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ORIGINAL ARTICLE

EFFECT OF LABORATORY WORKFLOW ON THE INTERNAL FIT OF PRESSED LITHIUM DISILICATE RESTORATIONS

Efecto del flujo de trabajo sobre el ajuste interno de restauraciones inyectadas de disilicato de litio

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ABSTRACT

Introduction: Computer-aided design and machining (CAD/CAM) and 3D printing provide interesting alternatives for fabricating patterns used in the heat-pressing technique of glass ceramics. However, there is limited evidence regarding the accuracy and precision of the resulting restorations. The aim of this study was to compare the internal fit of pressed lithium disilicate restorations produced from patterns created using manual wax-up, 3D printing, and CAD/CAM.

Materials and Methods: Thirty-six mandibular molar models with mesio-occluso-distal cavities were 3D printed. Injection patterns for these cavities were created using manual wax-up (MW), 3D printing (3DP), and CAD/CAM (CC) (n=12). Heat pressing was conducted using lithium disilicate, and the resulting restorations were adhesively cemented onto the models. The obtained samples were sectioned mesio-distally, and the internal fit between the restorations and the models was analyzed using a stereomicroscope. The results were evaluated using ANOVA and Tukey's post-hoc test (0.05).

Results: The highest fit values were observed for the CC group (135 μm), being significantly more accurate than those of the 3DP (203 μm) and MW (224 μm) groups. Additionally, the CC group also achieved the highest degree of precision.

Conclusion: The fabrication technique of injection patterns is a critical factor in determining the internal fit of pressed lithium disilicate restorations. While CAD/CAM remains the most accurate and precise method, 3D printing seems to be an interesting alternative for the future.

Keywords: Prosthesis fitting; Computer-aided-design/Computer-aided-machining; 3-D printing, Lithium disilicate; Ceramics; Workflow

RESUMEN

Introducción: El uso de diseño y maquinado asistidos por computadora (CAD/CAM), así como la impresión 3D, representan alternativas interesantes para la confección de patrones para la inyección de cerámicas vítreas. Sin embargo, existe poca evidencia sobre la exactitud y precisión de las restauraciones obtenidas. El objetivo del presente trabajo es comparar el ajuste interno de restauraciones inyectadas de disilicato de litio obtenidas a partir de patrones confeccionados mediante encerado manual, impresión 3D y CAD/CAM.

Materiales y métodos: Se imprimieron 36 modelos de molares mandibulares con una cavidad mesio-oclusodistal. Se confeccionaron patrones de inyección para estas cavidades mediante encerado manual (EM), impresión 3D (I3D) y CAD/CAM (CC) (n=12). Los patrones fueron inyectados con disilicato de litio y las restauraciones cementadas adhesivamente sobre los modelos. Las muestras obtenidas fueron seccionadas mesio-distalmente y se analizó el ajuste interno entre la restauración y el modelo con una lupa estereoscópica. Los resultados fueron analizados mediante ANOVA de una vía y la prueba post-hoc de Tukey (p=0.05).

Resultado: El grupo CC mostró los valores más altos de ajuste (135 μm), los que resultaron significativamente más exactos que los de los grupos I3D (203 μm) y EM (224 μm). CC también obtuvo los niveles más altos de precisión.

Conclusión: La técnica de confección del patrón es un factor determinante en el ajuste interno de restauraciones inyectadas de disilicato de litio. Pese a que el CAD/CAM sigue siendo la técnica más exacta y precisa, la impresión 3D aparece como una alternativa interesante de cara al futuro.

Palabras Clave: Ajuste de Prótesis; Diseño Asistido por Computadora; Impresión Tridimensional; Disilicato de litio; Cerámica; Flujo de Trabajo

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INTRODUCTION

Indirect glass-ceramic restorations are an essential tool in the therapeutic arsenal of the modern dentist, providing solutions for various problems, such as the loss of dental tissue caused by caries, fractures, or endodontic treatments. These materials, notable for their high resistance (over 400 MPa),[1] high translucency and aesthetics,[2] as well as their strong adhesive capacity,[3] have extended their indication to cover the entire restorative spectrum, while maintaining an adequate balance between a minimally invasive approach and exceptional mechanical properties.[4,5]

The heat pressing technique was one of the most significant advances in restorative dentistry of the last century, particularly due to its simplicity and ability to customize restorations to meet patient needs.[6] Although his technique was originally based on analogue methods (such as manual waxing of plaster models), the emergence of digital workflows, including CAD/CAM (computer-aided design – computer-aided machining), and 3D printing, has expanded the range of available alternatives.[7] Digital designs can be used to obtain patterns for the heat pressing technique, enhancing the precision and accuracy of restorations,[8,9] thus improving the overall efficiency of the process.

