**Purpose:** To investigate the marginal and internal adaptations of ceramic inlay restorations placed with immediate dentin sealing (IDS) vs delayed dentin sealing (DDS) procedures. **Materials and Methods:** Mesial and distal Class II cavities were prepared in 12 extracted molar teeth, which were randomly allocated into six groups of 2 teeth each. Lava Ultimate inlays were fabricated and luted to the cavities using All-Bond universal adhesive system and eCEMENT dual-curing resin cement following IDS/immediate cementation (control groups 1 and 2), IDS/delayed cementation (groups 3 and 4), or DDS/delayed cementation (groups 5 and 6) protocols. Teeth in groups 2, 4, and 6 were subjected to thermocycling of 500 cycles between 5°C and 55°C after inlay cementation. Following staining with silver nitrate solution, the marginal and internal gap volumes were determined using microcomputed tomography images. Statistical analyses were conducted using independent t test and one-way analysis of variance followed by Tukey post hoc test ($P < .05$). **Results:** Marginal gap volume for DDS ($1.856 \pm 0.323 \text{ mm}^3$) was significantly higher than that of IDS immediately after inlay cementation ($0.891 \pm 0.281 \text{ mm}^3$) ($P = .025$). Following thermocycling, the internal gap volume for DDS ($0.838 \pm 0.248 \text{ mm}^3$) was significantly higher than that for IDS ($0.098 \pm 0.066 \text{ mm}^3$) ($P = .000$), but the marginal gap volume of DDS ($1.964 \pm 0.956 \text{ mm}^3$) was not significantly different from that of IDS ($1.426 \pm 0.725 \text{ mm}^3$) ($P = .622$). **Conclusion:** Luted ceramic inlays have a superior marginal adaptation right after cementation and a superior internal adaptation after thermocycling when using the IDS technique compared to the DDS technique. However, marginal adaptation after thermocycling was not significantly different between the two techniques. *Int J Prosthodont* 2020;33:48–55. doi: 10.11607/ijp.6372

Immediate dentin sealing (IDS) has been described as the sealing of dentinal tubules with filled adhesive resin immediately after tooth preparation.¹⁻⁴ This procedure involves the application of a dentin bonding agent to freshly cut dentin directly after tooth preparation and prior to impression-making for indirect restorations.¹⁻⁴ Alternatively, delayed dentin sealing (DDS) includes the application of a dentin bonding agent to a previously cut dentin surface at the time of luting the indirect restoration. IDS has been assumed to result in superior bond strength, less gap formation, decreased bacterial leakage, and reduced dentin sensitivity when compared to DDS.¹ The potential benefits of the IDS protocol have been described in several studies.⁵⁻⁷

In two studies on extracted molar teeth, the tensile bond strength was reported to be significantly improved following the IDS protocol regardless of the ceramic inlay system (Ceramco 2 or IPS Empress 2) or the adhesive system (total-etch or self-etch adhesives) used. Another study evaluated fracture under shear force using different types of dentin bonding agents and concluded that IDS showed higher shear bond strength when compared to DDS.¹⁰
To compare marginal and internal gap formation at the tooth-ceramic inlay restoration interface after a period of thermocycling between the IDS and DDS techniques

3. To compare marginal and internal gap formation at the tooth-ceramic inlay restoration interface in both IDS and DDS techniques before and after a period of thermocycling

MATERIALS AND METHODS

Sample Preparation
Twelve freshly extracted human molars were included in this study. The teeth were extracted at the oral surgery department of the Faculty of Dentistry at King Abdulaziz University after the patients signed an adequate informed consent (048-04-17). After debriding the teeth from soft tissue and hard calculus, they were ultrasonically cleaned for 5 minutes, and half of the roots were cut using a low-speed diamond saw (Isomet Buehler). Samples were then stored in distilled water.

