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Original Article

Effect of Impression and Wax Pattern Fabrication Method on the Accuracy of Pressed Lithium Disilicate Inlays

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Abstract

Introduction: This study was conducted to evaluate the effect of different impression and wax pattern fabrication methods on the marginal and internal adaptation of pressed lithium disilicate inlays.

Methods: A mandibular first molar extracted due to poor periodontal prognosis was prepared for lithium disilicate mesio-occlusal inlay restoration with 1.5-mm pulpal depth, 5–8° divergence of internal walls, a 3-mm occlusal isthmus width, and a 2.5-mm proximal box width. Three groups were defined according to the impression and wax pattern fabrication method. In Group 1, conventional impressions were made with heavy- and light-body polyvinyl siloxane impression material, and stone dies were made using type IV dental stone. In Group 2, stone dies obtained in Group 1 were scanned using a laboratory scanner before application of the die hardener, and wax patterns were fabricated using computer-aided design (CAD) technology. In Group 3, the prepared tooth was scanned using an intraoral scanner, and wax patterns were made using the same CAD workflow. All the wax patterns were subsequently invested and processed using the press technique. The marginal and internal gaps of the inlays were evaluated using micro-computed tomography. The obtained data were analyzed using one-way analysis of variance (ANOVA) at a significance level of 0.05.

Results: The mean internal gap in Group 3 was significantly lower than that in Group 2 ($P<0.001$) but significantly higher than that in Group 1 ($P=0.003$). In addition, Group 2 exhibited a significantly greater internal gap than Group 1 ($P<0.001$). No statistically significant differences were observed among the three groups in terms of marginal gap values ($P>0.05$).

Conclusion: The impression and wax pattern fabrication methods did not significantly influence the marginal adaptation of pressed lithium disilicate inlays. However, the conventional impression technique combined with hand-made wax patterns resulted in the smallest internal gap among the evaluated methods.

Keywords: Inlay, Computer-aided design, Dental impression technique, Lithium disilicate, Dental marginal adaptation

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Introduction

Lithium disilicate glass-ceramics are widely used for the fabrication of intra-coronal bonded tooth-supported prostheses due to their favorable esthetic properties, excellent mechanical properties, and reliable bonding characteristics.[1,2] Lithium disilicate restorations can be fabricated using either the lost-wax pressing technique or computer-aided design/computer-aided manufacturing (CAD/CAM) milling technology.[3] In the conventional press technique, wax patterns are fabricated manually. Although this approach offers convenient laboratory handling and accurate contouring of the restoration,[4] it has several disadvantages, including the thermal sensitivity of wax, technique-sensitivity, and the time required for pattern fabrication.[4-6] In contrast, the fabrication of patterns using three-dimensional (3D) printing or CAD/CAM systems is based on computer-controlled manufacturing processes, which may improve standardization and reduce operator-dependent variability.[7]

Intra-oral scanning has been introduced as an alternative to conventional impression-making procedures.[8] The accuracy of conventional impressions may be affected by cumulative errors occurring during impression making, cast fabrication, and subsequent laboratory procedures.[9] Digital impressions have the potential to eliminate most of these sources of error.[10] However, their accuracy may be influenced by factors such as complexity of the preparation design, including the dimensions of the proximal box and the extent of class II inlay preparations.[11-13]

Pressed lithium disilicate restorations are generally believed to exhibit superior marginal accuracy compared with milled restorations.[3] Furthermore, manual fabrication of wax patterns is both time-consuming and technique-sensitive. Distortion of wax patterns may occur because of the high coefficient of thermal expansion of wax or during removal of patterns from the stone die.[4, 5, 14] Previous studies have shown that 3D-printed wax patterns can provide marginal adaptation comparable to that of conventional wax patterns; however, their accuracy may be adversely affected by preparation features such as corrugated or sloping surfaces.[15] Therefore, the detailed geometry of an inlay preparation could affect the accuracy of impression-making and wax pattern fabrication procedures. The aim of this study was to evaluate the marginal and internal fit of IPS e.max Press inlays made of wax patterns fabricated with three different workflows: (1) conventional impression and hand-made wax patterns, (2) conventional impression, scanning the stone dies in the laboratory, and CAD/CAM-milled wax patterns, and (3) intra-oral scanning and CAD/CAM-milled wax patterns. The null hypothesis was that the method of impression-making and wax pattern fabrication would not significantly affect the marginal and internal accuracy of pressed lithium disilicate inlays.

