European Journal of Prosthodontics and Restorative Dentistry (2018) **26**, 31-38

Marginal and Internal Gap of Handmade, Milled and 3D Printed Additive Manufactured Patterns for Pressed Lithium Disilicate Onlay Restorations

Keywords

3D Printing
Stereolithography
Additive Manufacturing Technologies
Lithium Disilicate Pressed Onlay Restorations
Multijet Technology

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Received: 07.06.2017
Accepted: 27.11.2017

doi: 10.1922/EJPRD_01733RevillaLeon08

ABSTRACT

Statement of the problem: On a pressed lithium disilicate restoration, the building up of a wax pattern of the future restoration is a necessary step on the fabrication process. Conventionally, a wax pattern can be produced by handmade or milled procedures; however, the development of additive manufacturing technologies allows a new fabrication method. Purpose: The present study measured the marginal and internal gap of handmade, milled and additive manufactured patterns for an onlay restoration. Material and methods: A preparation of an onlay restoration was made on an extracted mandibular tooth. A definitive cast was fabricated from a conventional silicone impression of the prepared tooth. Three groups were established: handmade (HM), milled (ML) and additive manufactured (AM); 4 specimens per group were obtained. The marginal and internal gap of each pattern was measured on the extracted molar through a computed tomography test. Sixty measurements were done to measure the marginal gap and another 60 measurements were calculated to analyze the internal gap on each pattern on the prepared tooth. A total of 1.440 measurements were completed. Mann-Whitney and Turkey statistical tests were used for pairwise comparison. Results: The mean of the marginal and internal gap was of 67.56 ± 6.08 µm and 80.62 ± 3.26 µm for the HM group, 85.28 ± 2.17 µm and 96 ± 1.97 µm for the ML group and 86.49 ± 1.74 µm and 91.86 ± 2.88 µm for the AM group, respectively. The HM group presented significantly lower marginal (p=0.029) and internal (p=0.029) gap compared to the ML and AM groups. There was no statistical significant difference (p=0.486) on the marginal gap between the ML and the AM groups, but the AM group, showed significantly (p=0.029) smaller internal gap than the ML group. Conclusions: All the groups presented less than 100 µm marginal and internal gap, which is considered clinically acceptable. Clinical implications: The three fabrication processes are viable options for manufacturing patterns for lithium disilicate onlay restorations, but the best marginal and internal fit was still obtained by the conventional handmade procedures.

INTRODUCTION

Since 1882, when Herbst introduced the first ceramic inlays, and thanks to improvements in all-ceramic materials characteristics, adhesion techniques and fabrication technologies, this kind of conservative restoration is an acceptable alternative for large cavities.[1-12] In 2006, a pressed lithium disilicate glass-ceramic LDGC (IPS Emax.Press, Ivoclar Vivadent) was introduced.

Because of its high strength (400 MPa), etchability, translucency and optimal aesthetics, this material offers versatile applications and can be used in several types of restorations, ensuring a minimally invasive approach, good function and aesthetics.[7,10-15]

On a pressed lithium disilicate onlay restoration, a fundamental step is the fabrication of a wax restoration pattern which traditionally is obtained by handmade procedures. This procedure relies on the hand skills and careful protocol execution of the dental technician. Nowadays, with development of computer-aided-design and computer-aided-manufacturing (CAD-CAM) technologies, the patterns can be produced by subtractive and additive manufacturing procedures.[7,14-15]

Additive manufacturing (AM) technologies are a CAM technology that build up a 3-dimensional (3D) object by adding layer-upon-layer under computer control;[16,17] where individual processes will differ depending on the material and machine technology used. Hence, in 2010, the American Society for Testing and Materials (ASTM) group "ASTM F42 – Additive Manufacturing", formulated a set of standards that classify the range of Additive Manufacturing processes into seven categories: stereolithography (SLA), material jetting, material extrusion, binder jetting, powder bed fusion (PBF), sheet lamination and direct energy deposition.[16] These technologies have multiple applications in the dental field.[17-20] The most common technologies employed for polymer 3D printing in dentistry are SLA, material jetting and material extrusion.[18,19]