Cavity Preparation
Two Class II cavities of approximately 4-mm buccolinguval width, 4-mm occluso-gingival height, and 3-mm mesio-distal depth (considering 2-mm depth at the gingival seat) were prepared separately on the mesial and distal aspects of each tooth using a high-speed handpiece with a cylindrical rounded-end diamond bur (Brasseler).

Inlay Fabrication
Cavities were digitally scanned using CEREC Bluecam chairside digital scanner (Dentsply Sirona), and inlays were milled from Lava Ultimate resin nanoceramic CAD/CAM blocks (REF no:3312A1-HT, 3M ESPE) using CEREC MC XL in-office milling machine (Dentsply Sirona). The materials used in this study are listed in Table 1.

Table 1  Materials Used

<table>
<thead>
<tr>
<th>Material</th>
<th>Product name</th>
<th>Composition</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD/CAM restorative block</td>
<td>Lava Ultimate</td>
<td>Nanoceramic resin ceramic (80%), Bis-GMA, UDMA, Bis-EMA, TEGDMA with silica nanomers (20 nm), zirconia nanomers (4–11 nm), nanocluster particles derived from the nanomers (0.6–10 µm), and silane coupling agents</td>
<td>3M ESPE</td>
</tr>
<tr>
<td>Temporary restorative material</td>
<td>Systemp.inlay</td>
<td>Monofunctional ethyl triglycol methacrylate, polyester urethane dimethacrylate; prepolymerized dimethacrylates, pyrogenic silicic acid fillers, catalysts, stabilizers, tridosan 0.3 &lt; 1%, and mequol 0.1 &lt; 0.3%</td>
<td>Ivoclar Vivadent</td>
</tr>
<tr>
<td>Etchant</td>
<td>Select HV etch</td>
<td>35% phosphoric acid with Benzalkonium chloride</td>
<td>BISCO</td>
</tr>
<tr>
<td>Dentin bonding adhesive system</td>
<td>All-Bond Universal</td>
<td>20%–50% bisphenol A-diglycidyl methacrylate, 30%–50% ethanol, 5%–25% MDP, 5%–25% 2-hydroxyethyl methacrylate</td>
<td>BISCO</td>
</tr>
<tr>
<td>Silane</td>
<td>Porcelain Primer</td>
<td>Coupling agent</td>
<td>BISCO</td>
</tr>
<tr>
<td>Resin cement</td>
<td>eCEMENT</td>
<td>Dual-curing resin cement</td>
<td>BISCO</td>
</tr>
</tbody>
</table>

Several other studies have investigated the marginal integrity at the dentin-resin interface after a resin-coating procedure whereby the dentin is covered with a bonding system and a low-viscosity composite immediately after tooth preparation and before impression-making for indirect ceramic restorations.11,12 Schenke demonstrated that when luting ceramic inlays, the resin coating technique using Panavia resin cement with Clearfil SE Bond and Protect Liner F resin coating (Kuraray) resulted in a lower marginal leakage at the dentin-resin interface than a conventional luting technique, although the marginal seal of the self-adhesive resin cement RelyX Unicem (3M ESPE) was reported to be the best.11 Consistently, Kitamaya reported in 2011 that a resin coating technique using a combination of a hydrophobic dentin bonding system (Clearfil Protect Bond, Kuraray) and a flowable resin composite (Clearfil Majesty Flow, Kuraray) with cementation using Clearfil Esthetic Cement was effective in reducing microleakage at the tooth-resin interface of Class II computer-aided design/computer-assisted manufactured (CAD/CAM) ceramic inlays, whether loaded or unloaded.12

To the authors’ knowledge, comparative data on the marginal and internal adaptations associated with IDS vs DDS techniques for indirect ceramic inlays are scarce. Therefore, the aim of this study was to further investigate the marginal and internal adaptations of the ceramic inlay restoration with IDS vs DDS techniques using microcomputed tomography (µCT) technology. The null hypothesis tested was that the IDS and DDS techniques would result in the same extent of marginal and internal gap formation at the tooth-resin interface of all ceramic inlay restorations. The specific objectives were:

