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Different Methods for Inlay Production: Effect on Internal and Marginal Adaptation, Adjustment Time, and Contact Point

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Clinical Relevance

Digital impressions and milling by a CAD-CAM system appear to be appropriate techniques since they promote similar marginal and internal adaptations when compared to the conventional impression and lost wax technique using pressed ceramic.

SUMMARY

The aim of this study was to evaluate the effect of different production methods of resin and ceramic inlays on marginal and internal adaptation, adjustment time, and proximal contacts. Forty premolars were selected, embedded (their roots), and prepared to receive inlays that were made as follows (n=10): LaRe—digital impression with a Lava C.O.S. scanner, followed by milling of Lava Ultimate block (composite resin) in a milling center; CeRe—digital impression with a Cerec 3D Bluecam scanner, followed by milling of Lava Ultimate block in Cerec; CeDis—digital impression with a Cerec 3D Bluecam scanner, followed by milling of IPS e.max CAD block (lithium disilicate) in Cerec; and PresDis—impression with polyvinyl siloxane, inlay made using the lost wax technique and IPS e.max Press pressed ceramic (lithium disilicate). Marginal and internal adaptations were measured using the replica technique. The inlay adjustments were performed using diamond burs in a contra-angle hand piece, and the time for adjustment was recorded using a timer, in seconds. The tightness of the proxi-

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mal contact was measured using standardized metal blades. The statistical analyses for marginal fit data showed that at the cervical edge, CeDis (177.8 μm) had greater misfit than CeRe (116.7 μm), while all the groups had similar adaptation at the occlusal edge. The groups had similar internal fit at the pulpal wall, while LaRe (104.7 μm) > CeDis (66.7 μm) = CeRe (76.7 μm) at the axial wall. The groups restored with lithium disilicate ceramic took more time for adjustment when compared to the resin restorative material. The lowest proximal contact, in micrometers, was seen in the CeRe group (8.8 μm).

INTRODUCTION

Apart from fracture resistance and esthetics, marginal accuracy is one of the most important criteria for the clinical success of all-ceramic restorations.[1,2] Poor marginal adaptation of restorations increases plaque retention inducing the onset of periodontal disease[3] and can lead to microleakage resulting in endodontic inflammation[4] and secondary caries.[5] After a five-year study conducted on more than 1000 restorations,[6] it was concluded that 120 μm was the maximum tolerable marginal opening. However, another study[7] considered a 150 μm gap to be clinically acceptable. These data indicate lack of consensus on the maximum value of the marginal gap. Marginal fit is influenced by several factors, such as finish line configuration, size of cement space, restoration production method, and cementation of the restorations.[8]

A good final marginal adaptation is possible only if an accurate impression is obtained. Hence, the accuracy of the impression is essential for the success of the restoration. Currently, the conventional impression technique using elastomeric materials or digital impressions can be used. Syrek and others[7] showed that the digital impression promoted better marginal fit of all-ceramic crowns when compared to conventional two-step impressions. According to those authors, this might be explained by the traditional work flow, where a master model is created for fabrication of the crown, while the crown coping is designed directly from the intraoral scan without creating an intermediate model or die in the digital work flow.

The computer-aided design/computer-aided manufacturing (CAD/CAM) system enables two types of scans: the direct, or chair-side model and the indirect, or lab model. In the first model, the dentist performs the "impression" of the preparation using an intraoral scanner, and the restoration is designed and milled in the dentist's office independent of the laboratory. In the indirect model, the dentist makes a conventional impression with an elastomeric material and sends the impression to the laboratory, where the impression is poured and a model is scanned using an extraoral scanner. Subsequently, the restoration is designed and milled by the technician via a CAD-CAM system. Although the accuracy of the extraoral scanning is satisfactory, the conventional impression can deform due to the contraction or expansion from impression materials and plaster, according to Ting-shu and Jian.[9] Furthermore, Mously and others[10] showed that different manufacturing techniques have affected the marginal and internal adaptation of ceramic crown restorations. Hamza and others[11] also showed that different CAD/CAM systems and different ceramic types and their interactions presented a statistically significant effect on the marginal fit.

