area that require further investigation is the validity of various digital workflows currently being utilized for digital crown fabrication.

It is well documented that long-term success in fixed prosthodontics is influenced by the accuracy of marginal adaptation of the restoration.[13] Marginal gaps can result in dissolution of cement, increased plaque accumulation, periodontal inflammation and secondary caries.[14,15] In an in vivo study by Felton et al. the marginal fit was strongly correlated with gingival inflammation.[16] Furthermore, Zoellner et al correlated the marginal adaptation of single restorations with secondary carious lesions using histologic evaluation and found that when taking into account the extension of secondary caries lesions undermined crown by up to 1 mm horizontally and 1.3 mm vertically.[17]

When CAD/CAM technology is used for the fabrication of all-ceramic restorations, multiple workflows can be implemented; indirect method involving milling or printing and investing of resin replicas that are later heat pressed, or a direct method which include the milling of various ceramic and composite materials. Two popular contemporary ceramic materials that can be milled in dental offices or laboratories are lithium disilicate and zirconia. Lithium disilicate blocks are partially sintered and relatively soft; they are easier to mill and obtain the desired restoration; after this process, the material is usually heated to 850°C for 20 to 30 minutes to transform the material to the fully crystalized stage. This sintering step is associated with a 0.2% shrinkage accounted for by the CAD software.[18] On the other hand, zirconia ceramics blocks can be milled in a partially sintered state (green state), or in a fully sintered state. The green state is easier and faster to mill; however, volume shrinkage of 25% to 35% occurs during the sintering process. Fully sintered zirconia requires more time and intensive milling process; this process may cause "microdefects" in the restoration or surface flaws that can degrade the final strength and potentially result in chipping of the marginal areas of the final restoration.[1]

Capturing the tooth preparation details via a final impression is a critical step in fixed prosthodontics therapy. Currently this can be performed utilizing conventional elastomeric impression materials or digitally by an optical surface scanner. Seelbach et al demonstrated that conventional impression techniques using vinyl polysiloxane were no better than digital impressions made using several intraoral scanners.[12] The aim of this investigation was to compare using microCT(μCT) technology the marginal fit of crowns fabricated using a model-less and model approach for both lithium disilicate and zirconia materials. Additionally we also evaluated the overall marginal fit of lithium disilicate and zirconia crowns. The null hypothesis is that crowns fabricated using the two different workflows would have similar marginal adaptation.

Materials and methods

Forty typodont maxillary left canine teeth were prepared for all ceramic crowns by dental students enrolled in the preclinical fixed Prosthodontics course at the University of North Carolina School of Dentistry. The preparation parameters were: 1.3 to 1.5 mm chamfer finish line, axial reduction of 1.5 to 1.8 mm, 2 mm incisal reduction and occlusal palatal clearance of 1.5 mm with a rounded/smooth outline. All the preparations were scanned using laser-based intraoral scanner (CEREC Blue Cam, Sirona, Charlotte, NC) after coating the preparation, adjacent teeth and opposing teeth with scanning powder (CEREC Optispray, Sirona, Charlotte, NC). For bite registration, maxillo-mandibular relations were captured using a buccal scan for virtual articulation. The digital files were sent via Cerec-Connect software to two different commercial dental laboratories for crown fabrication. Forty anterior all ceramic restorations (20 lithium disilicate, 20 zirconia) were fabricated. Two different workflows were used: a fully digital model-less approach and a printed cast digital approach.

