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Influence of restorative materials on occlusal and internal adaptation of CAD-CAM inlays

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Aim: To evaluate the occlusal and internal marginal adaptation of inlay restorations made of different materials, using CAD-CAM. **Methods:** Preparations were made for MOD inlays of one-third intercuspal width and 4 mm depth in 30 third human molars. The teeth were restored using CAD-CAM materials (n=10) of nanoceramic resin (Lava Ultimate), polymer-infiltrated ceramic network (VITA ENAMIC), or lithium disilicate glass-ceramic (IPS e.max CAD). The specimens were cemented with dual resin cement and sectioned at the center of the restoration, after which the two halves were evaluated, and photographed The occlusal and internal discrepancy (μm) was determined at five points: cavosurface angle of the occlusal-facial wall (CA-O); center of the facial wall (FW); faciopulpal angle (FPA); center of the pulpal wall (PW); and center of the lingual wall (LW). The data were submitted to the Kruskal-Wallis and the Dunn tests (α=0.05). **Results:** No difference was observed among the materials regarding the occlusal discrepancy at the CA-O, FPA, or PW internal points. The e.max CAD measurement at FW showed larger internal discrepancy than that of Lava (p=0.02). The internal discrepancy at LW was greater for e.max CAD than VITA ENAMIC (p=0.02). **Conclusion:** Lithium disilicate glass-ceramic presented greater internal discrepancy in relation to the surrounding walls of the inlay preparations.

Keywords: Dental marginal adaptation. Ceramics. Computer-aided design. Dental materials. Inlays.

Introduction

Indirect restorations are indicated in clinical situations where there is loss of coronary dental structure, and difficulty in obtaining contour and an interproximal contact point, or where anatomical shape must be addressed. Indirect restorations are durable, have adequate strength, and maintain their aesthetic quality[1]. Direct restorative procedures are based on inserting composite resin directly into the cavity to reestablish the dental anatomic form; however, indirect restorations are manufactured out of the mouth, and the polymerization stress is restricted to the resin cement, used in a lower layer. This advantage can increase the survival rate of the restoration, and is especially important for posterior teeth, which must support chewing forces[2]. Nevertheless, issues exist in conventional inlay manufacturing techniques, such as the delay in making the inlay, and the difficulty in molding the silicone and casting the models, factors which could cause greater distortion of the mold, and hinder the mounting of the articulator[3].

The development of computer-aided design and computer-aided manufacturing (CAD-CAM) technology makes it easier to perform indirect restorations, because the restoration can be designed and manufactured[2]. CAD-CAM systems can be used with several types of materials, including ceramics, resin composites and hybrids. Resin-based materials have been developed for CAD-CAM technology with a high degree of homogeneity[4]. Hybrid materials can consist of a combination of ceramics, polymers and lithium disilicate reinforced zirconia[5]. Polymeric materials are optimally indicated for indirect intracoronary restorations, owing to their adhesion to the dental structure, mechanical characteristics, and elastic recovery[6,7]. The biomechanical behavior of teeth and their interface with CAD-CAM inlay restorations have not been fully investigated.

The adaptation of unitary prostheses or partial restorations can affect their clinical success and survival rates[8]. The clinically acceptable marginal discrepancy ranges from 100 to 150 μm, whereas previous studies[9,10] have suggested that the fit of CAD-CAM restorations may produce a marginal discrepancy of less than 80 μm. Thus, CAD-CAM systems could improve the average fitting quality of prostheses more than conventional manufacturing methods, and investigations should be conducted to disseminate and popularize these findings among professionals worldwide.

The marginal adaptation of materials impacts clinical outcomes and failure rates, considering that any spaces or gaps left in the adhesive or cement may promote biofilm accumulation and marginal pigmentation, and lead to long-term degradation[9]. The adaptation of indirect restorations is more commonly studied in the cervical region, and the occlusal and axial walls. It is known that the smaller the gap in the cervical region, the lower the risk of gum irritation, microleakage, and secondary caries lesions[11]. In addition, better internal fit of the prosthetic parts improves the mechanical performance of restorations, by imparting strength and retention[12].