Material jetting technology is a process in which droplets of photopolymers are selectively deposited onto a build bed to develop a 3D object, which are then cured by an ultraviolet (UV) light.[16,17] After a thin layer is created, the process repeats itself by jetting additional layers until the part is fully formed.[18-21] A multijet or polyjet technology involves multiple nozzles jetting one or more liquid photopolymers onto the building platform to fabricate the 3D object.[16]

Different factors can affect the accuracy (precision and trueness) of the printed object as laser speed, intensity, angle and building direction,[22-26] number of layers,[22] software,[27] shrinkage between layers,[25] amount of supportive material[24] and post-processing procedures.

There are multiple available materials for 3D printers for the different 3D printing technologies. Between them, castable material is available for AM technologies. Following conventional procedures, a 3D printed castable pattern can be processed to obtained a dental restoration.[18-21,28-32]

Marginal fit is a key factor used in the evaluation of indirect restorations. Different methods have been used to measure *in vitro* the marginal and internal gap of a tooth-borne restoration.[33] However, x-ray microtomography (μ-CT) is a non-invasive tool that provide a 2-dimensional (2D) and 3D images of the examined samples, this method provides close sections of the internal and marginal space between the die and the sample, which allows a great number of measurement sites.[34]

American Dental Association (ADA) in its specification N.8 indicates that the thickness of the luting cement for a dental crown should not exceed 25 μm when using a type I luting cement or 40 μm when using a type II luting agent.[35] However, there is still no consensus on which is the ideal maximum marginal gap of a dental restoration, it has been considered as clinically acceptable from 50 to 120 μm gap.[36-38] Furthermore, it may be reasonable to think that all the procedures involved on the laboratory´s manufacturing steps of a restoration might outcome on a possible error accumulation.[38] Consequently, the wax pattern fabrication method is one of the crucial step for the marginal and internal gap of the final indirect lithium disilicate restoration.[39-41]

Several *in vitro* techniques have been suggested to measure the internal and marginal gap; among the non-destructive tests, computed x-ray μ-CT have been described.[42-44] This 3D high-resolution imaging system provides detailed cross-sectional information concerning the restoration-to-die fit without damaging the specimen.[45-47]

The objectives of the present study were to measure the marginal and internal gap of the onlay patterns produced by three different fabrication methods: handmade, milled and AM technologies. The null hypotheses were established: (1) There will be no statistical significance difference on the marginal gap between the patterns fabricated from different manufacturing process and (2) there will be no statistical significance difference on the internal gap between the patterns fabricated from different manufacturing process.

MATERIAL AND METHODS

SAMPLE PREPARATION

A freshly extracted caries free first mandibular molar non-endodontically treated stored in solution saturated with 0.1% thymol was obtained. The tooth was extracted for periodontal reasons. It was embedded in acrylic resin (Palapress, Haereus Kulzer) up to 3.0 mm below the cement-enamel junction (CEJ).

A mesio-occluso onlay preparation was executed by reducing the two mesial cusps. The gingival floor of the preparation was located 1 mm above the CEJ and have a 1 mm width; 1,5 mm cusp reduction; 2 mm isthmus reduction with a non-retentive tooth preparation. A round-ended tapered diamond bur was used with 1 mm width end bur (8845KR.314.021 and 845KR.314.021, Komet) and no internal sharp angles left.[12] *(Figure 1)*

A one-step double viscosity silicone (Light and heavy body Regular Virtual, Ivoclar Vivadent) impression was obtained and poured with die stone Type IV (GC Fujirock EP, GC) with a ratio of 22 mL water to 110 g dental stone mixed under vacuum for 30 seconds.

Figure 1: A, Preparation of the onlay restoration on an extracted mandibular molar.