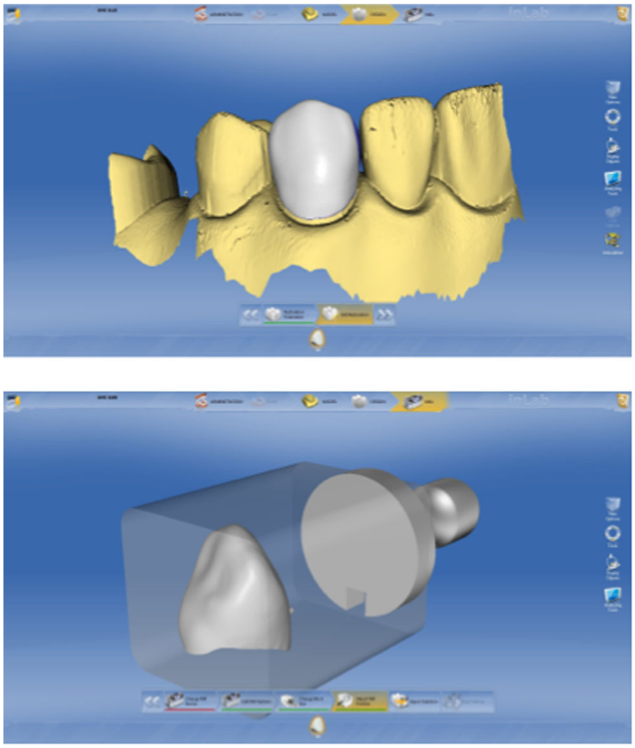


Figure 1 Crown design using InLab software (Sirona Dental).

For the model-less group the files were downloaded and transferred to the CAD software for crown design (Cerec In Lab 4.2.3). Crowns were designed and then sent to the CAM nesting software for the milling process (Fig 1). Luting space and adhesive gap were set at 80 μm. One dental laboratory used a 5-axis Roland DWX-50 milling machine to fabricate crowns from ArgenZ high translucency zirconia discs (98 mm). Milled crowns were sintered at 1530 to 1560°F. The second laboratory fabricated lithium disilicate crowns (IPS e.max CAD, Ivoclar Vivadent, Vident) using an MC XL milling machine (Sirona) and crowns were crystallized at 1545°F for 17 minutes. All restorations were stained, glazed, and returned for seating and cementation.

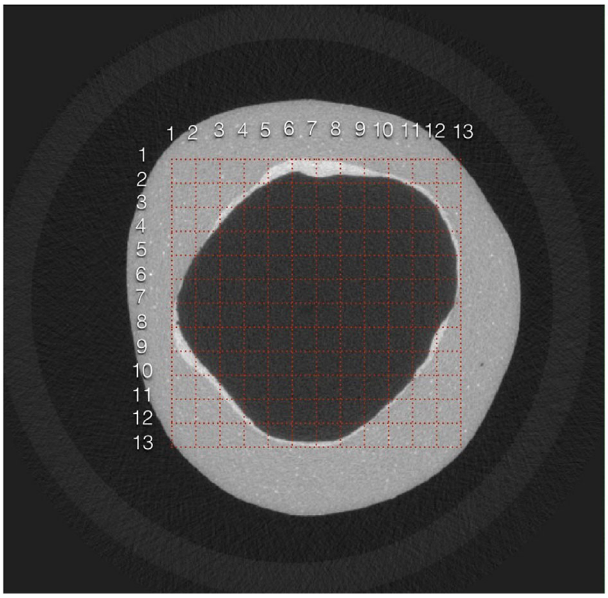
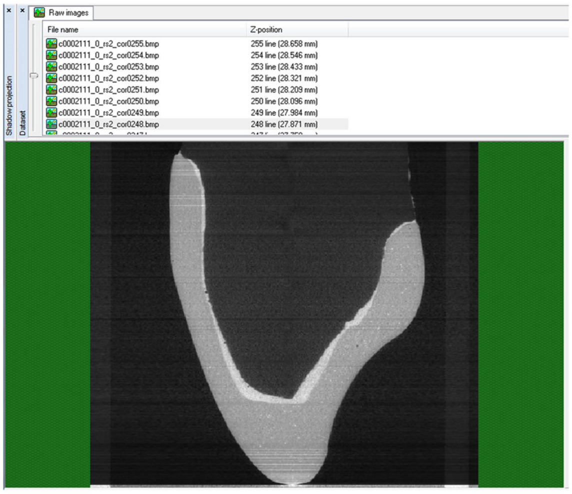


Figure 2 Esquematic representation of the 26 images selected for analysis in the micro-CT coronal view of the specimen.