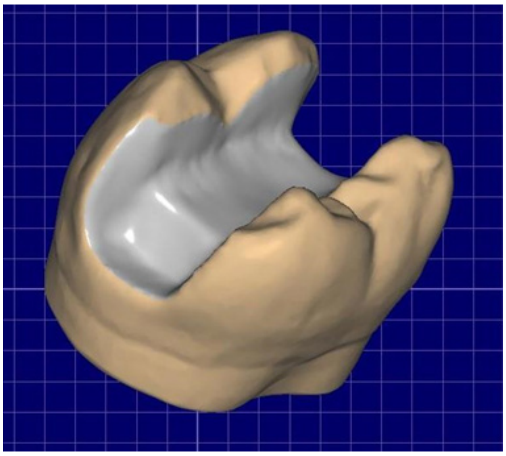
Although digital technologies seem to offer more sustainable and efficient solutions than analogue methods for the heat-pressing technique, there is currently insufficient evidence regarding their effect on the precision and accuracy of these restorations. Therefore, the aim of this research was to compare the internal fit of pressed lithium disilicate restorations obtained from patterns fabricated by manual waxing, 3D printing, and CAD/CAM. The working hypothesis was that the internal fit of pressed lithium disilicate restorations depends on the injection pattern fabrication technique.

MATERIALS AND METHODS

An *in vitro* experimental study was conducted. A mandibular second molar with a mesio-occluso-distal (MOD) cavity, with occlusal and axial depths of 3 mm, was designed using ExoCAD (v.3.1, DentalCAD, Rijeka, Germany), (Figure 1).

From this digital design, thirty-six 3D models were printed using Aquagray resin (Phrozen, Taiwan). After alcohol and water, the models underwent photopolymerization in a UW-01 oven (Creality, Shenzhen, China), following manufacturer's instructions.

Figure 1.
Digital design of a mandibular molar with a MOD cavity.



The resulting models were randomly assigned to one of the following groups (n=12) for the preparation of the injection patterns:

- Manual wax-up (MW): Wax patterns (Schuler Dental, Germany) were contoured by a single dental technician using the wax-up technique (Figure 2A). All patterns were made by the same technician.

- CAD/CAM (CC): MOD restorations were digitally designed (Figure 2B) and the injection patterns were subsequently milled from a castable wax disk (Harvest dental, Columbia, United States).

- 3D printing (3DP): Using the same digital designs as in group CC, injection patterns were 3D printed using a castable 3D resin (Prizma Marketech Labs., Brazil), as shown in Figure 2C. The obtained patterns were washed in alcohol and water, and then polymerized in the UW-01 oven.

Injection sprues were attached to the resulting patterns and then positioned in the investment ring. Following setting of the investment material, dewaxing was conducted at 850°C. The rings were then heat-pressed at 930°C using lithium disilicate (Mazic Press, Vericom, Korea), in a Vacumaat furnace (Vita Zahnfabrik, Bad Säckingen, Germany).

