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Influence of the Fabrication Technique on the Marginal and Internal Adaptation of Ceramic Onlays

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Clinical Relevance

CEREC BlueCam and CEREC OmniCam CAD-CAM systems were able to fabricate onlays with clinically acceptable marginal discrepancies, below 100 μm; however, the Press system presented superior internal and marginal adaptation.

SUMMARY

This study aimed to evaluate the marginal and internal adaptation of partial coverage crowns (ceramic onlays) fabricated with Press, CEREC BlueCam, and CEREC OmniCam systems, using two preparation designs and evaluating the internal discrepancies at different locations. Two phantom maxillary premolars (master teeth) received different preparation designs, with (BX) and without (NB) a modified occlusal box with round internal angles. Sixty IPS e-max ceramic restorations were fabricated with three systems: Press (n=20), CEREC BlueCam (n=20), and CEREC OmniCam (n=20). Both marginal and internal discrepancy width were measured by using a stereomicroscope at ×25 magnification. The data were evaluated statistically using analysis of variance followed by Tukey's Honestly Significant Difference test (α=0.05). The ceramic restorations fabricated with the Press system presented significantly smaller marginal and internal disadaptations than the BlueCam and OmniCam CEREC systems (*p*<0.0001). Regarding the preparation designs, preparation BX presented the smallest marginal discrepancies for all fabrication systems and larger internal discrepancies than for restorations fabricated with the Press system. The occlusal location presented a larger internal discrepancy compared with the axial locations. Although the three systems resulted in the fabrication of restorations within a clinically acceptable adaptation with marginal discrepancies below 100 μm, the Press system presented the smallest marginal and internal discrepancies. An improved marginal adaptation was observed in the preparation design with a modified occlusal box with rounded internal angles.

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INTRODUCTION

The introduction of computer-aided design/computer-aided manufactured technology (CAD-CAM) has allowed the use of high-performance materials to fabricate dental restorations.[1,2] Among these materials, ceramics have been widely used to attend to the increasing demand for conservative and esthetic treatments.[2-4] In this context, partial coverage crowns (PCCs) or onlays are indicated to restore complex cavity preparations to provide superior esthetics and anatomic contours in occlusal and proximal locations while preserving more tooth structure compared with full coverage crowns.[5] Glass ceramics possess excellent optical properties that result in highly esthetic restorations due to the so-called chameleon effect.[6] The preparation design for ceramic onlays requires divergent walls (15°), round internal line angles, supragingival margins, and avoidance of bevels and sharp angles. These features facilitate the scanning and milling procedures for CAD-CAM restorations.[2,4] Differently from traditional gold onlays, the use of frictional retention on preparations is contraindicated to prevent stress and consequent crack initiation in ceramic materials,[7] which are adhesively bonded to the dental tissues.[7-9]

A range of glassy and polycrystalline ceramic materials are available for laboratory and/or chairside use. They vary in composition and processing techniques, allowing different methods of fabrication, such as powder condensation (conventional powder slurry ceramics), heat-pressed (pressable ceramics), split casting (infiltrated ceramics), and milled (machinable or CAD-CAM ceramics).[10] The CAD-CAM system uses a scanning device, design software, and a milling machine to fabricate restorations.[1] As a result, the professional can take digital scans with a handheld three-dimensional intraoral scanner, using a compact chairside CAD-CAM unit that allows either sending them to a laboratory to fabricate the restoration or milling in-house.[1,11] The CAD-CAM system uses presintered ceramic blocks, which can be composed of feldspathic porcelain-based ceramics, leucite-reinforced glass ceramics, lithium-disilicate glass ceramics, glass infiltered ceramics (or polycrystalline alumina), or zirconia materials.[1,2] Each material presents different mechanical, physical, and optical properties, which should be taken into consideration according to the type of restoration (partial or total), location (anterior or posterior), and esthetic requirements.

