Fit Accuracy of Pressed and Milled Lithium Disilicate Inlays Fabricated From Conventional Impressions or a Laboratory-Based Digital Workflow

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ABSTRACT

Purpose: The impact of material on the adaptation of lithium disilicate inlays is poorly documented. This in vitro study aims at comparing the fit accuracy of pressed and milled inlays obtained from conventional impression and laboratory-based computer-aided design and computer-aided manufacturing. Material and Methods: A typodont molar was prepared for a mesio-occlusal ceramic inlay. The stone die generated from one conventional impression was scanned once using a laboratory scanner and the same design was used to produce 15 pressed lithium disilicate inlays from milled wax patterns (group CIDW), and 15 inlays from lithium disilicate blanks (group CICAD) with a 5-axis milling machine. Marginal and internal discrepancies were measured using the replica technique. Mixed-model ANOVA was applied to assess differences according to material and gap location at P<0.05. Results: Material and discrepancy location had a significant effect on fit measurements. Group CIDW showed significantly smaller marginal (37.4 µm) and internal (69.2 µm) discrepancies than group CICAD (59.6 µm and 93.7 µm respectively). Marginal discrepancies were significantly smaller than internal discrepancies within both groups. Conclusions: Pressed inlays generated from conventional impression and milled wax patterns yielded better fit accuracy than milled inlays obtained from conventional impression and subtractive manufacturing.

INTRODUCTION

Metal-free restorations are increasingly being incorporated into prosthodontic rehabilitations as a result of greater esthetic demands. Among ceramic materials, lithium disilicate glass ceramics are widely used in the fabrication of tooth- and implant-supported prostheses because of their excellent esthetic and mechanical properties.[1] Lithium disilicate restorations can be made by using either lost-wax hot pressing techniques or computer-aided-designed and computer-aided-manufacturing (CAD/CAM) digital milling of monolithic blocks.[2]

Pressed restorations are usually produced by burning out wax patterns that are conventionally shaped by laboratory technicians from conventional impressions. The wax patterns can also be produced by milling wax blocks through intraoral or extraoral digital impressions.[3] Similarly, milled lithium disilicate restorations can be obtained with chairside or laboratory CAD/CAM technologies. The chairside workflow allows clinicians to significantly shorten fabrication time by using intraoral scanning and in-office milling. It also eliminates the use of temporary restorations and provisional cements resulting in improved dentine adhesion.[4] When dental practitioners do not have access to in-office intraoral digital scanner and CAD/CAM technology, the impression can be conventionally made and the subsequent digital workflow completed in the dental laboratory with extraoral scanning of the stone die and milling of lithium disilicate blanks.

Most studies have demonstrated similar or better fit with the heat-pressed technique when compared with CAD/CAM subtractive technology under clinical and *in vitro* conditions for single crowns[5-14] and partial coverage restorations.[15-19] Other investigators reported less accurate fit with heat-pressed versus milled single crowns[20-23] and inlays.[24] These contradictory conclusions can be attributed to differences in the type of dental restoration,[25] fabrication material,[26] preparation design and finish line,[27-31] quality of the preparation,[32] impression technique,[5,10,33] accuracy of the scanning device,[5,7,9,20,27,34,35] design software,[36] spacer thickness settings,[7] level of expertise of the technician with the CAD/CAM system,[14,17] milling machine accuracy,[16] milling-related conditions such as quality and size of the burs,[7] technique used to evaluate fit accuracy,[37] and number of measuring points.[38]

Currently there is limited documentation relative to marginal and internal fit discrepancies of lithium disilicate inlay restorations[3,18,19,24] with none that directly compares pressed and milled inlays produced from conventional impressions.

The purpose of the present *in vitro* study was to compare the marginal and internal fit of heat-pressed and milled lithium disilicate inlays obtained from conventional impression and laboratory-based CAD/CAM technology. The null hypothesis was that discrepancies would be similar between heat-press and CAD lithium disilicate materials.