Once removed from the investment rings, the restorations were washed with a solution of 0.6% hydrofluoric acid and 1.7% sulfuric acid to remove the reactive layer. The restorations were then adhesively cemented onto the printed resin models using the following protocol:

1. The printed models were cleaned with 96% ethanol.

2. The restorations were conditioned with 10% hydrofluoric acid (Condac Porcelana, FGM, Brazil) for 20 seconds.

3. Ultrasonic washing of the etched restorations was conducted in a 96% ethanol bath for 5 minutes.

4. Two layers of silane (Prosil, FGM, Brazil) were applied.

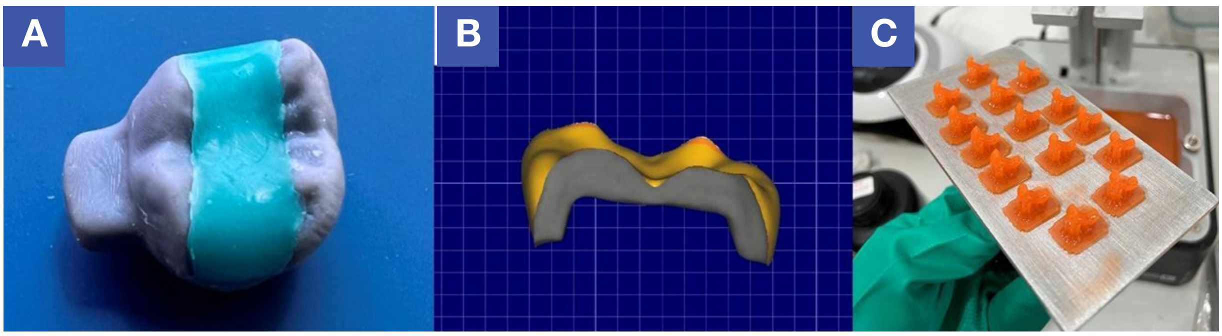
5. Dual resin cement (U200, 3M, St. Paul, MN, United States) was applied to the inner surface of the restoration, and finger pressure was used for cementation.

6. Excess cement was removed with a microbrush.

7. After two minutes of waiting setting, the restorations were light-cured for 30 s using a Bluephase N photocuring unit

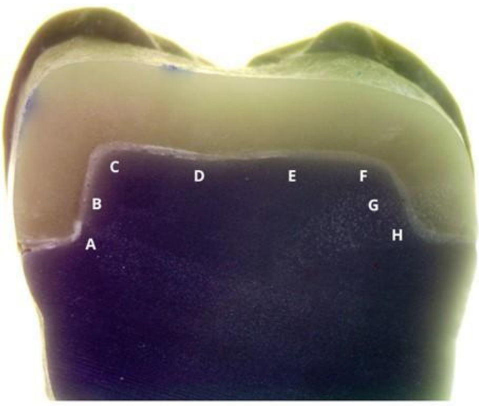
Figure 2.

Fabrication techniques for the injection patterns.



A: Manual waxing. **B:** CAD-CAM milling. **C:** 3D-Printing.

Figure 3.
Mesio-distal section of a sample indicating the location of the 8 measurement points for internal fitting (A-H).



(Ivoclar-Vivadent, Schaan, Liechtenstein) at 1200 mW/cm^2. Obtained samples were stored in a dry environment for 24 hours to ensure complete polymerization of the cement and were subsequently sectioned mesio-distally using a precision saw (IsoMet 1000, Buehler, USA) equipped with a diamond blade under continuous cooling.

Obtained sections were then analyzed with a stereomicroscope (SF-TRA, Am-Scope, United Scope LLC, Irvine, CA, USA) at 20x magnification. The internal fit was assessed by measuring the thickness of the cement layer at eight internal locations, designated with the letters A to H, (Figure 3).

All measurements were performed by the same observer, who was blinded to the fabrication technique used in each case. Additionally, one sample per group was prepared for scanning electron microscopy (SEM) analysis, and micrographs of the restoration-cement-model interface were obtained (TES-CAN VEGA II LSH, TESCAN ORSAY HOLDING a.s., Brno, Czech Republic).

The internal adjustment results were analyzed using bivariate descriptive statistics. A one-way analysis of variance (ANOVA) was conducted to test the working hypothesis. Multiple comparisons between groups were

Figure 4.
Distribution and standard deviation of the internal fit data for each group at each measurement location, The dotted line indicates an ideal reference value for internal fitting, set at 120 µm.