Considering the relevance of evaluating the marginal and internal adaptation of polymeric materials produced by the CAD-CAM method[8,9], the objective of this study was to evaluate the occlusal and internal adaptation of intracoronary indirect restorations made from different materials, specifically lithium disilicate glass-ceramic, hybrid ceramic, and composite resin, all using CAD-CAM technology. The null hypothesis tested was that the materials used for making inlays would not differ in terms of occlusal and internal fit.

Materials and Methods

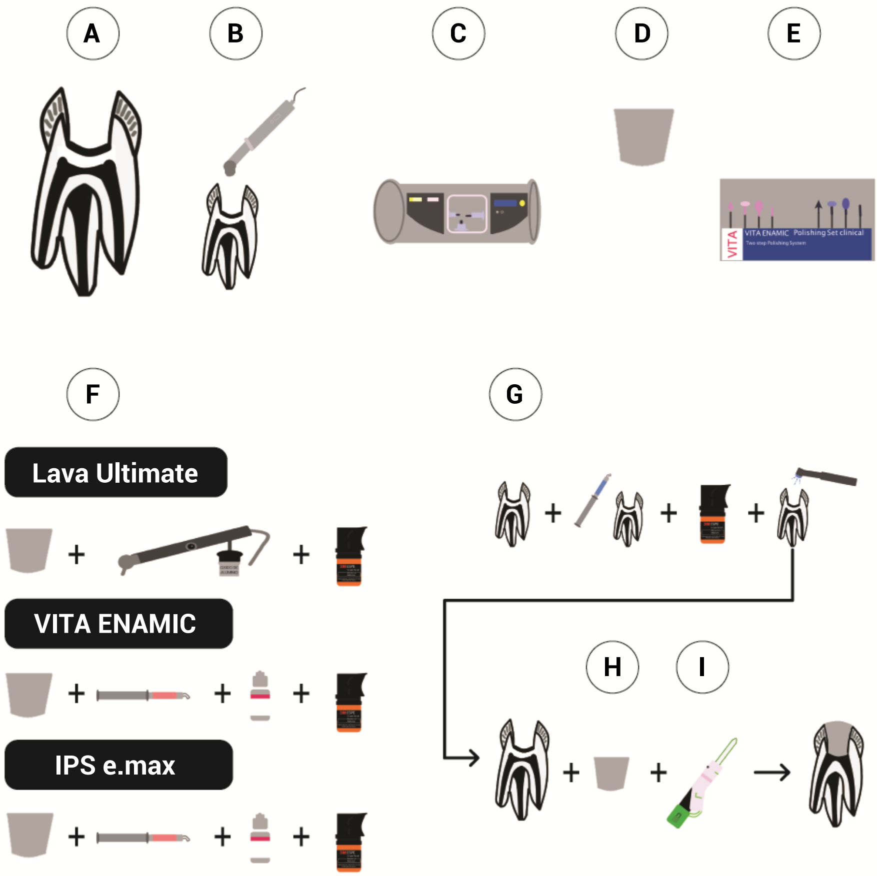
Experimental Design

This study was submitted to and approved by the Institutional Research Ethics Committee (CAAE: 69083117.5.0000.5374). The factors under study involved indirect restoration materials at three levels: nanoceramic resin (Lava Ultimate CAD-CAM Restorative for CEREC 3M ESPE, St. Paul, MN, USA); polymer-infiltrated ceramic network (VITA ENAMIC CAD-CAM for CEREC InLab, VITA Zahnfabrik, Bad Säckingen, Germany); and lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). The occlusal and internal marginal discrepancy was determined with images evaluated by Image J software. The experimental units consisted of 30 third molars restored with mesial-occlusal-distal (MOD) inlays produced by CAD-CAM. Table 1 presents the composition of the materials studied, and Figure 1 illustrates the study design and the sequence of the procedures.