File name	Z-position
c0002111_0_rs2_cor0255.bmp	255 line (28.658 mm)
c0002111_0_rs2_cor0254.bmp	254 line (28.546 mm)
c0002111_0_rs2_cor0253.bmp	253 line (28.433 mm)
c0002111_0_rs2_cor0252.bmp	252 line (28.321 mm)
c0002111_0_rs2_cor0251.bmp	251 line (28.209 mm)
c0002111_0_rs2_cor0250.bmp	250 line (28.096 mm)
c0002111_0_rs2_cor0249.bmp	249 line (27.984 mm)
c0002111_0_rs2_cor0248.bmp	248 line (27.871 mm)

Figure 3 Micro-CT sagittal image of crown at 100x magnification.

The model group workflow the files were also downloaded and transferred to the CAD software for crown design (Cerec In Lab 4.2.3). Casts for each specimen were also obtained after digital impression and virtual model acquisition (Sirona Infinident, Charlotte, NC). The dental laboratory received the printed casts to verify the marginal fit and contacts of the restorations previously designed using the virtual models and milled in monolithic ceramic materials. If needed the restorations were adjusted, then stained and glazed. After that, they were returned for seating and cementation.

All the crowns for both groups were seated by the dental students under faculty supervision following a standardized protocol consisting of evaluating the proximal contacts, marginal fit clinically using a dental explorer and GC fit checker silicone based material (GC Fit Chek, GC America), occlusal contacts and axial contours. After the crowns were approved by the supervising faculty they were cemented to the typodont tooth using a dual cure self-adhesive resin cement (Rely X Unicem, 3M ESPE). After the completion of the laboratory exercise all specimens were collected and submitted for analysis using μCT scanner.

All 40 specimens were scanned for marginal fit analysis using a quantitative microcomputed tomography scanner (Scanco micro-CT 40 scanner; Scanco Medical AG, Zürich, Switzerland) at the Biomedical Research Imaging Center (BRIC) at the University of North Carolina. Digital Imaging and Communications in Medicine (DICOM) files were generated using a 70-kilovolt peak (kVp) with a resolution of 1024 × 1024 pixels; the pixel size for the slice width were 8 μm nominal isotropic with a scan time of approximately 40 minutes.

All the images were analyzed in the sagittal and transaxial views with the a processing software (Skyscan, Bruker Corporation, Kontich, Belgium). The analysis protocol consisted of a total of 26 images within the 360° perimeter. Thus, 13 images per perspective (sagittal and transaxial) were evenly distributed around the cervical margin (Fig 2). For each image two horizontal and two vertical measurements corresponding to the buccal and lingual or mesial and distal were taken at 400× magnification (Fig 3). Totaling 56 measurements per tooth. The vertical measurements were made from the external crown margin to the most external point of the tooth. For the horizontal marginal fit, measurements are made from the most external point of the margin of the tooth to the crown margin (Fig 4).

The examiner was calibrated according to previous experiments[21,29] before starting all measurements and results were computed and organized in a Microsoft Excel document for statistical analysis. Descriptive statistics were performed; there were 10 specimens for each group with 13 correlated images with measurements for each surface according to previous publications.[21,29] Four continuous outcomes (Buccal, Lingual, Mesial, and Distal), were measured on each image for horizontal and vertical marginal fit. Logarithmic transformation was used for each outcome variable. Each of the variables were normally distributed after transformation. Linear mixed models were used to assess the main effect of two explanatory variables, model type (model and model-less) and material (Lithium disilate and Zirconia), on each outcome variable. The interaction term was not included due to the small sample size. The analysis was conducted separately for each direction. A compound symmetric variance-covariance structure was assumed. Level of significance was set at 0.05. Least square means for each outcome were calculated for the main effects from the linear mixed models. All analyses were performed with SAS 9.3 (SAS institute, Cary, NC).

A reliability analysis was performed by re-measuring four randomized selected images for each specimen and performing intra-class correlations to determine any systematic bias in the measurements.