Neves and others[12] evaluated marginal adaptation of lithium disilicate crowns manufactured from different CAD/CAM systems: the microcomputed (CEREC or E4D) technique and the ceramic pressed technique. They observed that lithium disilicate crowns fabricated using the CAD/CAM Cerec Bluecam system 3D scanner or the pressed technique had a significantly lower marginal leakage when compared to crowns manufactured using a laser scanner system/CAM E4D CAD.

Another alternative material for making inlays in CAD/CAM is the composite resin. Currently, resin nanoceramic blocks (LAVA Ultimate, 3M ESPE, St Paul, MN, USA) are available on the market. This material contains nanometers and nanoclusters of silica and zirconia, constituting a total of 80% of the weight of the nanoceramic.[13]

Inlays are quite feasible for clinical practice in the chair-side model. However, it is unclear whether this method would be advantageous for the clinician, considering the time consumed with the adjustment of the restoration. Furthermore, it is not known whether the interproximal contact of the CAD/CAM model is better than the conventional model using the pressed technique.

Thus, the aim of this study was to assess the different methods of inlay production using different materials in relation to marginal and internal adaptation, adjustment time, and proximal contact tightness. The null hypothesis was that there is no difference among the different inlay production methods and the material in relation to 1) marginal

Table 1: *Experimental Design*

Groups' Codes	Model	Impression Technique	Manufacture Inlays	Material	Ceramic Composition
LaRe	Lab-side	Intraoral dental scanner Lava C.O.S. (3M ESPE, St Paul, MN, USA) with titanium dioxide powder (Cerec Propellant, VITA, Bad Säckingen, Germany)	Center milling—the scans were immediately sent via the Internet to the dental laboratory (45-µm cement space according to the manufacturer's instruction)	Composite resin	About 80% weight nanoceramic and about 20% weight resin
CeRe	Chair-side	Intraoral dental scanner Bluecam (Sirona) with powder (Optispray, Sirona Dental Systems, Bensheim, Germany)	Milling: Cerec MC XL (40-µm cement space)[a]		
CeDis	Chair-side	Intraoral dental scanner Bluecam (Sirona) with powder (Optispray, Sirona Dental Systems)	Milling: Cerec MC XL (40-µm cement space)[a]	Lithium disilicate	SiO_2 57 to 80; Li_2O 11 to 19; K_2O 0 to 1; 3 P_2O_5 0 to 11; ZrO_2 0 to 8; ZnO 0 to 8; Al_2O_3 0 to 5; MgO 0 to 5; coloring oxides 0 to 8 (in% by weight)
PresDis	Lab-side	Conventional impression—one-step technique with polyvinyl siloxane	Lost wax technique with pressed ceramic. The investment ring was removed by using a separating disk and glass polishing beads and using IPS e.max Press Invex Liquid (Ivoclar Vivadent, Schaan, Liechtenstein). The ceramic inlays were cleaned in an ultrasonic cleaner and airborne-particle abraded.		

[a] *It was not possible to use 45 µm in that software.*

adaptation, 2) internal adaptation, 3) time for adjustment, and 4) proximal contact.

METHODS AND MATERIALS

This study was approved by the Committee of Ethics in Research of the Federal University of Santa Maria (UFSM), and the teeth were donated by the Human Teeth Bank of UFSM.

Sample size calculation for the marginal and internal fit outcome was based on the Tukey (5%) pairwise comparison after one-way analysis of variance (ANOVA) (http://www.stat.uiowa.edu/~rlenth/Power) to demonstrate a 30-µm[7] difference in mean maximum marginal and internal gap between the four groups. The sample size was calculated as 10 teeth per group, based on a significance level of 0.05, a power of 80%, and a standard deviation of 20 µm.[7]

Forty human maxillary premolars were selected according to the inclusion criteria of there being no cracks in the tooth and according to its vestibular-lingual dimensions. The teeth were numbered and, using a computer program (http://www.randomizer.org), randomly allocated into four testing groups (Table 1).

Embedding the Teeth in a Model

The premolars were embedded between two molars in a cylinder filled with polyurethane resin in order to simulate the interproximal contact of the inlay with the other teeth. To accomplish positioning of the teeth in the resin, the occlusal surface of each tooth was glued to an adapted surveyor with the crown perpendicular to the x-axis (ground); the teeth were embedded in a cylinder containing polyurethane resin (F16 Polyol, Axson Technologies, St Ouen I'Aumône, France) up to 3 mm below the cemento-enamel junction, with the occlusal surface parallel to the horizontal plane.