Table 1. Composition, manufacturer and lot of main materials used in the study

Materials, manufacturer, and lot	Composition
Lava Ultimate 3M ESPE St. Paul, MN, USA Lot: 1727700558 & 1635400334	20 nm Silica filler, 4–11 nm Zirconia filler, 80 wt% Bis-GMA, UDMA, TEGDMA, Bis-EMA
VITA ENAMIC VITA Zahnfabrik Bad Säckingen, Germany Lot: 40970 & 48001	SiO_2, Al_2O_3, Na_2O, 86 wt% UDMA, TEGDMA
IPS e.max CAD Ivoclar Vivadent Schaan, Liechtenstein Lot: W12668	SiO_2 (57 - 80% by weight), Li_2O (11 to 19% by weight), K_2O, MgO, Al_2O_3, P_2O_5 and other components
Single Bond Universal 3M/ESPE St. Paul, MN, USA Lot: 1702700590	Bis-GMA, HEMA, SiO_2, and ethyl alcohol
Hydrofluoric acid Maquira Maringa, PR, Brazil Lot: 587417	10% Hydrofluoric acid, thickener, dye, and purified water
Silane Maquira Maringa, PR, Brazil Lot: 7 898561 540287	Silane and ethanol
RelyX Ultimate Adhesive Resin Cement 3M/ESPE St. Paul, MN, USA Lot: 652581	Paste 1: Methacrylate monomers, radiopaque silanated fillers, initiator components, stabilizers, rheological additives. Paste 2: Methacrylate monomers, radiopaque alkaline fillers, initiator components, stabilizers, pigments, rheological additives, fluorescence dye, dark polymerize activator for Scotchbond Universal adhesives.

Legend: SiO_2 (Silicon dioxide); Li_2O (Lithium oxide); K_2O (Potassium oxide); MgO (Magnesium oxide); Al_2O_3 (Aluminum oxide); P_2O_5 (Phosphorus pentoxide); Bis-GMA (bisphenol A-glycidyl methacrylate), Na_2O (Sodium oxide); UDMA (Urethane dimethacrylate); TEGDMA (triethylene glycol dimethacrylate); HEMA (2-Hydroxyethyl methacrylate).



Legend: A) Class II cavity preparation; B) Scan of preparations; C) Inlay milling; D) Inlays made; E) Polishing of inlays; F) Tooth prepared with phosphoric acid, active application of universal adhesive and photoactivation; G) Lava inlay prepared with aluminum oxide blasting followed by application of universal adhesive. VITA ENAMIC and e.max CAD inlays prepared by conditioning with 10% hydrofluoric acid gel, and application of silane and universal adhesive; H) Inlay ready for cementation; I) Cementation of inlays.

Figure 1. Study design. CAD-CAM inlay manufacturing and cementation.

Sample Selection and Cavity Preparation

Thirty healthy third molars were obtained, scraped with periodontal curettes, and stored in 0.1% thymol solution. All the teeth were radiographed to establish the distance between the central groove and the pulp chamber ceiling. The total tooth length was recorded, as well as the crown length, the root length, the mesiodistal and buccolingual diameters of the crown, and the crown height. All these measurements were taken to make it easier to obtain equal distribution among the experimental groups, and ultimately ensure that all the groups would be composed of the same proportion of teeth of the same dimensions. The teeth were embedded in condensation silicone (Zetaplus Zhermack, Badia Polesine, Italy) to allow adaptation to a cavity preparation machine.

MOD cavities (Class II) of one-third intercuspal width and 4 mm depth were made by a cavity preparation machine (ElQuip, São Carlos, SP, Brazil), without a proximal box, using high rotation under abundant water irrigation, and a tapered trunk diamond tip (#2096 KG Sorensen, Cotia, SP, Brazil). Each diamond tip was used for three preparations, and then discarded. The #3131 diamond tip (KG Sorensen, Cotia, SP, Brazil) for intracoronary preparations was then used to determine the required cavity size. All the samples were stored individually in pots immersed in distilled water, and distributed randomly for restoration with the three materials studied (n=10).