IPS e.max lithium disilicate (Ivoclar Vivadent AG, Schaan, Liechtenstein) restorations can be fabricated by using either CAD-CAM milling procedures (IPS e.max CAD) or the lost-wax techniques (IPS e.max Press).[11] The use of a chairside CAD-CAM system offers advantages regarding the elimination of conventional impressions taken with polyvinyl siloxane (PVS) materials, need for disinfection, shipment to the laboratory, and use of temporary restorations. Although the three-dimensional intraoral camera can provide a high level of detail of the prepared teeth and the surrounding tissues, there are still questions regarding the accuracy of marginal and internal fit that the CAD-CAM systems can provide. Marginal fit is considered an important criterion for the clinical success of indirect restorations because the presence of gaps can favor biofilm accumulation and secondary caries.[5] Internal gap is related to the accuracy of the internal fit of the restoration and determines the space to be filled by the cement.[12] As a result, factors such as preparation design,[5,13,14] impression technique,[15] luting agent,[8] and system used to fabricate the restoration[2] may influence marginal and internal adapatation.

The survival rates of ceramic onlays range from 93% to 98% at five years and from 64% to 95% after 10 years.[16,17] The high success rate is attributed to the capacity of these glass-ceramic systems to be etched and bonded to the tooth structure with resin-based cements.[4,18] The most common causes of failure are related to fracture of the ceramic material and recurrent caries.[4,19] Previous studies have reported that lack of precision in internal fit could heighten the risk of fractures in ceramic materials.[20,21] For this reason, studies evaluating the internal space to be occupied by the cement are relevant. Furthermore, the internal and marginal adaptation of CAD-CAM restorations may be influenced by the characteristics of preparation design, because the internal features of the restorations are directly related to the diameter of the burs used in the milling machine during manufacturing.[21-23]

CAD-CAM systems have evolved since their introduction in the 1980s. The first Chairside Economical Restoration of Esthetic Ceramics (CEREC) systems, CEREC 1 and 2, presented poor esthetic results, and the average marginal discrepancies were approximately 308 and 207 μm, respectively.[24] Smaller marginal discrepancies have been reported for the CEREC 3 system, ranging from 27 to 162 μm.[25,26] In terms of internal fit, studies have reported internal discrepancies of 212 ± 45 μm for CEREC 2 and 146 ± 15 μm for CEREC 3.[25,27] Furthermore, the esthetic features of the CAD-CAM