Cavity Preparation

Standardized MOD inlay cavity preparations were performed on all premolars using a conical trunk diamond bur with rounded angles (KG Sorensen 3131, Barueri, Brazil). The burs were mounted in a high-speed hand piece and fixed to a modified optic microscope that enabled reductions to be obtained as parallel as possible to the long axis of the tooth. The preparations had the convergence of the bur (±10°) and the following dimensions: buccal-lingual width, 3 mm; occlusal box depth, 3 mm; and rounded internal line angles. Each diamond bur was used to prepare five teeth, and all preparations were polished using the same bur (# 3131, KG Sorensen, Cotia, Brazil) with a grain size of 25 μm.

Impressions and Inlay Manufacturing

LaRe—The impressions were made using the Lava C.O.S. scanner, which is a 3D-in-motion technology that captures 3D data in a video sequence and models the data in real time (Table 1), and the restorations were prepared using composite resin blocks (Lava Ultimate, 3M ESPE) in a milling center.

CeRe and CeDis—The impressions were made using the CEREC AC with a Bluecam scanner, which is a camera that has a blue light–emitting diode with a specific wavelength (Table 1). Half of the restorations were prepared using composite resin blocks (Lava Ultimate, 3M ESPE), and the other half was prepared using lithium disilicate blocks (Ivoclar Vivadent, Schaan, Liechtenstein). After milling, the lithium disilicate inlays were sintered according to the manufacturer's recommendation.

PresDis—A conventional impression was performed for each prepared tooth using polyvinyl siloxane (Elite HD + Regular Body, Zhermack, Badia Polesine, Italy) and the one-step technique. The mold was poured with type IV plaster one hour after removal. The fabrication of the lithium disilicate inlays was performed in accordance with the manufacturer's recommendations (IPS e.max Press, Ivoclar Vivadent). The inlays were waxed on a die for each tooth using three coats of die spacer (about 30 μm) (Yeti die spacer, Yeti Dental Products GmbH, Engen, Germany) according to the instructions of the ceramic manufacturer. All wax patterns were invested and pressed by a single dental laboratory technician (Table 1).

Adjustment Time

After manufacturing, the inlays were put inside the prepared teeth, and the interproximal contact between the inlay and each adjacent tooth was adjusted with the aid of an occlusal marker, AccuFilm II (Parkell, Edgewood, NY, USA), which is 21 μm thick. The adjustments were performed using diamond burs with a grain size of 25 μm for the resin inlays and a grain size of 40 μm for the lithium disilicate inlays using a slow-speed motor associated with a contra-angle hand piece up to 30,000 rpm for lithium disilicate and up to 6000 rpm for resin. The adjustment of the proximal inlays was performed with fine-grain diamond burs in order to avoid polishing, which might lead to additional wear. The time of adjustment was recorded using a timer in seconds.

Proximal Contact

The tightness of the interproximal contact was verified using metal strips of 8, 30, and 50 microns (Shimstock-Folie, Coltene, Altstätten, Switzerland) placed between the inlay and the molar on both sides of the inlay. This procedure was performed by the same operator without the application of force. A mean of the two proximal contacts was performed for each inlay.

Internal and Marginal Fitting

After inlay production, replicas were made of the intermediate space between the inner surface of the inlay and the tooth cavity. This was achieved by coating the tooth cavity walls with a thin layer of light-body additional silicone material, followed by seating the inlay into the cavity and applying a force of 750*g* on the inlay.

The inlay was removed after setting of the impression material, leaving a thin film of light-body material adhering to the cavity that represented the discrepancy between the inlay and the tooth cavity. For the purpose of stabilization, a medium-body material was applied that adhered to the light-body film in the cavity. This procedure enabled the removal and handling of the "cement replica" made from the light-body material. The points measured from the replica are shown in Figure 1.

The replica was cut in the middle, and the parts were observed in a stereomicroscope in order to measure the thickness of the light-body silicone, which corresponds to the internal and marginal fit, according to Figure 2. Three replicas of the cement replica were made for each tooth, and a mean was calculated from the three replicas.