The definitive cast was scanned with a specific dental laboratory scanner (Renishaw DS20, Renishaw) and the design of the future restoration was prepared with a homogeneous thickness: 1,5 mm cusps; 2 mm isthmus and 30 μm space for the luting procedures using a specific dental software (Exocad CAD, Exocad). The Standard Tessellation Language (STL) file was generated and used to fabricate all the computer aided manufacturing (CAM) specimen *(Figure 2)*.

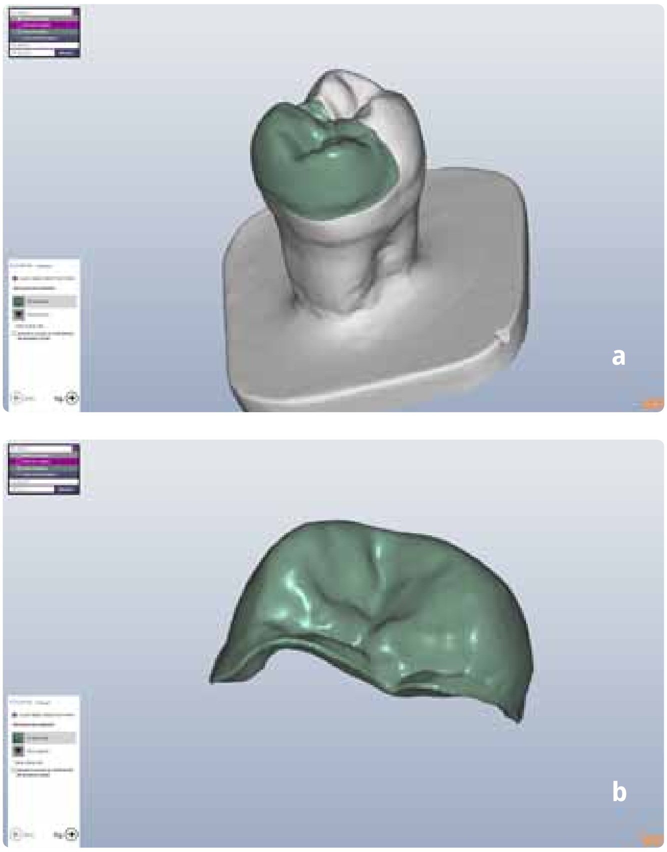

Figure 2: A, Occlusal view of the digitalization of the master cast. B, Digital design of the onlay restoration made by specific dental CAD software.

EXPERIMENTAL GROUPS

The following groups were established:

Handmade group (HM): A coat of die hardener (Die Hardener Yeti, Yeti Dental) and a coat of die spacer of 30 μm (True Fit Die Spacer, Patterson Dental) were applied on the die before the wax up patterns were prepared. The wax patterns (Renfert wax, Renfert GmbH) were hand made by an experienced dental technician. Each pattern was measure with a digital thickness caliper to assure the uniform thickness of the samples *(Figure 3)*.

Milled group (ML): The STL file was used to fabricate the milled patterns. Castable acrylic resin blocks (IPS AcrylCAD, Ivoclar Vivadent) were used to mill the patterns on a dental CNC machine (iMES-iCORE CORiTEC 250-i, iMES iCORE) *(Figure 3)*.

Additive manufactured group (AM): The STL file was used to manufacture castable 3D printed patterns (Visijet M3 Dent-Cast, 3D Systems) with a multijet printer (Projet MJP 3600 XHD Dental, 3D systems) *(Figure 3)*. The resolution of the selected printer at the x-, y- and z-axes is 750x750x1600 DPI or 29 μm respectively and 16 μm layer thickness. When the manufacturing process is completed, the additive manufactured castable patter was carefully removed from the cooled building platform using a putty knife and placed on metal basket inside a warming oven (158ºC) for 30 min in order to melt the supportive material. After this procedure is complete, the printed object was immersed on a hot (65ºC) mineral (EZ Rinse-C, 3D Systems) bath for 30 min, rinsed and dried.

Figure 3: Handmade (white), milled (blue) and 3D printed additive manufactured (yellow) pattern for the onlay restoration.