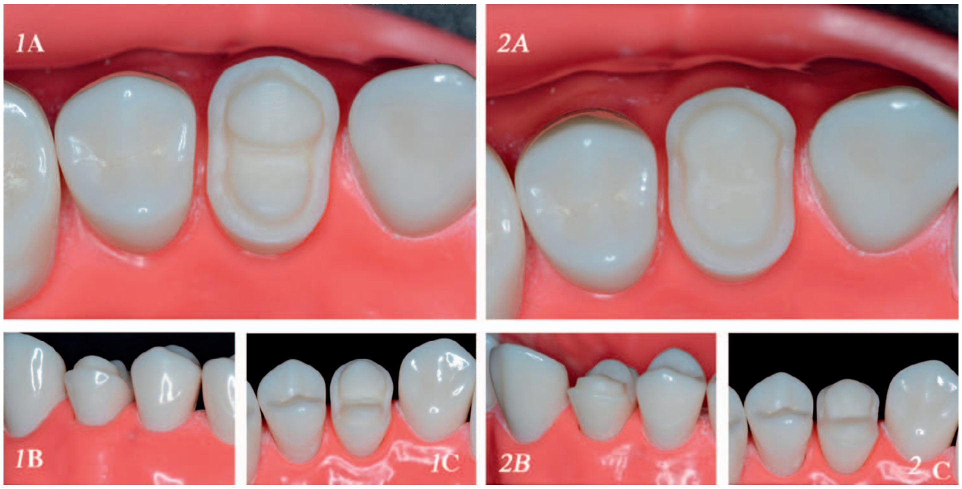

Figure 1. *Preparation BX (with occlusal box).*

Figure 2. *Preparation NB (without occlusal box).*

restorations have improved with the introduction of presintered ceramic blocks that are able to create a natural and harmonious transition between a more translucent shade at the occlusal to a more opaque and saturated shade at the cervical area.[28] Additionally, new technologies with improved software versions and three-dimensional intraoral scanners have been released. The CEREC OmniCam system has been introduced in the market, exempting the use of a reflective powder for image capture, and resulting in fewer clinical steps. However, there are still questions regarding its accuracy to generate restorations with superior adaptation compared with other systems. Hence, further investigations are necessary to understand the impact of CAD-CAM technology on the marginal and internal fit of ceramic restorations.

The present study aimed at evaluating the marginal and internal adaptation of PCCs (ceramic onlays) fabricated with heat-pressed (Press), CEREC BlueCam, and CEREC OmniCam systems, using two preparation designs. The three null hypotheses to be tested were that there are no differences on the marginal and internal adaptations: (1) between the three systems used to fabricate the ceramic onlays; (2) between the two preparation designs tested; and (3) between different locations of the internal space of ceramic onlays.

METHODS AND MATERIALS

Onlay Preparations

Two plastic teeth from a phantom model (maxillary right first premolars, Typodont, Kilgore International, Coldwater, Michigan, USA) received two ceramic onlay preparation designs (Figures 1 and 2). Both preparations presented divergent walls (15°), round internal line angles, 2-mm cusp reduction, 1.25-mm shoulder around the margins, and 0.5- to 1-mm supragingival margins. Preparation BX (box) consisted of a modified occlusal box with rounded internal angles and the reduction of both facial and lingual cusps. Preparation NB (no box) presented no occlusal box with the reduction of both facial and lingual cusps. Cavity preparations were performed with flat-end tapered diamond burs with rounded angles #6845 and #837 KR (Brasseler, Savannah, GA, USA) by the same operator using magnifying glasses (2.5×) and headlights.

Sixty indirect restorations were fabricated using three systems: pressable ceramics (n=20); CAD-CAM CEREC BlueCam (n=20); and CAD-CAM CEREC OmniCam (n=20). For the heat-pressed technique, 20 impressions were made using polyvinyl siloxane (Imprint 3, 3M ESPE, Minneapolis, MN, USA) impression material to obtain 10 plaster models from each preparation design, using a die stone of type IV gypsum (Lean Stone, Whip Mix, Louisville, Kentucky, USA). The models were sent to the laboratory to fabricate the restorations using presintered ceramic blocks (IPS e-max Press, Ivoclar-Vivadent AG). The restorations were milled in fine mode, using the milling machine burs (12S Step Bur, 1.4 mm; and 12S Cylinder Pointed Bur, 1.4 mm; Sirona MC XL, Dentsply Sirona, Konstanz, Germany). Burs were replaced after each 10 specimens to avoid variations between groups.

For the CAD-CAM CEREC BlueCam, a thin layer of a reflective powder (IPS Contrast Spray Labside, Ivoclar Vivadent AG) was used to spray the master models, and 20 digital scans were obtained, 10 from each preparation design. To standardize the acquisition process of digital models for the BlueCam group, a total of 10 to 15 snaps were taken from

Figure 3. *View of preparation BX with occlusal box: Ominican system.*

Figure 4. *View of preparation NB without occlusal box: Ominican system.*

predetermined areas of the maxillary right quadrant to allow the acquisition of satisfactory digital models. For the CAD-CAM CEREC OmniCam, 20 digital scans were obtained, 10 from each preparation design (Figures 3 and 4). The image acquisition of the OmniCam group consisted of a sequence of consecutive movements with the handheld scanner without the use of a reflective powder, following the manufacturer's instructions. For both CAD-CAM groups, biogeneric onlay restorations were designed using the CEREC 4.2 software, and restorations were fabricated in the milling cabinet (CEREC MC XL, Dentsply Sirona) using presintered ceramic blocks (IPS e-max CAD, Ivoclar Vivadent AG). The following preset parameters were used, as suggested by the manufacturer's instructions: spacer, 120°; marginal adhesive gap, 60 μm; occlusal milling offset, 0 μm; proximal contacts strength, 25 μm; occlusal contact strength, 25 μm; dynamic contacts strength, 25 μm; minimal thickness (radial), 500 μm; minimal thickness (occlusal), 700 μm.