Data Analysis

The data measured from the marginal and internal adaptation (marginal fit: occlusal and cervical edges; internal fit: pulp and axial walls) and adjustment time were analyzed using the one-way ANOVA and the Tukey test ($p=0.05$). The proximal contact data were analyzed using the Kruskal-Wallis test.

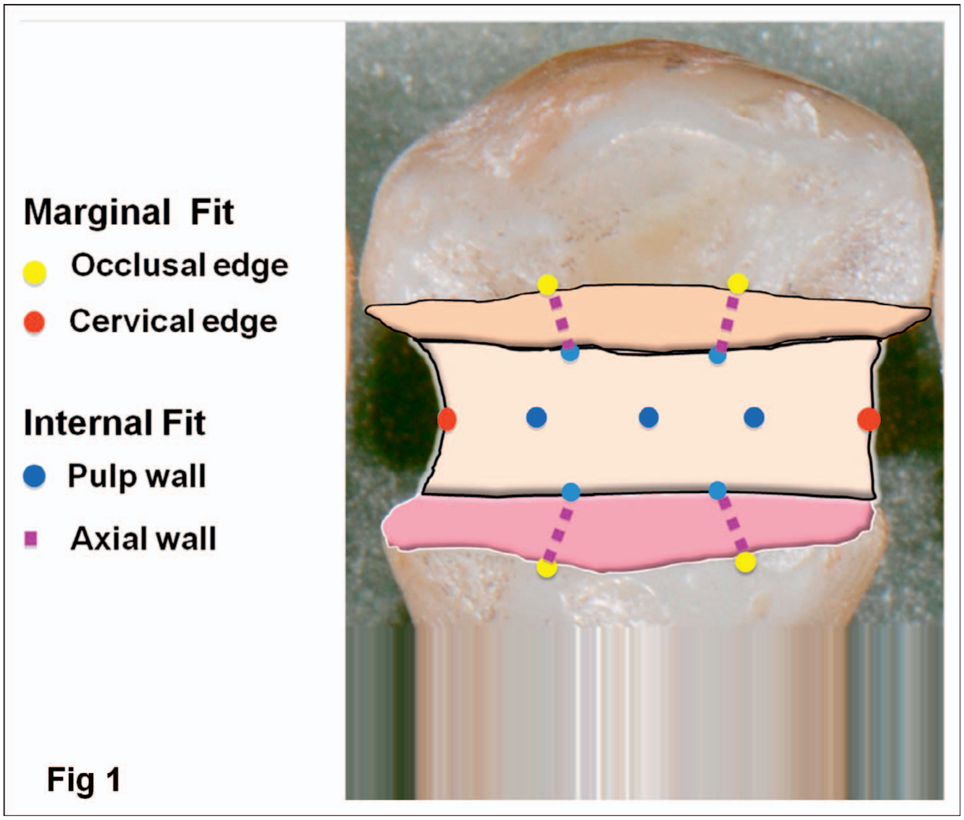

Figure 1. *Location of the points where the fit were measured.*

RESULTS

The Cerec system with the lithium disilicate group had higher marginal misfit at the cervical edge when compared to the Cerec system with the composite resin (p=0.03), while the occlusal edge presented no statistical differences (p=0.21) (Table 2).

For internal fit, statistical differences were noted for the axial wall (LaRe > CeDis = CeRe) (p=0.0007) (Table 2), while no significant differences were found among groups when considering the pulp wall (p=0.08).

The smallest adjustment time (p=0.01) occurred for the Cerec system and composite resin group, but it was not statistically different from the Lava C.O.S. scanner with composite resin (Table 3). The best proximal contact was observed with the Cerec system and composite resin group, and the worst was with the Cerec system and lithium disilicate group (Table 3).

DISCUSSION

The first null hypothesis (no difference among the inlay production methods and materials for marginal adaptation) was rejected since the Cerec system with composite resin and lithium disilicate groups had statistically different marginal fit at the cervical edge. The second hypothesis (no difference among the inlay production methods and materials for internal adaptation) was also rejected since the Lava C.O.S. scanner with the composite resin group and Cerec system with lithium disilicate and composite resin groups presented different internal fits at the axial wall. The Lava C.O.S. scanner with the composite resin group presented the largest misfit at the internal axial wall but the smallest misfit at the marginal occlusal edge. However, there was no statistical difference between the groups. On the other hand, the Cerec system with the lithium disilicate group presented the largest misfit at the marginal occlusal and pulp edge and the smallest misfit at the internal axial wall.