CAD-CAM inlay manufacturing

All the preparations were scanned directly (Cerec Blue Cam, Sirona Dental, Benshein, Hessen, Germany), and both the designs and the drawings of each inlay were made separately, considering a cement space of 100 μm[13]. Then, the inlays were milled according to the experimental group (nanoceramic composite resin, hybrid ceramic or lithium disilicate glass-ceramic).

The inlays of all the materials were made by an experienced professional, after which the materials were polished with abrasive rubber of two granulations (VITA ENAMIC Polishing Set Clinical, Vita Zahnfabrik, Bad Säckingen, Germany) for 5 seconds on the occlusal face, 5 seconds on the mesial face, and 5 seconds on the distal face, after which a medium-grain, followed by a fine-grain, rubber tip was applied for 5 seconds respectively on each side. The restorations were submitted to ultrasound individually for 3 minutes. Afterwards, they were polished with abrasive paste (Diamond excel, FGM Dental group, Santa Catarina, Brazil) for 5 seconds on each outer face, and again submitted to ultrasound for 3 minutes. Only lithium disilicate inlays were submitted to single-glaze firing and then oven-crystallized, according to the manufacturer's parameters (820°C for 10 min, Ivoclar Programat EP 3000, Ivoclar Vivadent, Schaan, Liechtenstein).

Cementation of inlays

The teeth were treated the same way in all the groups. The enamel was conditioned selectively for 15 seconds, then washed with water for 15 seconds, and dried gently, making sure to keep the dentin moist. Universal adhesive was applied (Single Bond Universal 3M ESPE, St. Paul MN, USA) for 20 seconds, followed by light air-blasting for 5 seconds, and photoactivation for 10 seconds. The internal treatment of the inlays depended on each individual material, as described in Table 2. All the inlays were cemented with dual resin cement (Rely X Ultimate 3M ESPE, St. Paul, MN, USA) using finger pressure[14] for 15 seconds. Excess cement was removed, and photoactivation was performed with LED light, at a minimum irradiance of 1000 mW/cm^2 (Bluephase Ivoclar, Vivadent, Schaan, Liechtenstein) for 1 minute. After cementation of the inlays, the margins were polished using the same polishing sequence and application time on each face, as previously described.

Table 2. Sequential steps of internal inlay treatments

Material	Internal treatment of inlays
Nanoceramic resin (Lava Ultimate)	1- Clean the restoration ultrasonically for 3 minutes and dry by air blast. 2- Blast with aluminum oxide (50 µm to 30 psi) until each inner surface is matte. 3- Apply alcohol to remove the excess from blasting. 4- Actively apply universal adhesive (Single Bond Universal 3M ESPE, St. Paul MN, USA) for 20 seconds. 5- Light air blasting.
Hybrid ceramic (VITA ENAMIC)	1- Condition with 10% hydrofluoric acid gel (Maquira, Maringa, PR, Brazil) for 60 seconds. 2- Wash with water for 30 seconds. 3- Apply silane (Maquira, Maringa, PR, Brazil). 4- Actively apply universal adhesive (Single Bond Universal 3M ESPE St. Paul MN, USA) for 20 seconds. 5- Light air blasting.
Lithium disilicate glass-ceramic (IPS e.max CAD)	1- Condition with 10% hydrofluoric acid gel (Maquira, Maringa, PR, Brazil) for 20 seconds 2- Wash with water for 30 seconds. 3- Apply silane (Maquira, Maringa, PR, Brazil). 4- Actively apply universal adhesive (Single Bond Universal 3M ESPE St. Paul MN, USA) for 20 seconds. 5- Light air blasting.