Measurement of Marginal Fit

To measure the marginal adaptation, each ceramic restoration was placed on the prepared master tooth and stabilized with composite resin (Filtek Supreme Ultra, 3M ESPE) at two external points away from the margins and connected by a metal wire. The margins of the restorations were measured at four locations (facial, lingual, mesial, and distal) using an optical stereomicroscope (Leica S6 D, Leica Microsystems, Buffalo Grove, IL, USA) at ×25 magnification and a digital camera (EC3, Leica Microsystems) coupled to the optical stereomicroscope. An imaging software (LAS Application Software Modules, Leica Microsystems) was used to measure the distance between the border of the ceramic restoration and the margin of the preparation at the four locations. For each location, three measurements were taken from four predetermined points, which resulted in a total of 48 measurements from each sample analyzed. The average number (μm) obtained from each location was calculated, and the data were submitted for statistical analysis.

Measurement of Internal Fit

The internal fit was evaluated using the replica technique reported by Souza and others[25] and Bottino and others,[26] which consists of measuring a thin layer of extra-light-body PVS impression material (Imprint 3, 3M ESPE) placed between the master tooth preparation and the restoration. The prepared tooth was filled with a thin layer of extra-light-body PVS, a ceramic onlay was placed over the PVS material, and a load of 750*g* was applied over the onlay to assure maximum fit. After the impression material was set, the load and onlay were removed, leaving a thin film of silicone adhering to the preparation, representing the space between the onlay and the tooth preparation. For the purpose of stabilization, a light-body PVS (Imprint 3, 3M ESPE) with a different color was placed in the space previously occupied by the onlay, which set over the light-body PVS film. With this procedure, the thin film of extra-light-body PVS could be removed from the preparation without plastic deformation, allowing it to be further cut according to the predetermined areas that would be evaluated.

The replica was then cut mesio-distally at two sites and bucco-lingually at one site (Figure 5). The internal space was measured using an optical stereomicroscope (Leica S6 D, Leica Microsystems) at ×25 magnification and a digital camera (EC3, Leica Microsystems) coupled to the optical stereomicroscope. Imaging software (LAS Application Soft-

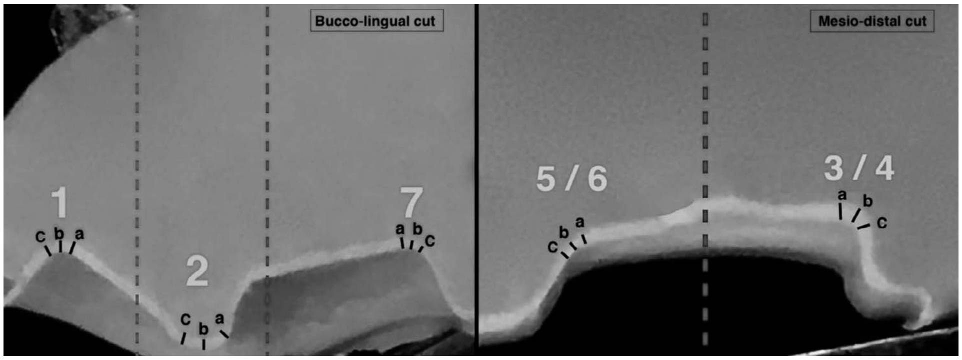

Figure 5. *PVS replica. Dotted lines represent cuts made on replica. Numbers represent locations of areas measured: 1, lingual; 2, oclusal; 3/4, mesial; 5/6, distal; 7, facial. Letters indicate the equidistant locations measured in each surface.*

ware Modules, Leica Microsystems) was used to measure the extra-light-body PVS layer thickness at the predetermined locations. A total of nine measurements were performed along the bucco-lingual slice and six measurements at the mesio-distal slices, resulting in 21 measurements from each sample. The measurements from each location were grouped as follows: axial (n=18) and occlusal (n=3). The average thickness of each location was calculated and submitted for statistical analysis.