MATERIAL AND METHODS

A typodont (Dentoform M-860; Columbia Dentoform® Teaching Solutions, Long Island City, NY, USA) mandibular right first molar was prepared for a ceramic class II mesio-occlusal inlay with diamond rotary instruments (Experten-Set 4562S Keramik-Inlays; Brasseler GmbH, Lemgo, Germany). The preparation design included a 2.5-mm-deep occlusal box, an isthmus width of 3 mm, and an overall convergence angle of approximately 8 degrees. The proximal gingival margin was located 1.5 mm above the cemento-enamel junction. The occluso-gingival dimension of the proximal box was 4 mm. All internal angles were slightly rounded *(Figure 1)*. Preparation was done freehand, and the vertical walls were adjusted with a surveyor (Kavo EWL, Type 990; Kavo, Germany).

Figure 1: Typodont mandibular first molar with class II mesio-occlusal inlay preparation.

One partial custom tray (mega-TRAY; Megadental, Germany) with occlusal rests was fabricated on the cast obtained from an irreversible hydrocolloid impression (Hydrogum 5; Zhermach, Rovigo, Italy) of the right quadrant of the typodont. One single-step dual viscosity master impression of the prepared tooth was made with light- and heavy-body polyvinyl siloxane (Hydrorise; Zhermach, Rovigo, Italy) at a room temperature ranging between 20°C and 22°C.[39] The cast was poured in Type IV stone (Resinrock; Whip Mix Corp., Louisville, KY, USA) following manufacturer's guidelines.

The stone die was scanned once by using a laboratory cast scanner (Ceramill Map400; Amann Girrbach GmbH) and the acquired 3D image transferred to the Ceramill software (Ceramill Mind v2.7.05; Amann Girrbach GmbH) for inlay design. The full-contour inlay anatomy was selected from the library available in the design system (Ceramill Mindform). The marginal discrepancy was set at 0 µm and the margin thickness at 0.2 mm. The simulated die spacer was programmed at 30 µm[7] starting 1 mm away from the margin. The surface tessellation language (STL) inlay design file was transferred to a 5-axis milling machine (In Lab MC X5; Dentsply Sirona) to produce 15 wax patterns milled from wax blocks (Dentsply Sirona) and 15 inlays milled from presintered IPS e.max CAD blanks (Ivoclar Vivadent AG; Schaan, Liechtenstein). The experimental design is illustrated in Figure 2.

One set of tungsten carbide rotary instruments of 0.5-, 1.0-, and 2.5- mm diameter (Denstply Sirona) was used for the group CIDW. One set of diamond rotary instruments of 0.6-, 1.2-, 1.4-, and 2.2-mm diameter (Dentsply Sirona) was changed for every group of 5 IPS e.max CAD inlays.

The milled wax patterns were invested in a phosphate-bonded investment (XPAND; Dentify GmbH, Engen, Germany), and pressed according to the manufacturer's recommendations using the lost wax technique. Fifteen IPS e.max Press (Ivoclar Vivadent AG) inlays were obtained from the wax patterns (group CIDW). The intaglios of the heat-pressed inlays were airborne-particle abraded with 100-µm aluminum oxide particles at 0.5 MPa.[40]

Figure 2: Experimental design
CIDW, conventional impression, extraoral digital scanning of the stone die, digital wax, and pressed restorations; CICAD, conventional impression, extraoral digital scanning of the stone die, and milled restorations.

The milled presintered inlays were subsequently crystallized in a porcelain furnace (Programat P500; Ivoclar Vivadent AG) at 840°C with the dwell time set at 7 minutes (group CICAD). No glazing was performed.

All inlays in the 2 groups were transferred to the master preparation, and their intaglios minimally adjusted with water-cooled diamond rotary instruments (Set 4562; Brasseler GmbH, Germany) after locating the points of contact with an elastomeric paste (Fit Checker II; GC, Bad Homburg, Germany).[41] These adjustments were limited to the occlusal axial walls.

Replicas of the space between the inner surface of the inlay and the cavity surfaces were made[37,42] by coating the tooth cavity walls with a thin layer of light-body silicone material (Hydrorise; Zhermach, Rovigo, Italy), after which the inlay was placed in the prepared cavity. For the standardization of load application during material setting, a metal weight of 39.2 N was placed on the upper surface of a vertically sliding platform positioned on top of the inlay/master tooth assembly until the impression material had fully polymerized.[43] After excess removal, the inlay was removed leaving a thin film of light-body material adhering to the master tooth. This film was stabilized by injecting a medium-body material (Elite HD; Zhermach) onto it. In the presence of defects or tears in the silicone film, the replica was discarded and the procedure repeated.