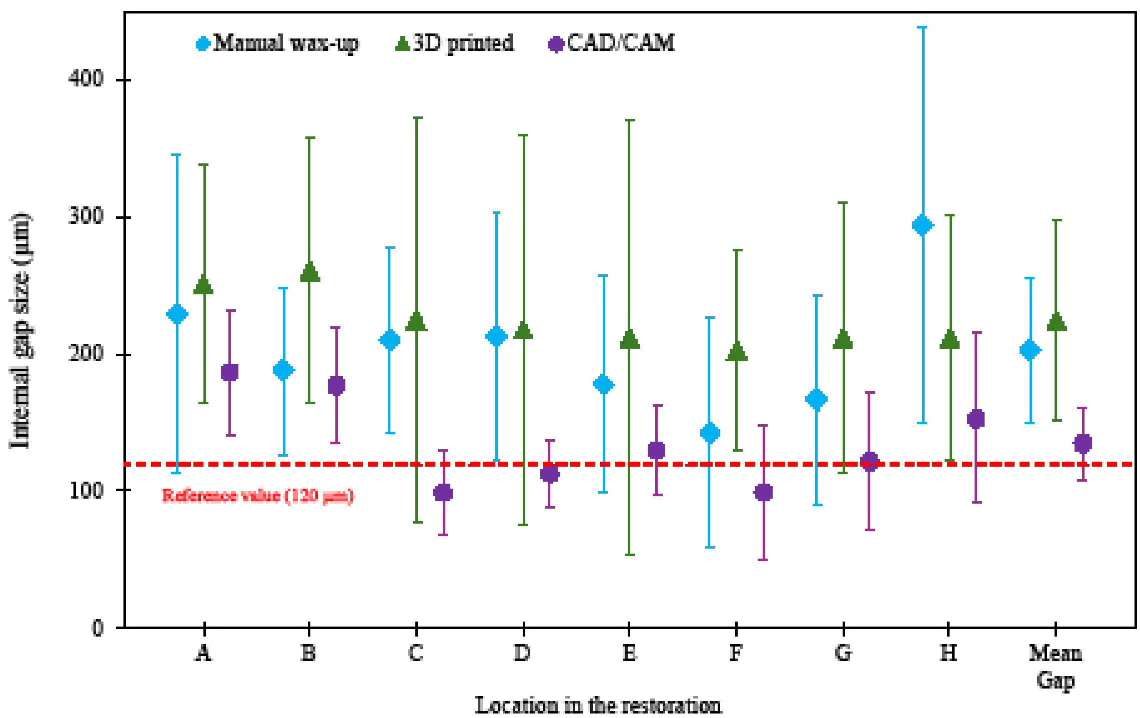


Figure 5.

Micrography of the internal fit of a restoration from the 3DP group. The insets show variations in the thicknesses of the cement layer (cem), proving that the fit level of the ceramic restoration (cer) is not uniform along the interface. Magnification of the general view: 72X. Magnification of the insets: 312X.