MEASUREMENTS

Four specimens of each group were obtained. A total of 12 patterns were fabricated. For the internal and marginal gap, a computed tomography (μ-CT) test was done for each specimen on the extracted tooth.

A total of 12 μ-CT were made. For the marginal gap, a coronal, sagittal and transversal cuts were fulfilled and 20 measurements/cut were calculated. For the internal gap, a coronal, sagittal and transversal cuts were fulfilled and another 20 measurements/cut were done for HM, MLp and AM *(Figures 4, 6 and 7)*.

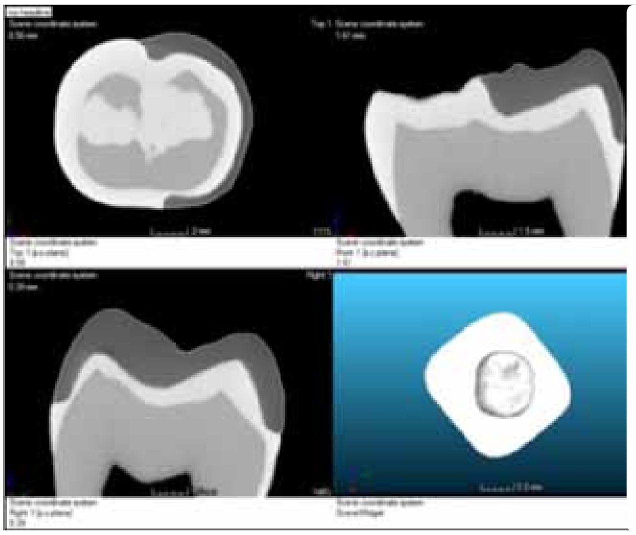

Figure 4: μ-CT of a handmade pattern on the prepared tooth, with different cut views.

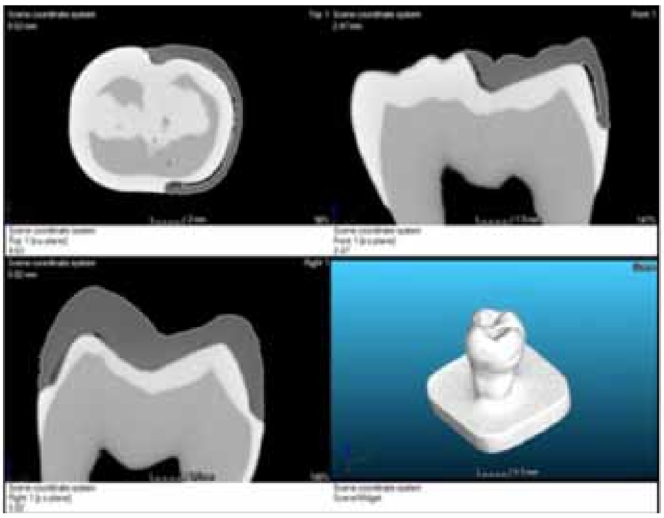

Figure 5: μ-CT of a milled pattern on the prepared tooth, with different cut views.

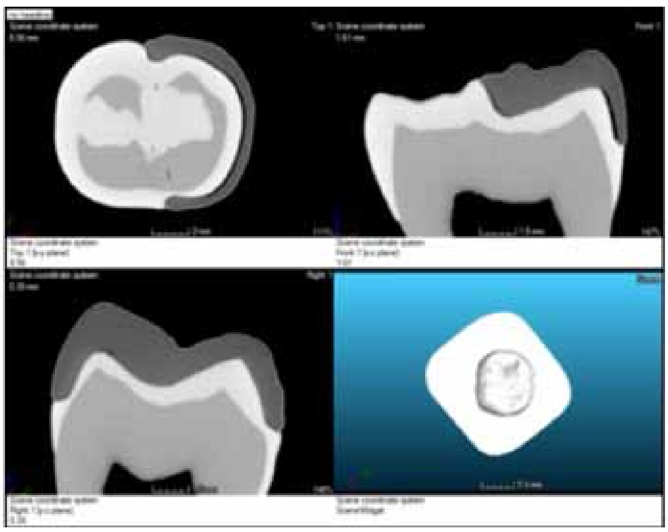

Figure 6: μ-CT of a 3D printed pattern on the prepared tooth, with different cut views.