Results

Tables 1 and 2 shows the statistical analysis of marginal fit. Table 1 presents the results of marginal fit for each surface and different materials. For all outcomes, the average marginal fit

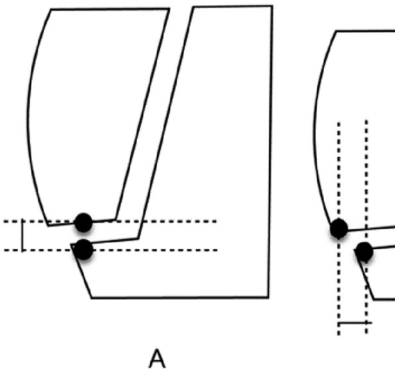


Figure 4 (A) Schematic representation of the vertical marginal fit to be evaluated in the Micro CT. (B) Horizontal marginal fit.

Table 1 Result of linear mixed models with compound symmetric covariance structure for each outcome by direction

Direction	Outcome	Effect	Num DF/ Den DF	F	*p* Value*
Sagittal	Vertical B	Model type	1/37	0.93	0.341
		Material	1/37	0.14	0.713
	Vertical L	Model type	1/37	0.38	0.543
		Material	1/37	8.56	0.006*
	Horizontal B	Model type	1/37	0.07	0.793
		Material	1/37	4.76	0.036*
	Horizontal L	Model type	1/37	17.48	<.001*
		Material	1/37	29.46	<.001*
Transaxial	Vertical D	Model type	1/37	3.57	0.067
		Material	1/37	4.20	0.048*
	Vertical M	Model type	1/37	0.83	0.367
		Material	1/37	4.30	0.045*
	Horizontal D	Model type	1/37	1.51	0.227
		Material	1/37	2.92	0.096
	Horizontal M	Model type	1/37	0.30	0.585
		Material	1/37	0.83	0.367

*Statistically significant difference ($p < 0.05$).

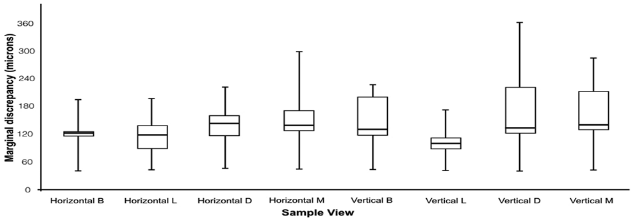


Figure 5 Box plot representation of the horizontal and vertical values (μm) for lithium disilicate group with a cast. Graphic representation of the specimen medians for the 4 groups including quartiles. (A) lithium disilicate model (B) lithium disilicate model-less (C) Zirconia model (D) Zirconia model-less.

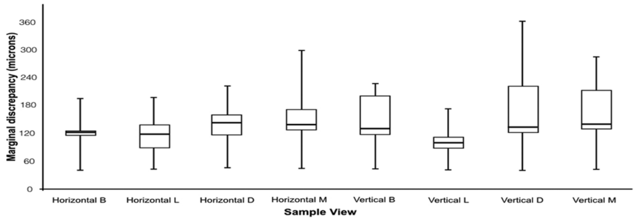


Figure 6 Box plot representation of the horizontal and vertical values (μm) for lithium disilicate group model-less.

was larger for zirconia than for lithium disilicate. Table 2 shows the difference between groups (model and model-less) and materials (lithium disilicate and zirconia) according to the different directions (buccal-lingual and mesio-distal) and outcomes (vertical and horizontal). The average marginal fit as determined by micro-CT analysis for the surfaces that showed statistically significant results were estimated as follows: the estimated horizontal marginal fit of the buccal view was 133.9 μm for lithium disilicate and 156.3 μm for zirconia ($p = 0.036$); the horizontal marginal fit in the lingual surface was 122.7 μm and 165.4 μm for lithium disilicate and zirconia ($p < 0.001$) respectively. On the other hand, the vertical marginal fit in the lingual view was 101.9 μm for lithium disilicate and 140.2 μm for zirconia ($p = 0.006$); the marginal fit in the distal surface was 104.6 μm for lithium disilicate and 126.4 μm for zirconia ($p = 0.048$); the marginal fit in the mesial surface was 111.8 μm for lithium disilicate and 142.9 μm ($p = 0.045$), respectively. In regard to the fabrication technique marginal discrepancies values were statistically different only for horizontal lingual between model-less (127 μm) and model (158.8) ($p < 0.001$). Table 3 shows the mean difference, standard deviation and paired t-test from the reliability analysis. The intraclass correlation coefficients results were 0.99 indicating high concordance between measurements beyond that expected by chance and there is no statically significant values from the paired tests indicating that there is no systematic bias and high consistency between measurements.