Materials and Methods

In this in vitro study, a mandibular first molar extracted due to poor periodontal prognosis was mounted in an acrylic resin block (Acropars, Iran) with the cemento-enamel junction (CEJ) positioned 1 mm above the resin surface. The tooth was prepared for a class II mesio-occlusal ceramic inlay using diamond burs (Experten-Set 4562S Keramik-Inlays; Brasseler GmbH, Lemgo, Germany) under microscopic magnification. The occlusal preparation was performed with a pulpal depth of 2.5 mm, an isthmus width of 3 mm, and an occlusal divergence of 5-8°. The mesial proximal box was prepared with a gingival margin located 1.5 mm coronal to the CEJ, an occluso-gingival height of 4 mm, and a wall divergence of 10-15°. All internal line angles were rounded. A surveyor (Kavo EWL, Type 990; Kavo, Biberach, Germany) was used to check the occlusal divergence.[15]

Based on a sample size calculation ($\alpha = 0.05$, $\beta = 0.20$, power = 80%, SD = 0.20, and d = 0.25), a total of 30 specimens were included.[16] The sample size was determined using the following formula:

$$n = [(Z1-\alpha/2 + Z1-\beta)^2 \times 2SD^2] / d^2$$

The specimens were divided into three groups (n = 10) according to the impression and wax pattern fabrication method. Group 1: conventional impression and hand-made wax patterns, Group 2: conventional impression, laboratory scanning of stone dies, and CAD/CAM-milled wax patterns, Group 3: intra-oral scanning and CAD/CAM-milled wax patterns. For Group 1, ten partial custom trays (Schellack Basisplaten; Cavex, Haarlem, Netherlands) were fabricated on a cast obtained from irreversible hydrocolloid impression of the prepared tooth. Ten definitive impressions were made using a one-step heavy- and light-body polyvinyl siloxane impression material (Hydrorise; Zhermach, Badia Polesine, Italy) at room temperature. The impressions were poured in type IV dental stone (Resinrock; Whip Mix Corp., Louisville, KY, USA) according to the manufacturer's instructions. No die spacer was applied.[15] Instead, two layers of die hardener (Die: Master duo; Renfert GmbH, Hilzingen, Germany) of nearly 18 µm thickness were applied to each die.[15] Ten standardized wax patterns were made manually, invested using phosphate-bonded investment material (Vacalon Z4 Investment), and pressed with lithium disilicate ingots (IPS e.max Press LT A3, IPS.emax press Ivoclar, Schaan, Liechtenstein) according to the manufacturer's recommendations for the lost wax technique. The intaglio surfaces of the restorations were air-abraded with 100-µm Al2O3 particles at 0.5 MPa pressure.[15]

For Group 2, the stone dies were scanned before application of die hardener using a laboratory scanner (Swing; DOF Inc., Seoul, South Korea). The inlay restorations were designed using CAD software (3Shape Dental System; 3Shape, Copenhagen, Denmark). A virtual die spacer of 30 µm was applied beginning 1 mm from the restoration margins. [15] A 5-axis milling machine (DWX51D, Roland DG Corp., Hamamatsu, Japan) was used for milling 10 wax patterns (Wax Blanc, Ymahachi Dental MFG Co., Gamagori, Japan) according to the resulting design. The press technique was subsequently used following the same protocol used for Group 1.

For Group 3, after scanning the prepared tooth with an intra-oral scanner (CEREC; Dentsply Sirona, Bensheim, Germany), the STL file was exported to the laboratory. The inlay patterns were designed and milled with the same protocol used in Group 2. All the wax patterns were invested and processed following the same protocol used for Group 1. The wax patterns were burned out at 915° C for 15 minutes and subsequently pressed with lithium disilicate in a ceramic pressing furnace (EP 600, Ivoclar Vivadent) at 800° C and 0.4 MPa pressure as recommended by the manufacturer. Then, all 30 inlays were seated on the original master preparation. Minor adjustments of internal surfaces were performed using a round fine-grit diamond bur under water irrigation in a high-speed handpiece after identification of pressure areas with a silicone fit-checking material (Fit Checker II; GC GmbH, Germany) (Figure 1).[15]