The replicas were sectioned with a scalpel in 2 directions, buccolingually (5 sections) and mesiodistally (3 sections) according to a previously described technique to ensure accurate and reproducible sectioning of the replicas.[3] The middle sections passed through the center of the restorations while the adjacent cuts were made at 1 mm intervals. Each of the 5 buccolingual sections enabled 7 measurements *(Figure 3A-B)*, whereas each of the 3 mesiodistal sections allowed 10 measurements *(Figure 3C-D)*. In each specimen, 65 measurements were evaluated, totaling 975 per group and 1950 for the entire study sample. The marginal fit was assessed under stereomicroscopy at ×40 magnification (Amscope 3.5; Irvine, CA, USA).

Discrepancy measurements according to Holmes *et al.*[44] were recorded in 9 locations *(Figure 3)*. Marginal fit was calculated as the average of the discrepancy measurements in locations A1 and A2, and internal fit was expressed as the mean of locations A3 to A9. All measurements were performed by 1 calibrated prosthodontist blinded to the study objectives. Intraobserver reliability was calculated by measuring the discrepancy at 17 points on 3 inlays at 10 different instances with an interval of 3 days between assessments. High intraobserver agreement of 0.987 was calculated by using the intraclass correlation coefficient test.

Five specimens from each group were randomly selected and sputter coated with gold (Cressington Sputter Coater 108auto; TED Pella Inc., Redding, CA, USA) for assessment under scanning electron microscopy (SEM). Qualitative analysis of the inlay proximal box and occlusal margins was conducted using the Seron AIS2100 SEM (Seron Technologies Inc., Korea) in high vacuum mode at 20-kV acceleration voltage and secondary electron detector under 300x magnification.

Descriptive statistics were obtained for the outcome measurements (marginal and internal fit) in the 2 groups. Mixed ANOVA was used for multiple comparisons and interaction among the explanatory variables with the material used (e.max Press versus e.max CAD) as the between-subject effect and discrepancy location (marginal versus internal) as the within-subject effect. Effect size (partial eta square) and observed power were estimated for each effect, where the minimal partial eta square observed was 0.022 and the largest 0.945, with an observed power of 0.12 to 0.999. Statistical significance was set at $\alpha=0.05$. The data were analyzed with statistical software (IBM SPSS v 24; IBM Corp).

RESULTS

A summary of marginal and internal fit measurements per group and for the overall sample is presented in Table 1.

Pairwise comparisons were significantly different between the 2 groups relative to the marginal (difference=22.2±9.4 µm; $P<0.001$), internal (difference=24.6±6.7 µm; $P<0.001$), and overall gap (difference=23.4±7.0 µm; $P<0.001$) with the milled inlays showing greater discrepancies than the pressed restorations. Significant differences were found between marginal and internal fit, with the marginal discrepancy (48.5±13.1 µm) being smaller than the internal discrepancy (81.4±15.5 µm) ($P<0.001$). The interaction material/discrepancy location was not significant, indicating independent effects of the material and discrepancy location on fit measurements, with $F(1,28)=0.62$ ($P=0.439$) *(Table 2)*.