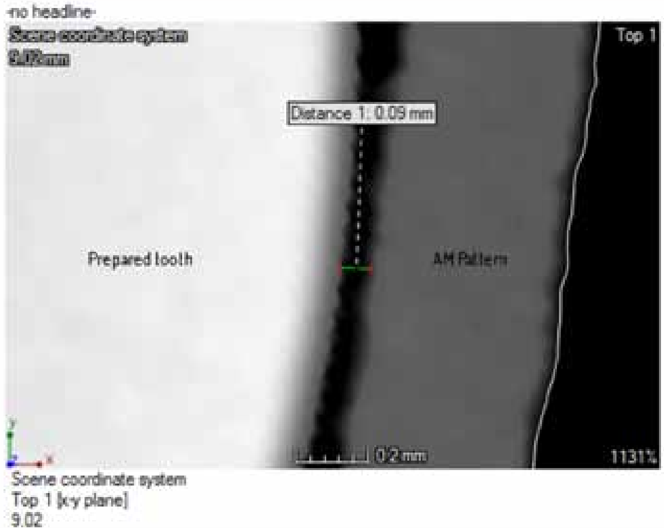

Figure 7: Measurement detail on the μ-CT of the prepared tooth with an additive manufactured pattern.

STATISTICAL ANALYSIS

For the statistical analysis, the SPSS 25 for Windows software (SPSS Statistics, IBM Corp) software was used. Data were analyzed Mann-Whitney and Turkey statistical tests for pairwise comparison ($p<0.05$).

RESULTS

The means of measurements (N=1.440) (μm) were calculated to analyze the marginal gap and internal gap. The mean for the marginal and internal gap were 80.61 ± 16.26 μm and 89.49 ± 16.46 μm, respectively. The statistical analysis revealed statistically significant differences (p=0.017) between the manufacturing process of the patterns for the marginal and internal gap *(Table 1, Figures 7 and 8*).

For the marginal gap, there were significant differences between the HM and the ML and AM patterns (p=0.029). There was no significant difference between the ML and the AM patterns (p=0.486). The mean of the marginal gap for the HM, ML and AM patterns were $^{67.56}$ μm (6.08), 85.28 μm (2.17) and 86.49 μm (1.74), respectively.

For the internal gap, Mann-Whitney and Turkey statistical tests for pairwise comparison reflected statistically significant difference (p=0.007) between the HM, ML and AM patterns. The mean of the internal gap for the HM, ML and AM patterns were 80.62 μm (3.26), 96 μm (1.97) and 91.86 μm (2.88), respectively.

Table 1. Statistics for the marginal and internal gap of the three groups: handmade (HM), milled (ML) and additive manufactured (AM) patterns.

	Marginal Gap (µm)		Internal Gap (µm)	
	Mean	SD	Mean	SD
HM	67.56^{a}	6.08	80.62^{a}	3.26
ML	$85.28^{b,c}$	2.17	96^{b}	1.97
AM	86.49^{c}	1.74	91.86^{c}	2.88

Similar letters indicate no significant differences for each parameter among the experimental groups tested.

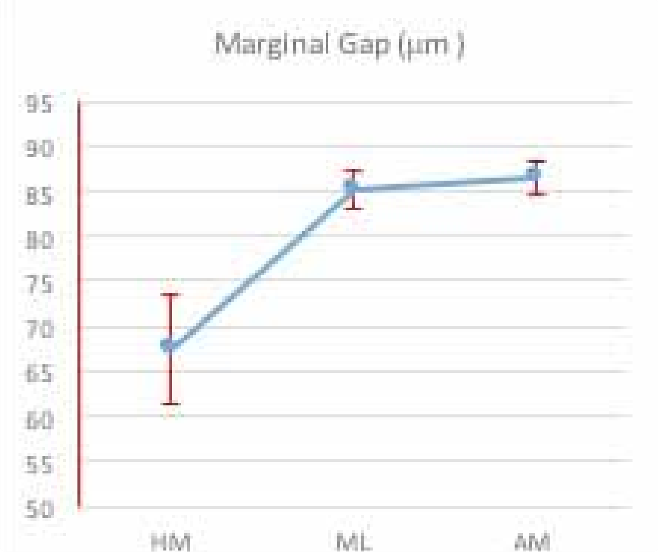

Figure 7: Mean of the marginal gap of the handmade (HM), milled (ML) and additive manufactured (AM) groups.