This difference of adaptation between composite resin and lithium disilicate might have occurred due to the composition of the material. Lithium disilicate has a high modulus of elasticity around 95 GPa, while the modulus of the studied resin is 12 GPa. The high modulus of the lithium disilicate may hinder milling, making its surface more irregular and decreasing its marginal accuracy. This relationship between high modulus of the ceramic and less accuracy in the Cerec system has also been demon-

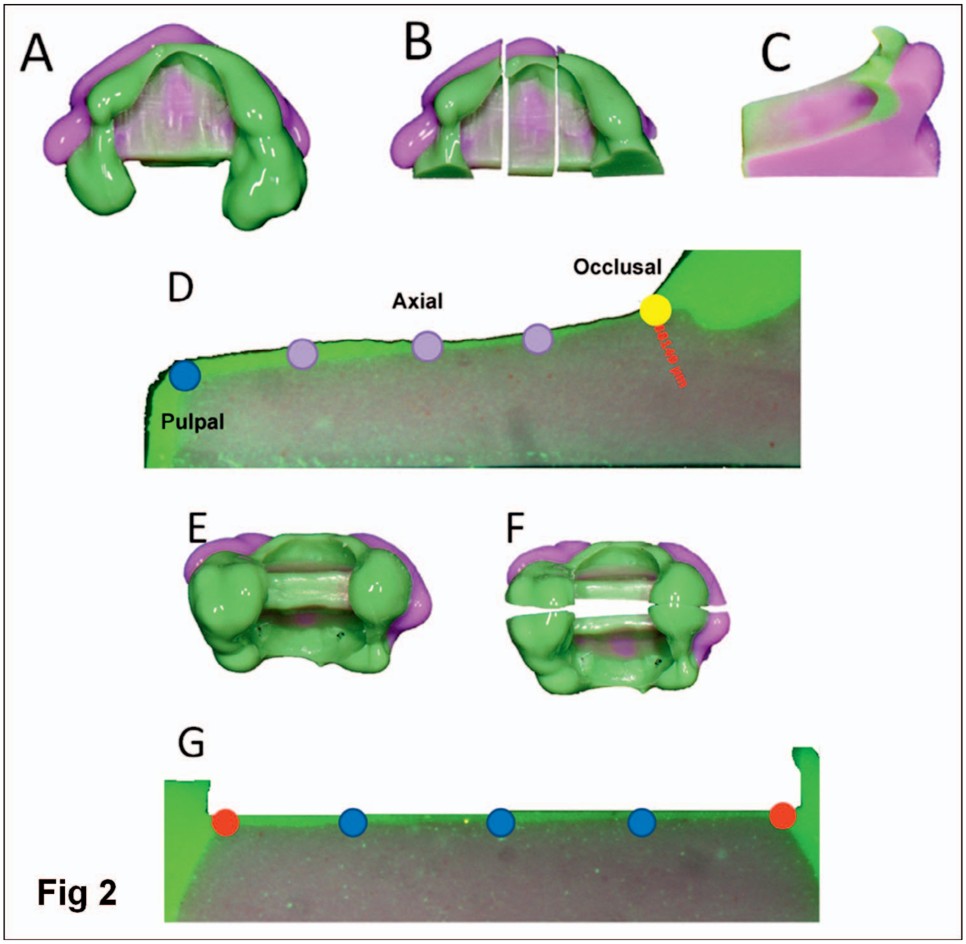

Figure 2. *Replica cuts and measures (μm). A: replica from the vestibular side. B: Cuts were performed in both vestibular and palatal sides. C: internal side after the cut was performed . D: stereomicrograph of section shown in C showing the measurement points of the green silicone. E: replica from the pulp side. F: cut performed of the pulp side. G: stereomicrograph of the internal side of the cut shown in "F" showing measurement points of the green silicone. The yellow ball corresponds with the occlusal edge and the red ones with the cervical edge. Violet balls correspond to the axial wall and blue ones to the pulp wall.*