Data Analysis

Marginal adaptation was analyzed using two-way analysis of variance (ANOVA) followed by Tukey's HSD test (α=0.05). Internal fit was analyzed using three-way ANOVA followed by Tukey's HSD test (α=0.05). Data were analyzed using statistical software Statistica 13.3 (StatSoft, TIBCO Software, Palo Alto, California, USA).

RESULTS

The results from marginal fit are shown in Tables 1 and 2. Two-way ANOVA (Table 1) showed that marginal discrepancy varied according to the fabrication system ($p<0.001$) and preparation design ($p<0.001$). No interactions were observed between the three fabrication systems and the two preparation designs ($p<0.068$). Tukey HSD test (Table 2) exhibited a significant difference in marginal discrepancies between the OmniCam, BlueCam, and Press fabrication systems. Restorations fabricated with the Press system (32.87±28.21 μm) presented the smallest average marginal discrepancy compared with restorations fabricated with the other systems. Beween the CAD-CAM systems, restorations fabricated with BlueCam (41.70±40.83 μm) presented significant smaller marginal discrepancies than restorations fabricated with OmniCam (55.26±46.85 μm). A significant difference was also observed between the two preparation designs ($p<0.0001$), with preparation BX yielding smaller marginal discrepancies than preparation NB.

The results from internal fit are shown in Tables 3 and 4. Three-way ANOVA (Table 3) showed that internal discrepancy varied according to the fabrication system ($p<0.001$), preparation design ($p<0.001$), and location of the preparation analyzed ($p<0.001$). Significant interactions were observed between variables fabrication system and preparation design ($p<0.022$). The Tukey HSD test (Table 4) showed statistically significant differences between the OmniCam, BlueCam, and Press systems. The restorations fabricated with the Press (118.15±64.98 μm) system presented significantly smaller internal discrepancies compared with the onlays fabricated with the OmniCam system (161.13±87.86 μm), which presented smaller internal discrepancies compared with restorations fabricated with the BlueCam system (167.47±92.04 μm). Regarding preparation design, a statistically significant difference was observed between preparations BX and NB ($p<0.001$), in which preparation NB (139.40±78.71 μm) generated restorations with smaller internal discrepancies than restorations fabricated for preparation BX (158.43±90.15 μm). Regarding the

Table 1: *Results From Two-Way ANOVA of Marginal Fit Analysis*

Variables of Interest	Degree of Freedom	Sum of Squares	Mean Squares	*F*	*p*
Fabrication system (FS)	2	244,185	122,092	79.237	<0.001
Preparation design (PD)	1	31,405	31,405	20.381	<0.001
FS × PD	2	8,274	4,137	2.685	0.068

Table 2: *Mean and SD of Marginal Discrepancies (μm) for Each Experimental Group[a]*

Group	Mean ± SD (μm)	p
Omni Cam system	55.26 ± 46.85 A	<0.0001
Blue Cam system	41.70 ± 40.83 B	
Press system	32.87 ± 28.21 C	
Preparation BX	39.97 ± 35.54 a	<0.0001
Preparation NB	46.58 ± 44.60 b	

[a] *Upper case letters indicate comparisons between systems and lower case letters indicate comparisons between preparation designs, according to Tukey HSD test (p<0.05).*

preparation location, axial and occlusal locations have shown a statistically significant difference ($p<0.0001$). Axial location (140.83±82.59 μm) presented smaller internal discrepancies compared with the occlusal location (197.45±85.30 μm). Additionally, after analyzing the interactions between fabrication systems and preparation designs (Table 5), the following results were observed: restorations fabricated with the Press system for preparation NB (99.36±42.37 μm) presented the smallest mean internal discrepancy of all groups; restorations fabricated with Press system for preparation BX (136.93±77.20 μm) presented no significant internal discrepancy compared with restorations fabricated with Omni Cam system for preparation NB (156.92±91.52 μm).