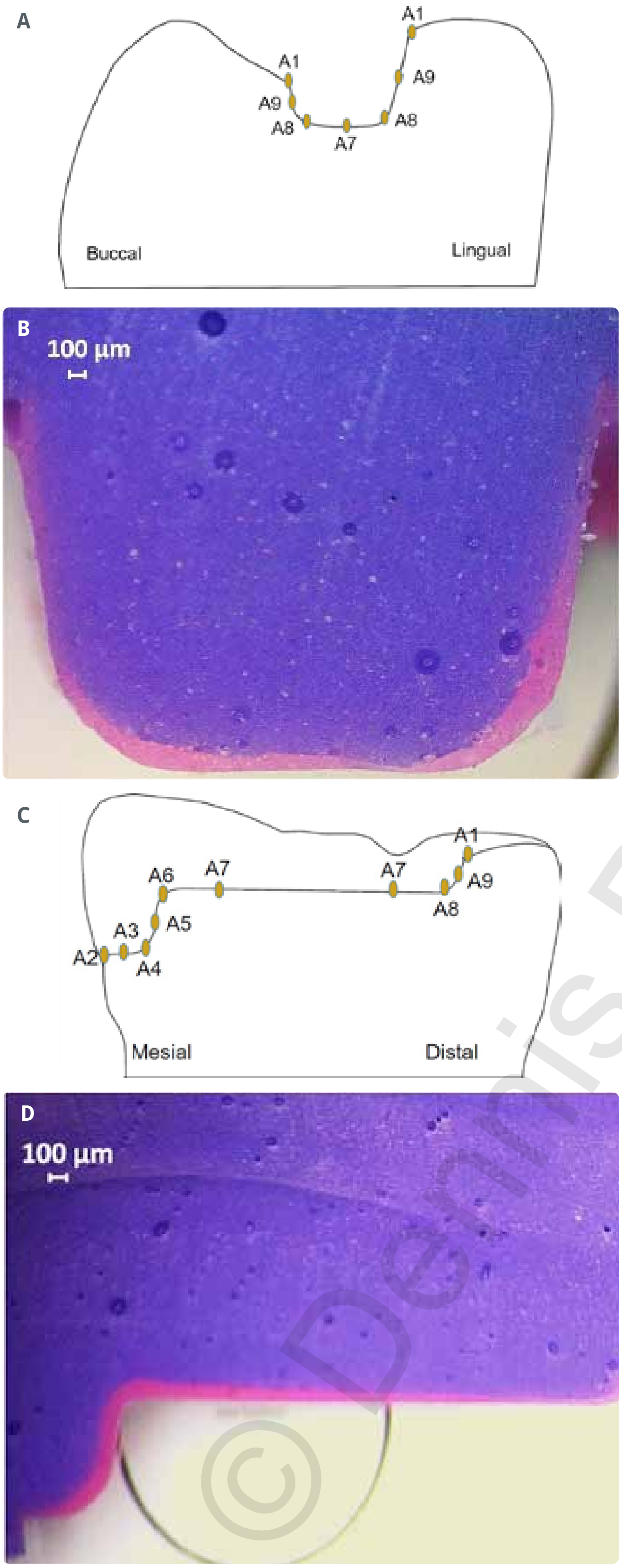

Figure 3A-D: (A) Schematic representation of typodont molar sectioned buccolingually with 7 measurement locations. (B) Buccolingual replica section showing the internal gap (pink) and the medium body (blue) used to stabilize the replica. (C) Nine landmarks in mesiodistal sections. (D) Mesiodistal replica section. The circle visible at the bottom of Figure 3D corresponds to the eye piece graticule of the stage micrometer slide.

SEM images of e.max CAD (*Figure 4A*) and e.max Press (*Figure 4B*) inlays demonstrated apparent visual differences related to margin characteristics. Margins of the pressed restorations showed a continuous smoother appearance than the milled inlays both at the proximal and occlusal boxes. Irregular margin profile with frequent micro-chippings of the margin edges were observed in the milled group.