Figures 5 to 8 also show the values of horizontal and vertical marginal fit for each group according to the tooth surfaces. The percentage of restorations that were under 120 μm was 48% for lithium disilicate and 25% for Zirconia restorations.

The intraclass correlation coefficients results were 0.99 indicating high concordance between measurements beyond that expected by chance and there is no statistically significant values from the paired tests indicating that there is no systematic bias and high consistency between measurements.

Discussion

Based on our experiments and results the null hypothesis that the different fabrication protocols (Model vs. Model-less) would not affect the marginal fit of the restorations was accepted. Our secondary outcome showed that marginal fit of lithium disilicate crows was different from zirconia crowns. One major limitation of this study was the fact zirconia and lithium disilicate crowns were fabricated by different laboratories and these could have affected the marginal fit of the restorations Nonetheless these two materials have different milling protocol and this also can be the reason for the different marginal fit.

Christensen (1966) suggested that clinically detectable supragingival and subgingival margins are in a range of 2 to 51 μm and 34 to 119 μm, respectively.[19]McLean (1971)

Table 2 Least square means from the linear mixed models ($p < 0.05$)

				Log-10 transformed values		Re-transformed to raw values	
Direction	Outcome	Effect		Est	Difference	Est	Ratio
Sagittal	Vertical B	Model_Type	Model	2.06	−0.06	115.82	0.88
			Model-less	2.12		132.34	
		Material	lithium disilicate	2.08	−0.02	120.67	0.95
			Zirconia	2.10		127.03	
	Vertical L	Model_Type	Model	2.09	0.03	123.65	1.07
			Model-less	2.06		115.64	
		Material	lithium disilicate	2.01	−0.14	101.95	0.73*
			Zirconia	2.15		140.25	
	Horizontal B	Model_Type	Model	2.16	0.01	146.05	1.02
			Model-less	2.16		143.35	
		Material	lithium disilicate	2.13	−0.07	133.91	0.86*
			Zirconia	2.19		156.35	
	Horizontal L	Model_Type	Model	2.20	0.10	159.85	1.26*
			Model-less	2.10		127.06	
		Material	lithium disilicate	2.09	−0.13	122.77	0.74*
			Zirconia	2.22		165.42	
Transaxial	Vertical D	Model_Type	Model	2.10	0.08	125.55	1.19
			Model-less	2.02		105.39	
		Material	lithium disilicate	2.02	−0.08	104.62	0.83*
			Zirconia	2.10		126.47	
	Vertical M	Model_Type	Model	2.08	−0.05	119.78	0.90
			Model-less	2.13		133.44	
		Material	lithium disilicate	2.05	−0.11	111.84	0.78*
			Zirconia	2.16		142.92	
	Horizontal D	Model_Type	Model	2.19	0.04	153.57	1.09
			Model-less	2.15		141.22	
		Material	lithium disilicate	2.14	−0.05	138.90	0.89
			Zirconia	2.19		156.13	
	Horizontal M	Model_Type	Model	2.12	−0.02	132.31	0.96
			Model-less	2.14		137.25	
		Material	lithium disilicate	2.14	0.03	138.90	1.06
			Zirconia	2.12		130.74	

B = buccal; L = lingual, D = distal; M = mesial.

*Statistically significant difference ($p < 0.05$) (see Table 2).