The marginal and internal gaps of seated restorations were evaluated using micro-computed tomography (micro-CT) (LOTUS-in Vivo, Behin Negareh Co., Tehran, Iran) (Figure 2). Scanning was performed using a micro-focus X-ray tube with a focal spot size of less than 5 µm, a power setting of 5 W, and a spatial resolution of 15 µm. Images were reconstructed using an ultra-sharp surface reconstruction filter. The scans were randomly coded using a random number generator before analysis. Gap measurements were performed using OnDemand software in 20 cross-sectional images per specimen. For the assessment of internal adaptation, [13] equidistant points were evaluated in each cross-section (three mesiobuccal, three distobuccal, one distal, three distolingual, and three mesiolingual points), yielding a total of 260 measurement points per specimen. For the assessment of marginal gap, two points were measured in each cross-section, resulting in a total of 40 measurements per specimen.

Data were statistically analyzed using SPSS software version 21 (IBM Corp, Chicago, Illinois, USA). The effects of impression and wax pattern fabrication methods on marginal and internal adaptation were analyzed using one-way analysis of variance (ANOVA). Pairwise comparisons were performed using Tukey's post hoc test at the significance level of 0.05.

Results

The normality of data distribution was confirmed using the Kolmogorov-Smirnov test ($P>0.05$). The mean values and standard deviations (SDs) of marginal and internal gaps are presented in Table 1. The impression and wax pattern fabrication method had a significant effect on the marginal fit of the restorations ($P<0.001$). The mean internal gap in Group 3 was significantly lower than that in Group 2 ($P<0.001$) but significantly higher than that in Group 1 ($P=0.003$). Furthermore, Group 2 exhibited a significantly greater internal gap than Group 1 ($P<0.001$). However, there was no significant difference among the three groups in terms of marginal gap values ($P>0.05$).

Discussion

In this study, we compared the marginal and internal accuracy of pressed lithium disilicate inlays made using either hand-made or CAD/CAM-milled wax patterns through conventional and digital impression workflows. The null hypothesis was partially rejected, since there was no significant difference in marginal fit among the three techniques.

Table 1. Mean (SD) Values of Marginal and Internal Gap of Three Study Groups

	Marginal gap			Internal gap		
	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum
Group 1	40.29 (3.65)	35.34	45.33	51 (3.80)	45.76	55.89
Group 2	44.5 (13.16)	10	130	86.27 (14.13)	15	310
Group 3	39.19 (4.26)	10	100	67.93 (4.56)	10	300

Figure 1. Seating of Pressed Inlay Restoration in the Original Preparation

In this study, a single extracted mandibular first molar was used to eliminate the variability related to preparation geometry and standardize experimental conditions. In order to better simulate clinical scanning, an extracted tooth was prepared instead of using a typodont.[15] In addition, since micro-CT was planned for gap measurements, using an acrylic resin tooth was considered less appropriate due to potential imaging artifacts.[17] Moreover, to minimize variability attributed to impression and scanning procedures, repeated impressions or repeated digital scans were not performed in this study.[15] Additionally, only a single scan of each stone die was obtained in Group 2. Wax was used for fabrication of inlay patterns since it has lower internal discrepancies compared with resin materials. Furthermore, wax is more cost-effective and easier to handle in the conventional method, and it causes less damage to the rotary instruments during subtractive manufacturing processes.[18]

Group 2 was designed to minimize operator-dependent errors associated with conventional wax pattern fabrication and to reduce variability introduced by different scanning systems.[19] In Group 3, CAD/CAM wax patterns were fabricated directly from scanning of the prepared tooth with an intraoral scanner. According to the findings, Group 2 (conventional impression with laboratory scanning and milled wax patterns) demonstrated the highest internal gap among the three groups. However, the fully digital workflow (Group 3) resulted in a higher internal and marginal accuracy as compared to Group 2, which is consistent with the findings reported by Homsey et al.[15] Nevertheless, all groups demonstrated marginal gaps within the clinically acceptable limit of 100 µ.[20] The higher internal discrepancy observed in Group 2 may be attributed to impression material and dental stone dimensional changes, as well as cumulative errors during the indirect digital workflow. [19] In addition, the accuracy of scanning may be compromised in areas with complex geometries. Features such as the proximal box depth, narrow access, and margin position can negatively influence the performance of intra-oral scanners due to restricted access and light scattering.[11,21-23] Variations in accuracy between intraoral and extraoral