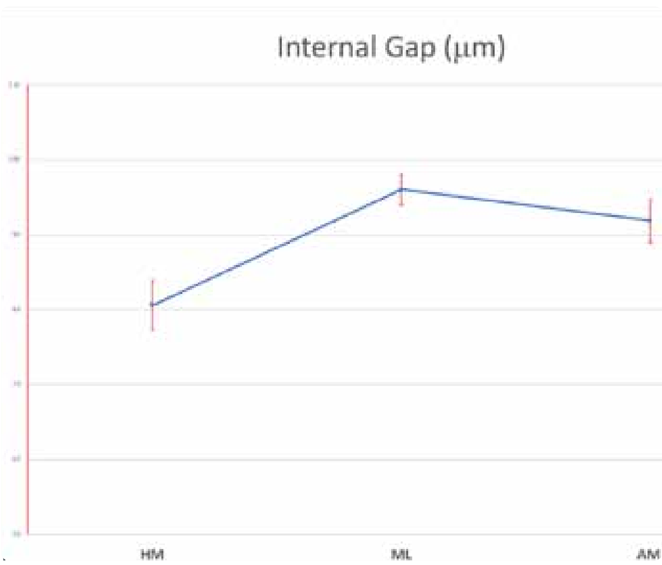

Figure 8: Mean of the internal gap of the handmade (HM), milled (ML) and additive manufactured (AM) groups.

DISCUSSION

The objectives of the present study were to measure the marginal and internal gap handmade, milled and AM patterns for a lithium disilicate onlay restoration. The null hypotheses were rejected, as there were statistically differences on the marginal and internal gap between the groups.

In the literature, different invasive and non-invasive methods were used to measure the marginal and internal gap, as direct-view, impression replica and cross-sectioning techniques, profilometry, digimatic micrometer and µ-CT scan.[33] CT scan provides high resolution images for measuring enamel thickness, dental restorations and assess the marginal and internal gap of crown restorations, it high cost limits the employment of this technique. On a µ-CT analysis, it has been recommended to make 50 measurements of the marginal fit to limit the numerical variance to ± 5 µm.[47,48] On the present study, 60 measurements per sample were made to analyze the marginal and internal gap respectively.

There are few published studies that measure the fit of the wax handmade or CAD/CAM patterns needed for manufacturing dental restorations, as well as a very few studies that analyse the marginal and internal fit of the restorations considering the fabrication method of its patterns.[46,48-56] Previous studies have demonstrated the distortion of the wax crowns related to the storage time, storage temperature and temperature of the wax manipulation.[48-51] Zelster *et al*[52] demonstrated that only the act of removing wax pattern from die causes an average 35 µm opening of the shoulder margin before investing.

In previous study by Shamseddine *et al*[39] the marginal and internal gap, with the replica technique, of the lithium disilicate crowns which patterns were obtained through hand formed or CNC machining procedures. The authors concluded that the marginal gap of the crown made from wax CAD/CAM manufacturing (105.14 ±39.60 µm) was significantly lower than that of the conventionally waxed crown (170.35 ±50.69 µm); for the internal gap, the crowns obtained from milled patterns an improved adaptation at the axial walls compared to the handmade group, although there were no statistically significant differences in the occlusal surface.