strated in other studies, such as Bottino and others[14] and Hamza and others.[11] Furthermore, Awada and Nathanson[15] reported that the material factor had a significant effect on the mean flexural strength, flexural modulus, modulus of resilience, and roughness of the margin edge for restorations. Those authors also showed that crowns milled from the new resin-based blocks seemed to have visibly smoother margins when compared with ceramic materials. It is likely more difficult to reproduce details at the margin when milling ceramic materials compared to polymeric materials due to the fact that the edge of the ceramic is thinner despite its greater strength and also to the fact that the lithium disilicate is more friable; consequently, their milling becomes more critical. In cases of inlays, the composite resin has some additional advantages since crystallization before cementation is not necessary, unlike the lithium disilicate. This makes the resin more practical for the chair-side system and cheaper since it makes a furnace in the office unnecessary.

In relation to internal adaptation, according to Hoop and Land,[16] the relatively large internal gap may allow restorations to seat further, effectively

Table 2: *Mean and Standard Deviation (in Parentheses) Values of Marginal and Internal Fit (μm)[a]*

Groups	Marginal Fit (μm)		Internal Fit (μm)	
	Occlusal Edge	Cervical Edge	Pulp Wall	Axial Wall
LaRe	105.9 (±40.3) A	130.9 (±38.4) AB	233.8 (±80.5) A	104.7 (±13.9) A
CeRe	145.3 (±106.5) A	116.7 (±42.1) B	227.5 (±94.2) A	76.7 (±24.6) B
CeDis	171.8 (±56.6) A	177.8 (±68.9) A	207.2 (±61.3) A	66.7 (±19.9) B
PresDis	132.0 (±54.8) A	149.5 (±27.6) AB	156.0 (±44) A	87.0 (±16.5) AB

[a] *Different letters indicate a significant difference (p<0.05) between the groups (column).*

Table 3: *Mean (Standard Deviation) Adjustment Time and Proximal Contact[a]*

Groups	Adjustment Time (s)	Proximal Contact (μm)
LaRe	322 (±263.8) AB	21.2 AB
CeRe	189.4 (±167.4) B	8.8 B
CeDis	497.8 (±276.5) A	29.2 A
PresDis	471.5 (±194.7) A	10.9 AB

[a] *Different letters indicate a significant difference (p<0.05) between the groups (column).*

reducing the marginal gap widths in inlays. According to Ender and Mehl,[17] Lava C.O.S. provides an accuracy of 45.8 μm with the scanning protocol recommended from the manufacturer, while Cerec Bluecam provides an accuracy of 23.3 μm. The difference of accuracy between these scanners can be explained due to the difference of the working principles and different light sources of the two scanners.

The Bluecam scanner works on the principle of stripe light projection, combined with active triangulation through the short wavelength of blue light. According to Sirona (the manufacturers of the Bluecam scanner), a pattern of parallel lines is projected onto the tooth, and these lines are distorted by the tooth contours. The distortions can be viewed from an angle (triangulation) that delivers information on the various elevations of the tooth. If the line pattern is shifted by moving the grid during the exposure, the measuring points can be clearly assigned. The Lava C.O.S. scanner is based on the principle of active (optical) wavefront sampling, which obtains 3D information from a single lens imaging system by measuring depth based on the defocus of the primary optical system. This device has three sensors that capture the surface to be scanned from different perspectives. With these three images captured at the same time, 3D surface patches are generated by proprietary image processing algorithms using the in-focus and out-of-focus information (Lava Chairside Oral Scanner C.O.S., 3M ESPE technical datasheet, 2009). However, it is important to consider that the cement and internal space for the Lava with the composite resin group was slightly greater than the other groups.

Moreover, the preparation might have influenced the quality of the image captured. All preparations were standardized through the use of one type of bur, regardless of the type of scanner or material of the inlay. Renne and others[18] showed that the preparation quality has a significant impact on marginal gap for crowns fabricated with a CAD/CAM system. According to Hoop and Land,[16] the inlay preparation for CAD/CAM should present 1.5 to 2 mm of pulpal floor depth, and the box walls should diverge in an occlusal direction by approximately 10° or more, which makes optical capture easier and reduces the risk of excessive binding during seating for the initial evaluation. In this study, the preparation had a convergence of 10° but was a little deeper (3 mm) in order to simulate the worst-case scenario.