1. To compare marginal and internal gap formation at the tooth-ceramic inlay restoration interface immediately following inlay cementation between the IDS and DDS techniques

2. To compare marginal and internal gap formation at the tooth-ceramic inlay restoration interface after a period of thermocycling between the IDS and DDS techniques

3. To compare marginal and internal gap formation at the tooth-ceramic inlay restoration interface in both IDS and DDS techniques before and after a period of thermocycling
Dentin Sealing and Inlay Cementation
For dentin sealing, whether immediate or delayed, total etching of the cavities was performed with 35% phosphoric acid etchant for 15 seconds, followed by rinsing with water for 30 seconds and a brief air flushing. Then, two coats of All-Bond Universal dentin bonding agent (BISCO) were applied and scrubbed with a microbrush for 10 to 15 seconds, air dried for 10 seconds, and then light cured with Elipar LED curing unit (3M ESPE) of 1,200 mW/cm² for 10 seconds and calibrated by an external light meter (Pujing, DC02). For temporization, cavities were gently air dried. Liquid strip glycerine gel (Ivoclar Vivadent) was applied to the cavity to isolate the sealed dentin, an adequate amount of Systemp.inlay temporary material was placed into the cavity, excess material was removed, and the filling was contoured and then light cured for 10 seconds. This temporary material is highly elastic; therefore, it was easily removed after curing in one piece by inserting a probe into the material and pulling it out of the cavity without damaging it. For luting the Lava Ultimate ceramic inlays, one coat of porcelain silane primer (BISCO) was applied to the fitting surface of each restoration and allowed to settle for 30 seconds before air drying for 5 seconds. Then, eCEMENT adhesive dual-curing resin cement (Lot No: 1500007181, BISCO) was applied to the fitting surface, after which the inlay was placed into its corresponding cavity and the excess cement was removed. The cement was cured for 40 seconds from each aspect for a total time of 120 seconds for each inlay. Each luted restoration was then finished with fine diamond burs (Brasseler) and polished using a polishing rubber cup.

Thermocycling
Thermocycling was performed for groups 2 through 6 after inlay cementation (Fig 1). Thermocycling of 500 thermal cycles between 5°C and 55°C was carried out in a water-bath thermocycler (THE-1100, SD Mechatronik) with a dwell time of 15 seconds in each bath and a transfer time of 5 seconds.

Mounting and Sealing of Teeth
The roots of the teeth were mounted in an acrylic resin mount (Orthodontic Resin Caulk, Dentsply) prepared by using a custom-made rubber silicon mold (Exafast putty, GC America). The coronal part of the samples was covered with nail polish (Revlon), leaving a distance of ∼1 mm around the tooth-restoration interface. This allowed the silver nitrate to penetrate the interface through the interfacial gap and not through other cracks on the crown surface.

Silver Nitrate Staining
To allow a silver nitrate stain to penetrate into possible interfacial gaps at the tooth-inlay interface, samples were submerged in a 50 wt% silver nitrate solution (AgNO₃, 50% by weight) for 24 hours. Ammonical silver nitrate was prepared by dissolving 25 g of silver nitrate crystals
(Sigma Chemical) in 25 mL of distilled water. A concentrated (28%) ammonium hydroxide (Sigma Chemical) solution was used to titrate the black solution until it became clear as ammonium ions complexed the silver into diamine silver ions ([Ag(NH₃)₂]⁺). This solution was diluted to 50 mL with distilled water, giving a 50 wt% solution (pH = 9.5). The time point of AgNO₃ staining is presented in Fig 1.

### µCT and Image Analyses
Samples were scanned after submersion in the silver nitrate solution (Fig 1). Scanning of samples was performed using SkyScan 1172 µCT scanner (Bruker microCT, Kartuizersweg 3B). The scanning parameters used were: 100 kV, 100 µA, 830 ms of exposure, angle of rotation = 0.600 degrees, 720 projections, and 2 frames per projection. The total scanning time for each sample was approximately 2 hours and 30 minutes. NRecon (version 1.6.7.2; SkyScan) and Data Viewer software (version 1.5.2.4 64-bit, SkyScan) (Bruker, Microet) were used for the 3D reconstruction of acquired µCT images and image visualization, respectively.