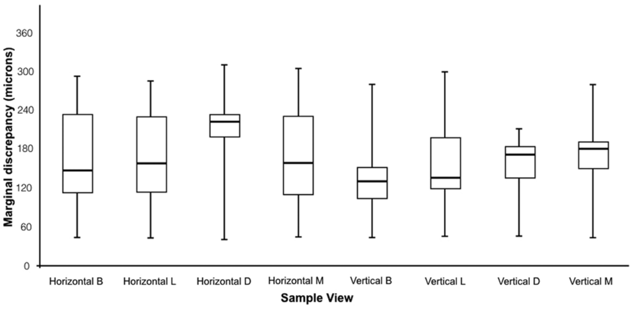


Figure 7 Box plot representation of the horizontal and vertical values (μm) for Zirconia group with a cast.

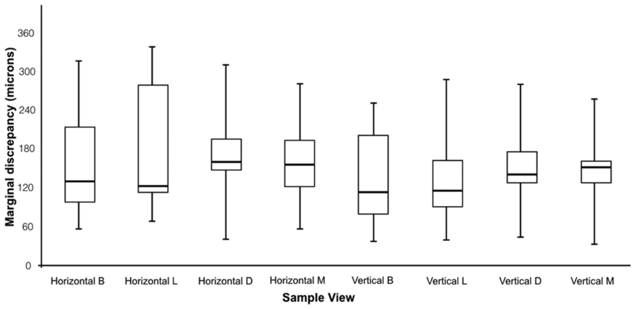


Figure 8 Box plot representation of the horizontal and vertical values (μm) for Zirconia group model-less.

suggested that 120 μm should be the limit for clinically acceptable marginal discrepancies.[20] There are other classifications of acceptable marginal fit. Neves et al showed different acceptable marginal discrepancies described in the literature and also suggested a new acceptable limit under 120 μm.[21] Holmes, et al defined absolute marginal fit for the first time and affirmed that that marginal fit should be considered as the angular combination of the vertical and horizontal error.[22]

Table 3 Mean difference and paired t-test

		Original (matched to reassessment)		Reassessment		Paired t-test		
Direction	Variable	Mean	Std Dev	Mean	Std Dev	t	DF	*p*
Sagittal	VBD	147.55	95.47	148.29	92.87	−0.66	39	0.51
	VLM	142.87	97.19	141.97	98.17	0.51	39	0.62
	HBD	151.30	48.55	153.32	47.95	−2.03	39	0.05
	HLM	156.32	78.47	156.68	77.04	−0.27	39	0.79
Trans-axial	VBD	136.37	79.38	137.62	77.73	−1.00	39	0.33
	VLM	139.51	94.39	138.78	94.12	0.63	39	0.53
	HBD	157.19	61.92	154.89	60.68	1.30	39	0.20
	HLM	141.72	57.47	141.19	57.30	0.38	39	0.71

Evaluation techniques for clinical and laboratory measurement of marginal fit include the use of direct view and clinical evaluation techniques, cross-sectioning technique, replica technique, profile projector, digimatic micrometer, 3D reconstruction and micro computed tomography (μCT).[23] The main advantages with 3D reconstruction and μCT methods is that angulation and deformation are not incorporated in the analysis of the specimens and they represent non-destructive methods of investigation.[21]

It is important to note that the crown marginal fit is a culmination of an entire digital workflow. The marginal fit in CAD/CAM is dependent on the size of the cutting instrument, precision of the milling unit, digital cast rendering, the machine calibration and system for image capturing. So, to make a fair comparison, it is necessary to consider the system, its version, the measurement technique, the type of restoration (crowns, inlays, onlays), and restorative material.[21,24] The materials per se do not represent the only variable in the process. A central difference in the fabrication of the zirconia versus lithium disilicate crowns was the CAD/CAM mill. This is complicated by the dry versus wet nature of milling zirconia versus lithium disilicate, the potential differences in nesting programs, tool path determination and integral dimensional constraints or calibration effects of the individual mills. Further, the dimensional inaccuracies associated with shrinking during the sintering process and individual handling may have affected the fabrication of the zirconia crowns.