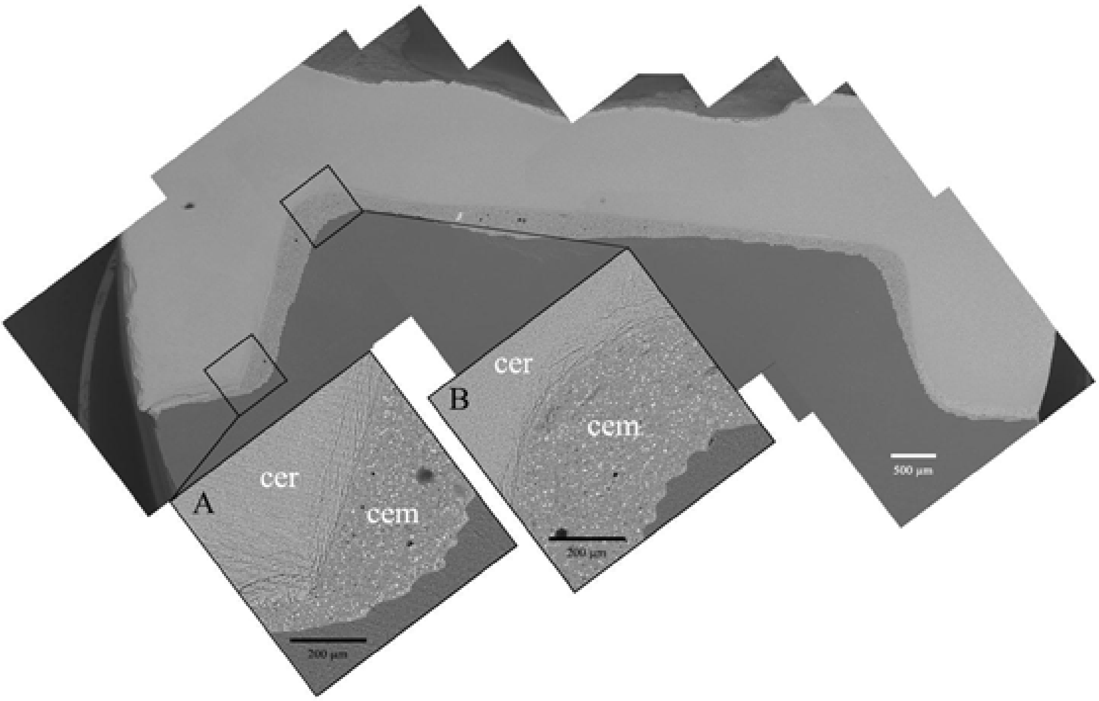


Table 1

Mean values of the internal gap (µm) of the restorations at each of the measured points, with their respective standard deviations (in parenthesis).

Point	Manual waxing	3D printing	CAD/CAM
A	229 (116)^{A}	251 (87)^{A}	187 (46)^{A}
B	188 (61)^{A}	261 (97) ^{B}	177 (42)^{A}
C	210 (68)^{B}	225 (148)^{B}	99 (31)^{A}
D	213 (90)^{B}	218 (142)^{B}	113 (24)^{A}
E	178 (79)^{A}	212(159)^{A}	130 (33)^{A}
F	143 (84)^{A,B}	203 (73)^{B}	99 (49)^{A}
G	167 (77)^{A,B}	212 (99)^{B}	122 (51)^{A}
H	294 (144)^{B}	212 (90)^{A,B}	153 (62)^{A}
Mean	203 (53)^{B}	224 (73)^{B}	135 (27)^{A}

Mean values followed by the same superscript letter in each row are not statistically different.

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performed using Tukey's post hoc test with a confidence level of 5%. Statistical analyses were carried out using SPSS-27 software.

RESULTS

The results obtained for internal fit are presented in Table 1. The mean fit value of the CC group (135 µm) was significantly lower than that of the MW (203 µm) and 3DP (224 µm) groups, which did not differ significantly from each other.

At the internal level, no statistically significant differences were observed between the three groups at points A and E, while the largest differences were found at points C and F. Most of the values of the MW group were statistically comparable to those of the 3DP group.

The distribution of the internal fit along the restoration-model interface is shown in Figure 4. Using a minimum fit value of 120 µm as a reference, it is clear the CC group consistently exhibits greater accuracy than the MW and 3DP groups.

In addition, the lower standard deviations in this group also highlight its greater precision. Figure 5 shows a micrograph of a sample from the 3DP group, highlighting the inhomogeneity in the thickness of the cement layer. It is interesting to note that, in the peripheral areas of the restoration, the final fit is better than in the internal areas, as illustrated in the insets.

DISCUSSION

New technologies, such as CAD/CAM and 3D printing, are playing a crucial role in modern dentistry, revolutionizing traditional approaches to the fabrication of indirect restorations. The rapid evolution of these technologies has created an innovative landscape, providing not only greater efficiency, but also enhanced precision and customization in dental treatments.[7] The results of this study partially confirm this trend, revealing a clear difference in both the accuracy and precision of digital versus analog techniques in the fabrication of wax patterns for the injection of glass ceramics.

Consequently, the initial hypothesis is confirmed, as the method of pattern fabrication had a significant effect on the internal fit of the resulting restorations. One of the main challenges when studying the fit of indirect restorations is the lack of consensus regarding the ideal value of internal fit. In this study, a minimum acceptable value of 120 µm was established, a magnitude supported by various studies in the literature.[10-12] In this regard, the best results were observed in the CC group, which had an average fit of 135 µm across the 8 analyzed locations, being therefore the closest to the ideal value. In contrast, the MW and 3DP groups recorded values of 224 µm and 203 µm, respectively, distancing themselves from what would be defined as clinically acceptable based on this criterion.