In 2016, Fathi *et al*[40] measured the internal and marginal gap of the metal crowns fabricated from handmade, milled and additive manufactured castable patterns using the replica and sectioning technique. For the 3D printed samples the authors selected the 3Z lab Solidscape printer, smooth curvature printing technology (jetting material technology) with a resolution of 5000x5000x8000DPI and 45 µm layer thickness. For the marginal gap measurements, using the silicone replica technique the marginal discrepancy obtained was 160 ± 24 µm, 110 ± 11 µm and 63 ± 6 µm for the handmade, milled and additive manufactured groups respectively; for the cementation and sectioning technique, the results were 141± 31µm, 124 ±54μm and 36 ±5μm for the for the handmade, milled and additive manufactured groups respectively. The authors concluded that all the techniques produced restorations with a clinically acceptable gap, furthermore the metal crown obtained from a 3D printed pattern showed a lower marginal and internal gap in both measurement techniques. In the present study, the marginal and internal gap obtained only with the castable patterns was analyzed, a further research of the gap obtained from the restorations manufactured from the different patterns could be interesting to develop as a secondary part of the present study. Fathi *et al*[40] did not analyze the gap of the castable patterns.

Based on the results of the present study, we can conclude that there was statistically significant difference on the marginal gap between the handmade and the CAD-CAM patterns; furthermore, the lowest marginal gap were obtained on the handmade group (67.56 ± 6.08 μm). Moreover, the mean marginal gap between the groups goes from 67,56 to 86,49 μm, which it is considered in the acceptable clinical range. Similar results were obtained for the internal gap analysis where statistical significance differences were obtained between the three groups. The best internal fit was achieved by the HM group (80.62 ± 63.26 μm), followed by the AM (96 ± 1.97 μm) and ML group (91.86 ± 2.88 μm).

Different variables affect the manufacturing process likewise the tooth preparation,[13,55,57,58] die fabrication[59] and number of coats of the die spacer;[60,61] moreover, on the digital workflow other factors have influence on the accuracy of the manufactured object such as the digitizing procedures,[62-66] the digital design of the restoration, the digital determination of the die spacer, milling/printing strategies and post-processing procedures.[67-73]

The majority of the published studies analyzed the marginal and internal gap on crowns[41-46] and fewer number of studies articles evaluated the gap of the crowns considering the fabrication method of its pattern.[39,40] Moreover, in the knowledge of the authors, there is no study that analyzed the marginal and internal fit of an onlay restoration based on the manufacturing method of its pattern, or even further, measure the gap of the pattern. We should also take into consideration that the present study only analyzed a single step of the multiple ones needed to manufacture a pressed lithium disilicate onlay restoration. The whole process, from the impression to the delivery of the restoration, may accumulate additional distortions that can affect the clinical fit of the restoration.[68-70]

The main goal of the present study was to analyze the available dental applications of the polymers AM technologies, therefore the accuracy and reproducibility of the printers are a key factor in this study. One printer and one technology was analyzed, however it cannot be extrapolated to the rest of the technologies and printers, as different results may be found.[56]

AM technologies have demonstrated that the remaining material can be processed in the future[16-18,56] and no tooling is needed.[16-21,54] Furthermore, 3D printing allows to print more than one pattern at a time, the number of patterns will depend on the size of the patterns and the size of the building platform. In addition, AM technologies present a free complexity on the printed objects, while on our current gold standard ¨milling procedures¨ the access and tool size limits the desired final shape of the fabricated object.[17-22] Nevertheless, AM technologies seems to be more capable to reproduce a more detailed intaglio surface and occlusal anatomy details on a AM pattern, thus the method could be extended to the pressed lithium disilicate restoration.

CONCLUSIONS

From this study, the following could be concluded:

- For a pattern onlay fabrication, the three manufacturing methods (handmade, milled and additive manufactured) tested presented a clinically acceptable marginal and internal gap, ranging their mean from 67.56 μm to 86.49 μm and from 80.62 μm to 96 μm, respectively.
- Handmade onlay patterns showed a significantly lower marginal and internal gap compared to the CAD/CAM wax patterns.
- 3D printed onlay patterns presented significantly lower internal gap than the milled patterns but no difference was observed in terms of marginal gap.

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