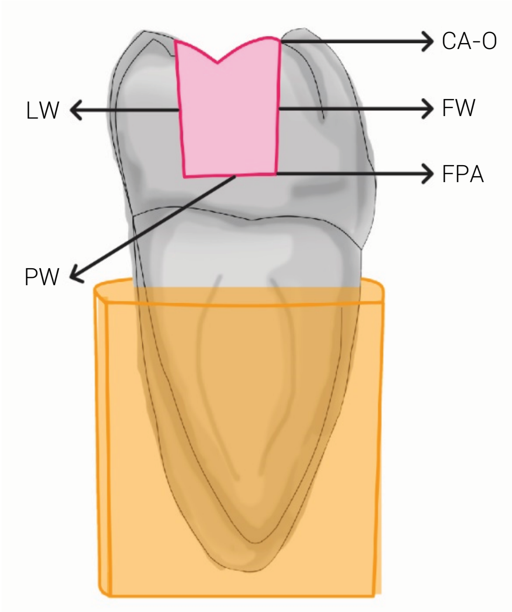
Occlusal and internal adaptation at the tooth/restoration interface

The specimens were placed on a precision cutter (Isomet Buhler) and sectioned in the central region toward the lingual vestibule. Each half of the dental element was photographed with a digital camera (Sony α-200, Sony, Japan), using a standardized procedure, and a 105 mm lens (Sigma Lens for Sony, Sigma Corporation, Japan). The camera was docked at a height of 10 cm between the lens and the sample. Digital camera specifications were also standardized as follows: firing speed of 1/125, diaphragm opening at F16, ISO 200 sensor sensitivity, manual function with the flash triggered.

The images of the two halves of each tooth were introduced in the Image J software (Image Processing and Analysis in Java, Bethesda, MD, USA)[15], and the average cement space gap of each half was calculated per sample. The occlusal and internal discrepancy, or cement space (µm), was determined[16] at five points: CA-O (occlusal fit); center of the facial wall (FW, internal fit); faciopulpal angle (FPA, internal fit); center of the pulpal wall (PW, internal fit); and center of the lingual wall (LW, internal fit) (Figure 2).

Statistical analysis

Exploratory analysis indicated that the data did not meet the assumptions of parametric analysis, and Kruskal Wallis and Dunn tests were performed considering a significance level of 5%. The analyses were performed using R* software (R Core Team, R Foundation for Statistical Computing, Vienna, Austria).



Legend: CA-O (cavosurface angle of occlusal-facial wall); FW (facial wall); FPA (faciopulpal angle); PW (pulpal wall); LW (lingual wall).

Figure 2. Illustration of the site of the points where the measurements were performed.

Results

Table 3 shows that there was no significant difference among the materials, regarding marginal discrepancy (µm) at CA-O, FPA and PW (internal fit). The measurement at FW showed significantly higher marginal discrepancy (p=0.02) when lithium disilicate glass-ceramics (e.max CAD) versus nanoceramic resin (Lava) was used. In contrast, the marginal discrepancy at the LW, on the inner face of the restoration (LW), was significantly greater (p=0.0198) for e.max CAD than VITA ENAMIC.

Table 3. Median (minimum value - maximum value) of the internal marginal adaptation in micrometers (µm) for the five points assessed, according to the material used (n=10).

Material	Point				
	CA-O	FW	FPA	PW	LW
Lava[1]	98.5 (67-301) a	77 (58-243) b	310 (123-939) a	261 (89-861) a	111.5 (74-174) ab
e.max CAD[2]	138 (78-728) a	187.5 (80-281) a	354 (192-635) a	360.5 (188-826) a	177 (67-738) a
VITA ENAMIC[3]	105.5 (56-424) a	127.5 (36-380) ab	296 (143-841) a	237 (131-700) a	100 (92-160) b
p-value	0.3484	0.02	0.4818	0.3329	0.0198

Legend: [1]Nanoceramic resin (Lava Ultimate CAD-CAM Restorative for CEREC 3M ESPE, St. Paul, MN, USA); [2]Lithium disilicate glass-ceramic (IPS e.max Cad, Ivoclar Vivadent, Schaan, Liechtenstein); [3]Polymer-infiltrated ceramic network (VITA ENAMIC CAD-CAM for CEREC inLab, Vita Zahnfabrik, Bad Säckingen, Germany). Points assessed: CA-O (cavosurface angle of occlusal-facial wall); FW (facial wall); FPA (faciopulpal angle); PW (pulpal wall); LW (lingual wall). Median followed by different lowercase letters indicates a statistically significant difference between the materials at a set point.