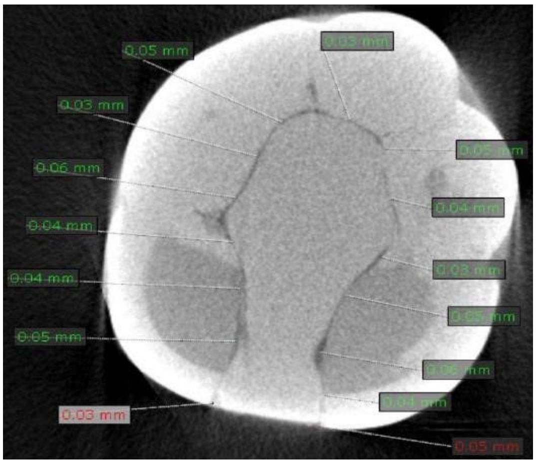

Figure 2. Micro-CT Evaluation of the Internal and Marginal Adaptation of Inlays

scanners have also been previously reported.[24] Moreover, the comparatively large size of milling burs in relation to the dimensions of the internal geometry of preparation may result in over-milling and unintended material removal in confined areas.[18]

In previous studies, inlays fabricated from hand-made wax patterns showed marginal gaps between 58 µm[25] and 95 µm[18] and internal gaps between 20 µm[26] and 118 µm,[15] which are consistent with the results of this study. In the conventional method (Group 1), lower wax wettability on complex surfaces and distortion of the wax patterns during removal from the die may contribute to internal discrepancies.[18]

No statistically significant differences were found in marginal fit among the three groups. This indicates that the impression technique and subsequent digital or conventional workflow did not significantly affect the marginal fit. This finding suggests that both conventional impression followed by laboratory digitization and direct intraoral scanning may produce clinically acceptable marginal adaptation for pressed lithium disilicate inlays. However, Group 1 showed better marginal fit, which could be attributed to the use of die hardener and the improved adaptation of wax to the preparation angles in the conventional workflow compared with milled patterns, where limitations of bur size may reduce precision in fine details.[18] In the present study, die hardener was used instead of die spacer due to its superior flow properties and its ability to produce a more uniform film thickness in the complex geometry of the preparation.[14]

The inconsistencies in the literature regarding the preferred method of impression making and wax pattern fabrication might be because of various measuring techniques, different numbers of measured points, different models of milling machines (number of axes), spacer settings, the complexity of the preparation design, and accuracy of scanners.[25,27,28] Micro-CT was used in this study for gap measurement due to its non-destructive nature and ability to provide high-resolution three-dimensional quantitative assessment of internal adaptation in any direction.[25,28] This method overcomes limitations associated with the replica technique, including tearing of elastomeric film upon removal, void formation, and sectioning errors.[28] Moreover, the number of points that could be measured is not limited in the former method despite the replica technique. In the present study, more than 200 internal and 40 marginal measurement points per specimen were analyzed to enhance measurement precision.[28]

A limitation of this study was using in vitro settings for conventional and digital impression making. Additionally, the presence of adjacent teeth could have affected the accuracy of digital impressions, particularly in proximal box regions. Moreover, micro-CT evaluation was performed in a limited orientation, and it is recommended that clinical studies should be conducted to validate these findings.

Conclusion

Within the limitations of this in vitro study, the following conclusions were drawn:

1. All groups presented marginal gaps within the clinically acceptable range (< 100 µm).
2. No statistically significant differences were observed among the three groups regarding the marginal fit.
3. The mean internal gap in the conventional impression method combined with hand-made wax patterns was significantly lower compared with other fabrication methods.

Authors' Contribution

Conceptualization: Koosha Gholamrezaie
Data Curation: Babak Meimandi
Formal Analysis: Babak Meimandi, Koosha Gholamrezaie
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Writing–Original Draft: Elaheh Beyabanaki
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Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Ethical Approval

The present study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1398.038).

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