Moreover, the technician's impact on design also influences outcomes; for example, the virtual configuration of the die spacer between the tooth and the restoration is essential for the accuracy of the marginal adaptation. Studies have demonstrated that the difference of marginal fit between CAD/CAM restorations is directly related to the gap parameters from the computer design and also related to the intrinsic properties of the CAD/CAM system.[25] Recent studies compared restorations fabricated utilizing digital impression systems to ones compared with traditional impression techniques and found out that both techniques results in acceptable marginal fit.[3,4,12] Although, CAD/CAM fabricated restorations provide acceptable marginal fit, recent evidence still show improved marginal fit. with heat pressed fabricated ceramic restorations.[7,10,26] Also, in commercial laboratories protocols should be established to evaluated fit of crowns that are fabricated and avoid errors in calibration and wear and tear of machines.

The approach employed in the present study was to simulate a realistic environment to evaluate restorations made by clinicians on daily basis were no standardized preparations are used, the majority of the investigations focus primarily in achieving the best possible accuracy that can be obtained from the systems under ideal conditions eliminating the influence of common clinical errors. For a precise analysis of the materials and systems used in this study a more standardized protocol would help to support the results and understand the differences between the different materials. In relation to the CEREC system, most investigators assessed inlay and onlay restorations based on previous CEREC casts before CEREC Bluecam; this data cannot be directly compared to the actual system as the manufacturer has improved the camera, software and hardware since then. More recently during the preparation of this manuscript after the acquision of data an even more recent scanner has been released (Cerec Omnicam) that could also affect our results. Recent standardized in vitro studies from Lee et al reported a mean marginal fit of 89.5 μm using Mark II milling blocks.[27] More recently, Neves et al. reported a marginal fit of 39.2 μm for lithium disilicate in a standardized in vitro study from the Roland DWX-50 milling machine.[21] Another important factor to consider is the cement and the cementation process. The cement generally can increase the fit of marginal extent, since the excesses adhere to the tooth surface and in the restoration.[28] Additionally, the specimens in this study were cemented using a resin cement and by students performing their first cementation exercise. This may help explain the larger that usual marginal fit of the restorations that were deemed clinically acceptable by the supervising faculty utilizing conventional crown marginal fit evaluation methods.

An important finding of our study is that there is no significant difference between the marginal fit of crowns fabricated with a fully model-less digital approach versus the digital protocol utilizing printed casts. Our results are in agreement with a previous study which reported no significant difference between the marginal fit of crowns fabricated with a full model-less digital approach versus the conventional technique using stone casts.[29] Thus, both workflows are valid protocols for the fabrication of monolithic ceramic restorations. The elimination of cast fabrication would facilitate and expedite the manufacturing process without compromising the marginal adaptation of restoration. Also, the fabrication of casts with different 3D printers have to be evaluated as this can also be a source of error in this process. Most importantly all the equipment used in fabrication of an all ceramic restoration including, intra-oral scanners, 3D printers and milling machines have to be evaluated on a routine basis to ensure proper calibration.

During the fabrication process, dental laboratories use stone or printed casts mainly to check proximal contacts, occlusal contacts and contours. The process is very standardized and predictable once clinicians reach the learning curve of the digital system they use for crown fabrication. However, having casts for verification is not as important for monolithic restorations. Digital dentistry is a great tool for evaluation of restorations during the fabrication process as it provides ways view restoration in magnified fashion and also quantifies proximal and occlusal contacts.

Conclusion

No statistically significant differences were observed when comparing model or model-less workflows for the processing of single unit lithium disilicate and zirconia crowns, in regards to their marginal fit. Within the limitation of this study and equipment used both workflows are valid protocols for the fabrication of monolithic ceramic restorations. The use of a printed model did not improve the marginal fit of lithium disilicate or zirconia crowns. Both materials are also clinically acceptable, no matter which workflow was used to obtain the restoration.

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