Discussion

Indirect restorations are used to restore large and deep cavities. However, conventional techniques have a limited run time, and require molding, plaster casts and mounting of the articulator, which may decrease technique accuracy[17]. CAD-CAM technology emerged to facilitate the planning and fabrication of prostheses and restorations performed by computer, and features a reading tool, which creates a virtual model for the preparation of prostheses[1]. The resulting information is then sent to manufacture the restoration of the model using a software process. This technology also allows the cementation time[6] of the restoration to be reduced to a single session[10], decreases the chances of error, and provides better marginal adaptation[18]. Considering the results, the null hypothesis was partially rejected, because a difference was found in the adaptation at the interface of the surrounding wall with the CAD-CAM inlay.

Even when the parameters for adaptation are entered in the software, the program may not reproduce them when the part is milled[19]. Considering the tooth preparation used in the present study, it should be borne in mind that non-retentive cavity preparations display better adaptation of milled parts than more retentive preparations, and that cementation may increase marginal discrepancy[20]. The evolution of CAD-CAM systems has led to the development of restorative materials that currently include aesthetic ceramics, high strength ceramics, and both definitive and temporary polymeric materials[2,3]. According to a previous study[21], ceramics are the most widely studied materials of all those used in CAD-CAM technology, owing to their aesthetics, low thermal conductivity, and biocompatibility; however other materials have emerged to enable different treatments to be performed.

Commercially acquired lithium disilicate glass-ceramic blocks (IPS e.max CAD) consist of 70% lithium disilicate[22]. In fact, use of these ceramic blocks in the present study led to obtaining adequate values[9,10] of discrepancy for the cavosurface angle of the occlusal-facial wall, faciopulpal angle and pulpal wall. Unlike other materials, these blocks must then be submitted to firing to complete the crystallization process, at which point they reach their highest strength. Awada and Nathanson[6] reported that lithium disilicate blocks had high fracture resistance and a low wear rate. These properties have promoted their widespread use in crown-making, especially because this material leaves the restorations with color and translucency similar to those of the tooth[1,2]. Although there are other clinical parameters that come into play, lithium disilicate has greater antagonist enamel wear than nanoceramic resin (Lava) and polymeric materials (VITA ENAMIC)[23].

Nanoceramic resin (Lava, 3M ESPE) resulted in lower discrepancy than lithium disilicate glass-ceramic in the facial wall. In addition to having the advantages inherent in ceramic, this material absorbs chewing forces, hence reducing restoration stress[7,24]. Commercial nanoceramic resin blocks have high wear resistance because of their low elastic modulus, and because they are composed of about 80% nanoceramic particles, incorporated into a highly polymerized organic matrix[6,7]. Thus, Lava is indicated for making unitary adhesive restorations, such as crowns, inlays, onlays and laminates, inasmuch as it absorbs the chewing load and promotes less wear of the antagonist.

VITA ENAMIC is composed of two interconnected networks, that of a dominant ceramic, and that of a polymer. Although it showed adaptation values similar to those of nanoceramic resin (Lava), its marginal discrepancy values in the lingual wall were smaller than those of the lithium disilicate glass-ceramic (e.max CAD). VITA ENAMIC networks consist of urethane dimethacrylate crosslinked (UDMA) with triethylene glycol dimethacrylate (TEGDMA)[25]. Moreover, the differences of nanoceramic resin and polymer-infiltrated ceramic compared to lithium disilicate glass-ceramics may have occurred in the regions analyzed. This is because the lower modulus of elasticity (Lava - 16 GPa and ENAMIC - 21.5 GPa)[26] of these two materials is similar to that of dentin (20 GPa)[25], hence making them commonly indicated for inlays. In addition, these hybrid ceramics are more malleable and ductile, thus allowing thinner margins. Elmougy et al.[27] suggested that VITA ENAMIC was harder than Lava, because of its higher ceramic content. Intracoronary restorations do not cover the cusps; the materials employed should be able to bond to the walls of the preparation using resin cementation.