### Microleakage and Internal Void Volume Measurement
To segment the silver nitrate stain, multi-level thresholding feature in 3D was applied to the dataset to identify different density phases with a high gray level for high-density subjects. The 3D volume of the internal voids and the silver nitrate penetrant at the interface between the inlay restoration and its corresponding cavity surface were calculated using CT-analyzer software.

### Statistical Analyses
The data were analyzed using independent t test and one-way analysis of variance (ANOVA) followed by post hoc multiple comparisons Tukey test using IBM SPSS Statistics version 22 software. The level of statistical significance for both was set at $P < .05$.

### RESULTS
The means and standard deviations (SDs) for the volume of silver nitrate penetrant (the marginal gap volume) and the volume of internal voids (the internal gap volume) for different adhesion techniques are presented in Table 2. $P$ values for comparisons between different adhesion techniques for marginal and internal gap volumes are presented in Table 3. µCT images of luted ceramic inlays are shown in Fig 2.

### Marginal and Internal Gap Volumes Immediately After Inlay Cementation
Marginal gap volume for DDS/delayed cementation (group 5) was significantly higher than both IDS/delayed cementation (group 1) ($P = .002$) and IDS/immediate cementation (group 1) ($P = .057$) and IDS/delayed cementation (group 3) ($P = .031$). Internal gap volume, on the other hand, did not differ significantly among groups 1, 3, and 5 ($P = .059$) (Fig 3).

### Marginal and Internal Gap Volumes After Thermocycling
Marginal gap volume after thermocycling was not significantly different between the different adhesion techniques; however, the internal gap volume for DDS/delayed cementation/thermocycling (group 6) was significantly higher than that of IDS/immediate cementation/thermocycling (group 2) ($P = .002$) and IDS/delayed cementation/thermocycling (group 4) ($P = .000$) (Fig 4).

### Effect of Thermocycling on Marginal and Internal Gap Volumes
There was no statistically significant difference between the marginal and internal gap volumes before and after thermocycling for the IDS/immediate cementation technique (group 1 vs 2) (Fig 5) or for the IDS/delayed cementation technique (group 3 vs 4) (Fig 6). However, a statistically significant difference was found in the internal gap volume for the DDS/delayed cementation technique (group 5 vs 6; $P = .015$) (Fig 7).

### Table 2 Marginal and Internal Gap Volumes for Different Adhesion Techniques

<table>
<thead>
<tr>
<th>Study groups</th>
<th>Marginal gap volume (mm$^3$), mean ± SD</th>
<th>Internal gap volume (mm$^3$), mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (IDS(IC))</td>
<td>1.012 ± 0.632$^a$</td>
<td>0.351 ± 0.176$^a$</td>
</tr>
<tr>
<td>Group 2 (IDS/TC)</td>
<td>1.544 ± 0.684$^a$</td>
<td>0.240 ± 0.152$^a$</td>
</tr>
<tr>
<td>Group 3 (IDS/DC)</td>
<td>0.891 ± 0.281$^a$</td>
<td>0.063 ± 0.075$^a$</td>
</tr>
<tr>
<td>Group 4 (IDS/DC/TC)</td>
<td>1.426 ± 0.725$^a$</td>
<td>0.098 ± 0.066$^a$</td>
</tr>
<tr>
<td>Group 5 (DDS/DC)</td>
<td>1.856 ± 0.323$^a$</td>
<td>0.323 ± 0.193$^a$</td>
</tr>
<tr>
<td>Group 6 (DDS/DC/TC)</td>
<td>1.964 ± 0.956$^a$</td>
<td>0.838 ± 0.248$^a$</td>
</tr>
</tbody>
</table>

Superscript letters indicate homogenous subsets (within which $P > .05$) where comparison has been made with respect to the study groups. IDS = immediate dentin sealing; IC = immediate cementation; DDS = delayed dentin sealing; DC = delayed cementation; TC = thermocycling; SD = standard deviation.