In the present study, the digital intraoral impression and CAD/CAM systems, regardless of the type of scanner, did not show superior accuracy when compared to the conventional impression and press ceramic technique. This result is in agreement with Addi and others,[19] who reported that after luting there were only slight differences of fit between the restorations fabricated using three different manufacturing techniques and ceramics and that long-term follow-up studies would be necessary to assess the clinical significance of the slight differences between the systems. According to Neves and others,[12] lithium disilicate crowns fabricated using the Cerec 3D Bluecam scanner CAD/CAM system or the heat-pressing technique had similar vertical misfit. Bindl and Mormann[4] also evaluated the marginal and internal fit of all-ceramic molar crown copings made from CAD/CAM and conventional techniques (pressed technique), and they demonstrated the same accuracy of fit between the two models.

The literature is controversial regarding the clinically acceptable thickness of the marginal gap. According to Holmes and others,[20] a marginal gap of 100 to 120 μm is acceptable for avoiding potential degradation or dissolution problems that can contribute to cement loss. However, many other studies[10,21,22] consider marginal gap values of 100 to 200 μm to be clinically acceptable for cemented restorations. Another important consideration is that the marginal gap measurements used in the present study were the absolute marginal discrepancy,[8] which can provide larger values than actual marginal gap measurements.

In relation to the proximal contact and adjustment time, hypotheses 3 and 4 were rejected. As shown in Table 3, longer adjustment times led to less tight proximal contacts. The Cerec system with the lithium disilicate group presented the longest adjustment times and the less tight proximal contacts, which was statistically different from the Cerec system with the composite resin group, which presented the shortest adjustment time and the tightest proximal contact. These comparisons show that these differences among the groups produced from the Cerec system seem to have occurred due to the difference between the materials and not due to the inlay production method, as lab-side and chair-side models, because pressed lithium disilicate and the Lava C.O.S. scanner with composite resin groups were not statistically different from the Cerec system with lithium disilicate and composite resin, respectively. Despite the fact that the lithium disilicate is harder than the resin, care was taken in relation to the use of the bur with greater grit and more rpm for the lithium disilicate when compared to the resin.

Another factor to consider is that the thickness of the occlusal marker (21 μm) used to adjust the interproximal contact was larger than the mean of the contact point for the Cerec system with composite and pressed lithium disilicate groups. It shows that a slight adjustment was made in these groups; however, the pressed lithium disilicate group might have been slower due to the hardness of the lithium disilicate in relation to resin.

Dorfer and others[23] quantified the proximal contact strength *in vivo* by the creation of interproximal frictional forces during the removal of a 50-μm-thick metal strip. Those authors concluded that the contact point might be significantly influenced by location, tooth type, chewing, variations in the time of the day, and periodontal condition of the tooth. Therefore, the interproximal contact of the present study can be considered satisfactory for all groups since the least tight contact point measured was 29.2 μm, which was much less than the metal strip of 50 μm used to quantify the proximal contact strength.

A limitation of this study was the use of few types of ceramics since the feldspathic and other resin and ceramics could have been investigated, although it was not possible to fabricate lithium disilicate inlays using the lab model with the Lava system. Using other types of restorative materials would have been interesting for more comparisons in relation to marginal and internal fitting, time of adjustment and tightness of the interproximal contact; however, the main purpose of the present research was highlighted the different methods of inlay production.

Further studies should be conducted with other parameters and other types of materials indicated for inlay production. It would be interesting to evaluate other types of scanners with or without powder as well as to verify whether these different methods of inlay production influence the bond strength and fatigue loading conditions.

CONCLUSION

- For marginal fit at the cervical edge, the composite resin material presents a better fit than the lithium disilicate with the CEREC system, while there is no difference among the material/methods for inlay production at the occlusal edge.
- For the internal fit at the axial wall, the Lava C.O.S. presents a worse fit than the CEREC system but was similar to pressed ceramic. Additionally, there was no difference among the different inlay production methods when considering the pulp wall.
- All of the inlay production methods promoted acceptable interproximal contacts.
- The groups restored with lithium disilicate ceramic took more time for adjustment when compared to the resin restorative material.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Federal University of Santa Maria. The approval code for this study is 52827416.1.0000.5346.

Conflict of Interest

The authors of this article 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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