Thus, according to the present results, the differences in the composition of the materials studied explain why different adaptations were made to the inlays[20]. The results of this study indicated a discrepancy in the LW and FW for e.max CAD. This could be related to the fact that lithium disilicate ceramics is harder[23], and to the high crystalline phase content, which may make it more difficult to adapt the ceramic to the walls.

Although all the materials used (VITA ENAMIC, e.max CAD and Lava) were acquired using the same CAD-CAM method, they have different properties. Thus, although CAD-CAM machinability was the same for all three materials, the block wear can be expected to be different for each of the materials manufactured. Conversely, given that the process of obtaining the inlays by CAD-CAM manufacture was the same, a very similar fit could be achieved between the ceramic and the polymeric materials. However, when the machinability of the polymeric and lithium disilicate-based materials was compared, the former showed faster CAD-CAM-induced wear[28], perhaps because the former is not as hard as the latter. In general, the machinability of a CAD-CAM material affects brittleness and marginal chipping, and IPS e.max CAD presents higher brittleness and marginal chipping values, compared to resin-based or hybrid indirect materials[29]. In addition, the edges of polymeric materials chip less, because these materials are less friable than lithium disilicate ceramics[28]. These characteristics of polymeric materials could be why they were able to adapt better to the PW cavity and angles. Moreover, the polymer-based materials adapted better than the ceramic materials, specifically at the cervical margin[20].

Microstructure is one of the critical factors that influence the adhesion of materials in the cavity[30]. Materials with a polymeric mesh have better adhesion, and a lower chance of fracture, compared with materials with a scattered filler. The surface structure of the restoration is modified by blasting or etching with hydrofluoric acid to increase the micromechanical retention even further[24]. However, micromechanical bonds do not necessarily promote the best bond. The chemical bond between the materials and the cement[11], promoted by silane, is also of great importance. Roughness increases the contact surface, interlocking the cement with the polymeric ceramic[31]. Comparatively, mechanical gripping is of great importance to ceramic-loaded polymers, while chemical bonding is more relevant to polymer-infiltrated ceramic material[32].

Several factors may influence marginal and internal adaptation, such as preparation design, location of the margin, milling, milling drill size, milling machine calibration, scanner, restorative material, pressure applied during cementation and cement space thickness[33]. It stands to reason that any changes in these variables can interfere with the results, and should be investigated in future research. Another form of standardizing pressure during cementation should be looked into, since it impacts cement thickness and the occurrence of bubbles. Furthermore, any 2D assessments made using photographs should be complemented with 3D analysis, since the latter characterizes the margins more generally.

In conclusion, polymeric materials resemble acid-sensitive ceramic in marginal adaptations and promote better internal adaptation when obtained by CAD-CAM. E.max CAD presented a greater internal discrepancy in relation to the surrounding walls. However, there was no difference among the materials, regarding the pulpal wall, the cavosurface, or the faciopulpal angles of the inlays.

Data availability

Datasets related to this article are available upon request to the corresponding author.

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Disclosure statement

The authors declare no conflict of interest.

Author contribution

A.C.R. Cabral: conceptualization, data curation, formal analysis, funding acquisition, investigation, validation, visualization, writing original draft, review & editing.

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R.T. Basting: formal analysis, investigation, validation, visualization, review & editing.

C.P.Turssi: formal analysis, investigation, validation, visualization, review & editing.

F.L.B. Amaral: formal analysis, investigation, validation, visualization, review & editing.

F.M.G. França: conceptualization, data curation, formal analysis, funding acquisition, investigation, validation, visualization, project administration, supervision, writing original draft, review & editing.

All authors actively participated in the discussion of the manuscript's findings, and have revised and approved the final version of the manuscript.

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