### Table 3 P Values for Comparisons Between Different Adhesion Techniques for Marginal and Internal Gap Volumes

<table>
<thead>
<tr>
<th>Study group</th>
<th>Marginal gap volume</th>
<th>Internal void volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups 1 vs 3 vs 5</td>
<td>.025$^*$</td>
<td>.059</td>
</tr>
<tr>
<td>Groups 2 vs 4 vs 6</td>
<td>.622</td>
<td>.000$^*$</td>
</tr>
<tr>
<td>Groups 1 vs 2</td>
<td>.297</td>
<td>.380</td>
</tr>
<tr>
<td>Groups 3 vs 4</td>
<td>.218</td>
<td>.508</td>
</tr>
<tr>
<td>Groups 5 vs 6</td>
<td>.841</td>
<td>.015$^*$</td>
</tr>
</tbody>
</table>

$^*P < .05$. 

immediate cementation (group 1) ($P = .057$) and IDS/delayed cementation (group 3) ($P = .031$). Internal gap volume, on the other hand, did not differ significantly among groups 1, 3, and 5 ($P = .059$) (Fig 3).
**DISCUSSION**

The rationale behind the different groups in this study was to simulate distinct clinical settings. Control groups simulate a clinical situation where the patient is provided with a cavity preparation, dentin sealing, and cementation of the indirect restoration all performed at the same visit. IDS groups imitate a clinical situation where the patient is provided with cavity preparation, dentin sealing, and a provisional restoration in a single visit, then the permanent indirect restoration is luted on a following visit. Finally, DDS groups represent a

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**Fig 2** Two-dimensional µCT images of luted ceramic inlay restorations showing the marginal and internal gaps at the tooth-restoration interface. (a) Group 1 (immediate dentin sealing [IDS]/immediate cementation [IC]). (b) Group 2 (IDS/IC/thermocycling [TC]). (c) Group 3 (IDS/delayed cementation [DC]). (d) Group 4 (IDS/IC/TC). (e) Group 5 (delayed dentin sealing [DDS]/DC). (f) Group 6 (DDS/DC/TC). InR = inlay restoration; En = enamel; Dn = dentin. The adhesive layer may contain a void (solid arrow) or silver stain precipitation or deposits (dotted arrow).
thermocycling when using the IDS technique compared to the DDS technique. Although no studies were found in the literature inspecting the adaptation of indirect restorations using IDS vs DDS techniques except for reports on fracture mode after cyclic loading, the results of this study on the improved marginal and internal adaptation of the IDS technique can be supported by several previous studies reporting on the improved microtensile bond strength and shear bond strength associated with the IDS technique. Moreover, while control groups 1 and 2 showed larger gap volume values than those of the IDS groups 3 and 4, respectively (Table 2), this difference was not statistically significant, and so a superior seal in the IDS groups over the control groups common clinical practice whereby the patient is treated with a cavity preparation and a provisional restoration in the first visit followed by a second visit for dentin sealing and cementation of the indirect restoration. The required sample size here was calculated based on the reported mean and SD of mean microleakage volume (mm³) among microhybrid composites, preheated microhybrid composites, and flowable composites in Zavattini et al. Assuming an alpha of .05 and a power of 80%, the sample size required for this study was a total of 12.