DISCUSSION

The present study verified the marginal and internal adaptation of PCCs fabricated with the Press, CEREC BlueCam, and OmniCam systems using two preparation designs. The first null hypothesis asserting that there would be no differences in the marginal and internal adaptations between the three systems used to fabricate ceramic onlays was denied. The superior marginal fit obtained with the Press system compared with the CAD-CAM systems is in agreement with previous studies.[29-31] In the present study, the mean marginal discrepancies of the ceramic onlays were 55 μm for the CEREC OmniCam, 41 μm for the CEREC BlueCam, and 32 μm for the Press system. These results are consistent, although numerically smaller, with the mean marginal discrepancies reported in previous investigations, which are between 80 and 85 μm for ceramic onlays fabricated with the CEREC BlueCam system[32,33] and 42 and 48 μm for the Press system.[34] A different finding was reported by Guess and others,[34] who observed no statistically significant differences in the marginal adaptation between the Press and CAD-CAM systems. Although the present study has identified the presence of larger marginal discrepancies on the CAD-CAM restorations, the average marginal discrepancies were still within a clinically acceptable range (below 100 μm).[35,36] Furthermore, the slight difference of 10 μm might be clinically irrelevant, and clinical studies are encouraged to evaluate the long-term performance of partial ceramic restorations. The use of a reflective powder spray to allow image capture when using the CEREC BlueCam system did not negatively affect the marginal and internal adaptation of the restorations. This finding is in agreement with da Costa and others,[37] who also demonstrated no

Table 4: *Mean and SD of Internal Discrepancies (μm) for Each Experimental Group[a]*

Group	Mean ± SD (μm)	p
Omni Cam system	161.13 ± 87.86 A	<0.0001
Blue Cam system	167.47 ± 92.04 A	
Press system	118.15 ± 64.98 B	
Preparation BX	158.43 ± 90.15 a	0.001
Preparation NB	139.40 ± 78.71 a	
Axial location	140.83 ± 82.59 1	<0.0001
Occlusal location	197.45 ± 85.30 2	

[a] *Upper case letters indicate comparisons between systems, lowercase letters indicate comparisons between preparation designs, and numbers indicate comparisons between locations according to Tukey HSD test (p<0.05).*

Table 3: *Results From Three-Way ANOVA of Internal Fit Analysis*

Variables of Interest	Degree of Freedom	Sum of Squares	Mean Squares	F	p
Fabrication system (FS)	2	382,722	191,361	30.389	<0.001
Preparation design (PD)	1	67,186	67,186	10.670	0.001
Location (L)	1	494,592	494,592	78.545	<0.001
FS × PD	2	47,715	23,858	3.7890	0.022
FS × L	2	24,395	12,198	1.937	0.144
PD × L	1	1,028	1,028	0.163	0.686
FS × PD × L	2	6,765	3,382	0.537	0.584

Table 5: *Mean and SD of Internal Discrepancies (μm) for the Interaction Between Fabrication System and Preparation Design*[a]

Fabrication System	Preparation Design	Mean ± SD	p
Omni Cam	BX	165.34 ± 84.05 A	0.022
	NB	156.92 ± 91.52 AB	
Blue Cam	BX	173.01 ± 104.28 A	
	NB	161.93 ± 77.77 A	
Press	BX	136.93 ± 77.20 B	
	NB	99.36 ± 42.37 C	

[a] *Upper case letters indicate comparisons between the combination of fabrication systems and preparation designs.*

influence in the use of a reflective powder on the marginal adaptation of onlays fabricated with the CEREC BlueCam. Regarding the internal fit evaluation, a similar trend could be observed with the smallest mean internal discrepancy exibited by the ceramic onlays fabricated with the Press system. These findings are in agreement with the results reported by Guess and others,[34] who observed larger internal discrepancies for ceramic onlays fabricated with the CAD-CAM system in comparison to the heat-press system. Previous studies have suggested that the ideal internal space to be occupied by the resin luting cement should be between 20 and 40 μm[38,39]; however, the values reported in the scientific literature are far above this ideal range and may vary from 85 to 308 μm.[39,40] The mean internal discrepancy observed in the present study varied from 99.36 to 167.47 μm and is in a similar range with the previously reported findings.[41,42]