There are few studies in the literature comparing the fit of restorations obtained using differently fabricated injection patterns, especially those obtained using digital technologies.[6] In the study by Guachetá *et al.*,[9] injected lithium disilicate veneers made from a digital design and printed in castable resin were compared with veneers made using manual waxing. Although the digital model group had a smaller internal gap than the waxed samples (61.21 µm *versus* 68.03 µm), these differences were not statistically significant.

In another study by Ottoni *et al.*,[8] crowns made from 3D-printed patterns were compared with those obtained using the milled pattern technique. The internal fit obtained using micro-computed tomography showed similar outcomes for both groups, suggesting comparable accuracy between the two techniques. On the other hand, using an experimental design, very similar to the one adopted in the present study, Homsy *et al.*,[13] found that, for pressed restorations (IPS e.max Press), the best marginal and internal fits were obtained from subtractively manufactured wax patterns (CAD-CAM), compared with patterns produced by manual waxing or 3D printing. As in the present study, no differences were observed between the two additive techniques.

The larger mismatch observed here in restorations obtained using the 3D printing technique could be explained by factors such as the software used for the design,[14] the number of layers configured for the final print, the arrangement of the supports adhered to the printing base,[15] the printing speed,[16] the contraction inherent to this type of material,[17] and the post-processing in alcohol once the print was completed and removed.[15] On the other hand, the lower accuracy observed in the manual waxing technique can be attributed to the negative effects of the thermal sensitivity of the patterns, which, when subjected to heat during casting, can experience a higher thermal expansion, potentially altering their dimensions.[18]

Another relevant factor is that the handling of the patterns is directly linked to the skills and knowledge of the dental laboratory technician.[13,18,19] The higher accuracy and precision of the CC group could be explained by the lesser influence of the human factor, as the patterns were obtained systematically through machining. In addition to the more detailed and faithful reproduction of the dental anatomy, this technique ensures a higher precision of the restorations,[20] in an effecient and faster manner,[21,22] thus, significantly reducing working times.

Although the restorations in the 3DP group were not statistically more accurate than those in the MW group, a slight trend towards better internal adaptation was observed (Table 1). This technique is still relatively new, so it faces challenges inherent to its development and is dependent upon several factors that may have contributed to errors in the manufacturing process.[14-17] Improving the quality of 3D-printed patterns, therefore, requires a full understanding of these factors to improve their accuracy and consistency.[23]

One of the limitations of this work was

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the use of 3D-printed tooth models. Although this approach is innovative and allows for the creation of identical cavities for cementation of restorations, its use prevents a direct comparison with studies carried out on real teeth, especially regarding the adhesive fixation of restorations. However, by isolating the precision factor in cavity preparation, it is possible to better analyze the effect of the manufacturing technique on the accuracy of the resulting patterns.

The findings of this study confirm the leadership of CAD/CAM technology in the digital transformation process. However, 3D printing represents an increasingly efficient alternative, both in terms of time and cost. It is therefore essential to continue researching and investing in this technology,, whose contribution to dentistry, both present and future, is promising.

CONCLUSION

The laboratory workflow is a determining factor of the internal fit of injected/pressed lithium disilicate restorations, with the CAD/CAM technique achieving levels of fit and precision not only approaching the ideal of 120 µm, but also significantly surpassing those of manual waxing and 3D printing techniques.

Although 3D printing seems to be a more efficient and innovative solution, its development still requires improvements in several factors that currently influence its performance.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

ETHICS APPROVAL

The work reported in this paper did not include work on humans, animals or tissues derived from these. Therefore, bioethics approval was not required for its execution.

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AUTHORS' CONTRIBUTIONS

Fabián Acuña: Conceptualization, methodological design and execution, analysis of the results and writing of the manuscript.
Elizabeth Parra: Methodological execution and analysis of the results.
Luis Luengo: Analysis of the results.
Vilma Sanhueza: Methodological execution.
Ornella Contreras-Ferrada: Methodological execution.
Michael Wendler: Conceptualization, methodological design, review of the manuscript.

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