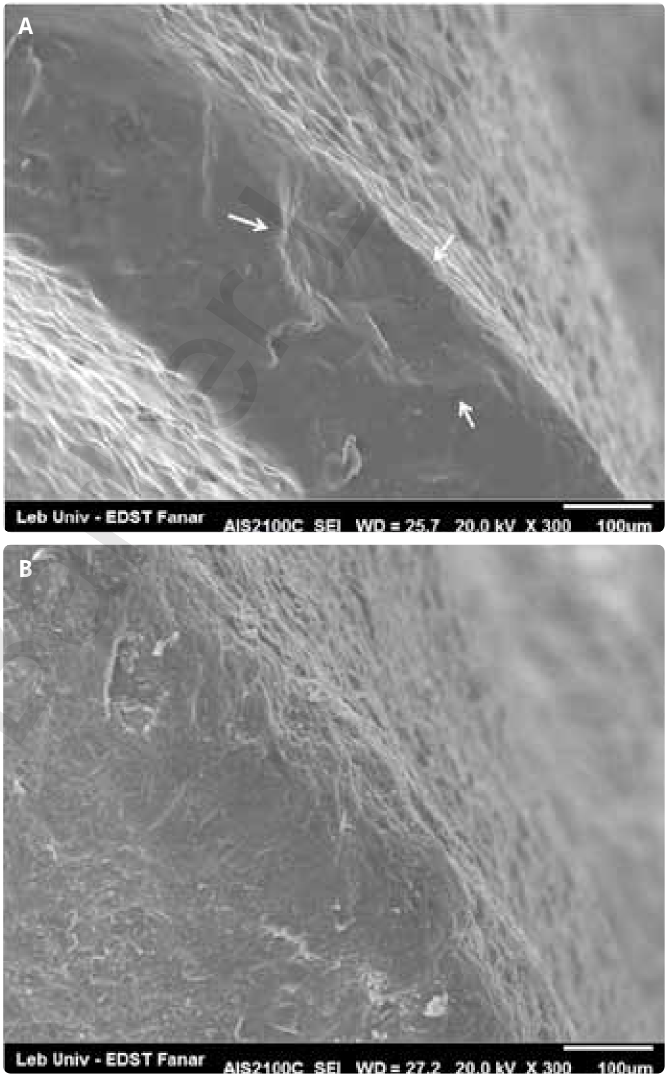

Figure 4A-B: (A) Representative SEM image of the margin edge of a milled inlay showing a micro-chipping (white arrows). (B) SEM image showing a more regular profile of the margin edge of a pressed inlay (300x magnification).

DISCUSSION

The purpose of the present study was to compare the marginal and internal fits of digitally waxed and heat-pressed lithium disilicate inlays versus CAD/CAM milled inlays produced through conventional impressions and laboratory-based digital workflow. The results support rejection of the null hypothesis stating that fit accuracy would be similar between materials.

Table 1. Descriptive statistics of marginal, internal, and overall fit by group

	Marginal Fit				Internal Fit			
	Mean ±SD (μm)	Range (μm)	95% CI		Mean ±SD (μm)	Range (μm)	95% CI	
			Lower Bound	Upper Bound			Lower Bound	Upper Bound
Group CIDW (n=15)	37.4±7.4	26.6-50.1	33.3	41.4	69.2±9.4	58.4-91.0	64.0	74.3
Group CICAD (n=15)	59.6±5.9	49.9-70.0	56.3	62.8	93.7±9.5	78.7-108.4	88.5	99.0
Overall	48.5±13.1	26.6-70.0	43.6	53.3	81.4±15.5	58.4-108.4	75.6	87.2

SD, standard deviation; CI, confidence interval; CIDW, conventional impression, extraoral digital impression of the stone die, digital wax, and pressed restorations; CICAD, conventional impression, extraoral digital impression of the stone die, and milled restorations

Table 2. Results of mixed-model ANOVA

	Type III Sum of Squares	*df*	Mean Square	F	*P*	Partial Eta Square	Observed Power
Material (e.max Press versus e. max CAD)	4106.292	1	4106.292	82.749	<.001	0.747	.999
Discrepancy location (marginal versus internal)	16308.302	1	16308.302	484.138	<.001	.945	.999
Interaction: material/ discrepancy location	20.767	1	20.767	.616	.439	.022	.118

In the present study, significantly smaller marginal and internal gaps were observed with the heat-pressed inlays when compared with milled restorations. To the authors' knowledge, only 3 *in vitro* studies reported similar comparisons but with different experimental designs.[18,19,24] In an acrylic premolar tooth model and using X-ray microtomography for fit measurement, Alajaji *et al.*[18] reported that conventional pressed inlays showed better marginal and internal adaptation than milled inlays obtained from intraoral digital impressions and CAD-manufacturing with 3- and 5-axis milling machines. Similar conclusions were reported by Rippe *et al.*[19] who used maxillary premolar human teeth and the replica technique for fit assessment. The authors demonstrated significantly lower marginal gaps with the conventionally pressed inlays compared with the inlays produced with a 4-axis milling unit from intraoral digital impressions. Sener-Yamaner *et al.*[24] evaluated marginal fit of lithium disilicate mesio-occlusal-distal inlays on extracted human first molar teeth prior to and following cementation using the direct-view technique under optical microscopy. The authors demonstrated better overall adaptation of the milled restorations when compared to the pressed inlays both before and after cementation. The analysis and comparison of data from different investigations are difficult and conclusions should be interpreted with caution since there is still no standard protocol for the assessment of fit accuracy of indirect restorations. It is likely that detail reproduction is more difficult when fine milling ceramic materials due to the brittleness and high modulus of elasticity of the IPS e.max CAD lithium disilicate.[19] These physical characteristics may result in micro-chipping during milling making the surface more irregular and decreasing fit accuracy.[19,45-48] In contrast, the molten IPS e.max Press flow under plunger compression in the ceramic oven would allow accurate reproduction of the anatomical features carved in the wax patterns and therefore minimal discrepancies.[49] In the present study, milled inlays were associated with micro-chippings along the margin edges despite the use of new burs for every 5 restorations and milling under fine settings. Other factors- such as the dimensions of the milling tool, the quality of diamond abrasives on the milling tool, the settings used for the milling cycle including spindle speed, feed rate, and power output of the milling spindles- may affect the margin quality of ceramic-based restorations.[45]