The second null hypothesis asserting that there would be no differences in the marginal and internal adaptations between the two preparation designs was denied. Although the presence of additional vertical walls in the occlusal box, as in preparation BX, might have potentially generated areas of interference, this preparation resulted in superior marginal fit of the ceramic onlays. This result may be related to the features of machinable CAD-CAM restorations, in which only two burs are used to cut and shape the internal features of the restorations and may have resulted in enlarged internal spaces due to the standardized diameter of burs.[21-23] The higher numerical values of internal discrepancies of preparation BX can be visualized in Tables 3 and 4 compared with preparation NB, without the box. Additionally, the features of the preparation design, in which divergent walls and internal round angles were carefully executed and refined to avoid the presence of any sharp angles and undercuts, may have contributed to proper and easy adaptation. Schaefer and others[43] reported that preparations with sharp internal line angles tend to generate oversized dimensions, as opposed to preparations with round internal line angles, in which reduced marginal and internal discrepancies were observed. Regarding internal fit, the analysis of interaction showed that the presence of an occlusal box in preparation BX did not interfere with the internal adaptation of the CAD-CAM ceramic onlays; however, preparation BX resulted in significantly larger internal discrepancies for the ceramics fabricated with the Press system compared with preparation NB. Seo and others[13] also verified significant differences in the marginal and internal gaps of ceramic onlays depending on the preparation designs.

The third null hypothesis that stated there would be no differences between different locations of the internal space of ceramic onlays was denied. The axial locations presented the smallest average discrepancies, whereas the occlusal location showed the largest. The presence of larger internal spaces in the occlusal location is in agreement with previous studies.[34,41,42,44] Souza and others[44] reported a larger occlusal cement thickness (282 μm) compared with the axial (117 μm) for restorations fabricated with CEREC. The results from the present study exhibited an average occlusal cement thickness (197 μm) far below that reported by Souza and others,[44] whereas axial location (140 μm) was slightly larger than the findings of Souza and others.[44] Kokubo and others[40] ascribed the differences of internal adaptation to variations of the scanning process, preparation height, convergence angle, and variations between the CAD-CAM systems.

The methodology used in this study employed phantom master teeth that received two different preparation designs, which were subsequently used for the evaluation of the marginal and internal adaptations. The restorations were placed and stabilized on the master teeth without the use of a luting agent for bonding, allowing the possibility of further evaluations if needed. This protocol is in accordance with previous studies that used a similar procedure.[45,46] Regarding the internal fit, an indirect evaluation by means of the silicone replica technique was used. This protocol allowed further evaluation when needed and enabled cutting the silicone replica according to the predeterrmined areas to be measured.[30,45] Because of the nature of laboratory studies, this investigation had the chance of evaluating a large number of samples in standardized conditions; however, clinical studies might have posed different challenges that were not simulated in the present experiment. Future longitudinal clinical studies would be relevant to evaluate the long-term performance of ceramic restorations fabricated with pressed and CAD-CAM systems.

CONCLUSIONS

Based on the findings of this laboratory study, the following conclusions were drawn. 1) The marginal and internal adaptation of ceramic onlays were influenced by the fabrication technique. The Press system generated onlays with significantly smaller marginal and internal disadaptations compared with the BlueCam CEREC system, which presented smaller disadaptations than the OmniCam CEREC system. 2) An improved marginal adaptation was observed in the ceramic onlays with a modified occlusal box with internal rounded angles; however, the presence of an occlusal box resulted in larger internal marginal discrepancies in restorations fabricated with the Press system. 3) The occlusal location presented larger internal discrepancies than the axial locations.

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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.

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