The current study indicates that luted ceramic inlays have a superior marginal adaptation right after cementation and a superior internal adaptation after thermocycling when using the IDS technique compared to the DDS technique. Although no studies were found in the literature inspecting the adaptation of indirect restorations using IDS vs DDS techniques except for reports on fracture mode after cyclic loading, the results of this study on the improved marginal and internal adaptation of the IDS technique can be supported by several previous studies reporting on the improved microtensile bond strength and shear bond strength associated with the IDS technique. Moreover, while control groups 1 and 2 showed larger gap volume values than those of the IDS groups 3 and 4, respectively (Table 2), this difference was not statistically significant, and so a superior seal in the IDS groups over the control groups.
cannot be concluded. Therefore, comparable marginal and internal gap volumes between these respective groups is suggested for the current sample size.

This study also concludes that the marginal adaptation after thermocycling was not significantly different between IDS and DDS techniques, emphasizing the effect of the aging process on the reduction of the difference between these tested groups. In line with this result, a report by Ferreira-Filho et al has shown that the microtensile bond strength is largely related to the duration of aging of luted samples, as IDS groups presented higher bond strength than the DDS group only within 7 days of water storage but did not differ significantly after 3 months of the same condition.

Thermocycling was performed to simulate the thermal effect of the oral environment on the restorations during the provisional phase and after cementing the indirect restoration. Changes in temperature during the process of thermocycling will result in dissimilar dimensional changes of the resin cement fillers and matrix phases, creating internal stresses and possible microcracking. In the present investigation, a significant increase in the internal void volume was detected in the DDS group as a consequence of thermocycling. Several previous studies have demonstrated the negative effect of thermocycling aging on resin cements. A recent study by de Oliveira et al concluded that thermocycling significantly reduced the microtensile bond strength of CAD/CAM fiber-reinforced composite using a conventional three-step adhesive system, All-Bond 3, with C&B self-curing adhesive resin cement. Another study by Nalcaci and Ulusoy showed that thermocycling aging of 10,000 cycles can significantly increase the microleakage of resin composites (hybrid resin composite Feltik Z250 and flowable resin composite Feltik flow) bonded to dentin surfaces. Nevertheless, in the present study, thermocycling of 500 thermal cycles between 5°C and 55°C did not result in a significant change in the before-and-after marginal and internal gap volumes of luted inlays in the IDS group. This could be related to the frequency of cycles used in the present study, which was probably insufficient for producing a significant difference in the IDS groups. Consistent with this rationalization, a study by Leesungbok et al demonstrated that a minimum of 7 days of 1,500 thermal cycles for an immediately sealed dentin surface is needed to decrease the mean bond strength of IPS Empress ceramic discs bonded to a dentin surface with All-Bond 2 adhesive system and Duo-Link resin cement.

The current investigation includes some shortcomings. First, the sample size could have been increased to detect reliable significant differences among groups. Second, the number of thermal cycles could have been amplified and implemented under cyclic loading to better represent the actual clinical situation.

CONCLUSIONS
Within the limitations of the present in vitro investigation, the following can be concluded:

- The IDS technique results in a smaller marginal gap volume at the tooth-restoration interface than the DDS technique immediately after cementation, but not after thermocycling of the luted indirect ceramic restoration.
- Thermocycling results in a bigger internal gap formation with the DDS technique than with the IDS technique.
- Thermocycling does not result in a significant increase of either the marginal or internal gaps with the IDS technique.
- Thermocycling results in a significant increase of the internal gaps but not the marginal gaps with the DDS technique.

ACKNOWLEDGMENTS
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REFERENCES
Clinical Performance of Occlusal Onlays Made of Lithium Disilicate Ceramic in Patients with Severe Tooth Wear up to 11 Years

The aim of this study was to evaluate the survival and complication rates of monolithic occlusal onlays made of lithium disilicate ceramic in patients with severe tooth wear for up to 11 years of clinical service. In a prospective nonrandomized clinical study, seven patients (four men, three women; median age 44.3 ± 6.56 years old) underwent full-mouth restoration with a total of 103 adhesively bonded occlusal onlays made of lithium disilicate ceramic (IPS e.max Press, Ivoclar Vivadent). All restorations were examined during annual recall visits using different bonding techniques: An in vitro study. J Indian Prosthodont Soc 2018;18:212–218.

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