Although the full digital workflow is becoming increasingly incorporated into dental practices worldwide, it is still relatively far from being the standard of care. There is still a large gap between dentists and laboratory technicians whereas technicians have digitalized their workflow to a large extent much earlier than clinicians that continue to use traditional dentistry in their routine practice. For practitioners with no access to intraoral scanners or in-office digital technology, the impression can be conventionally made and the resulting master cast digitized with an extraoral laboratory scanner to produce CAD/CAM manufactured restorations. According to the present results, it may be more advantageous to use pressed inlays produced from digital wax patterns than milled inlays if better fit accuracy is the desired outcome. The question whether mean fit differences of 22.2 μm to 24.6 μm can have a significant impact on the clinical performance of the 2 materials remains to be ascertained. Other considerations such as costs, mechanical and esthetic properties may direct clinicians' and patient's choice of material.

In general, the digital flow includes 2 phases to generate any restoration: 1) the CAD phase represented by the direct (intraoral) or indirect (extraoral) digital impression and the software design; and 2) the CAM phase where the restoration is generally manufactured through subtractive techniques by milling solid material blocks.[50] In the present study, the CAD phase was standardized by performing one single extraoral scanning to eliminate potential errors associated with repeated digital impressions and intraoperator variability.[51] In addition, one single design was used to generate both pressed and milled inlays. As a result, the fit differences between the CIDW and CICAD inlays can be solely attributed to the type of lithium disilicate material and related manufacturing technique. In the 3 previously published studies comparing heat-pressed and milled lithium disilicate inlays,[18,19,24] several master dies or preparations were produced and a single impression was taken of each sample. This experimental design is likely to add the potential scanning errors into the mean discrepancy values of each material and may affect the reliability of the results.

There is no consensus on which is the best non-destructive method for the assessment of fit accuracy of indirect restorations. The replica technique is considered easy to perform and reliable, however it is associated with several drawbacks such as difficulties in identifying the margins of the restoration, possible tearing of the silicone film when removing the restoration, as well as sectioning plane error.[37,52] The increasingly used microcomputed tomography (micro-CT) allows 2- and 3-dimensional assessment of a large number of reference points in several directions and sections with easy identification of critical distances.[52] Shortcomings of micro-CT involve identifying the prosthesis axis and the relative orientation of the rotational axis of the micro-CT resulting in slicing planes that may not coincide exactly with the buccolingual or mesiodistal directions.[53] In a recent study that compared the silicone replica technique to micro-CT,[54] the authors reported a strong positive correlation between the marginal and internal gap values determined by micro-CT and replica technique and suggested that both techniques can be used to determine the fit of indirect restorations.

In the present study, care was taken to standardize the load applied for inlay positioning on the master preparation,[3,43] to discard replicas with defects, to standardize the sectioning process,[3] and to use a large number of measuring points (65) exceeding that recommended by Groten *et al.*[38] (50) to produce clinically relevant discrepancy measurements. All these factors are likely to increase the consistency of the present findings.

CONCLUSIONS

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

1. Pressed and milled inlays fabricated with conventional-digital approaches had clinically acceptable ranges of fit accuracy;
2. Better fit accuracy was demonstrated with the pressed inlays.

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