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# Effect of Dentine Sealing after Abutment Scanning on the Marginal and Internal Gaps of Zirconia Crowns: An *In Vitro* Study

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## Abstract

**Objectives:** This study aimed to assess the effects of applying dentine sealing material after abutment scanning on the marginal and internal gaps of zirconia crowns and the thickness of different adhesive systems.

**Methods:** Forty extracted human molars were milled into uniform abutments and randomly chosen for scanning and fabricating a zirconia crown using CAD/CAM. Specimens were divided into four groups according to the dentine sealing technique: the control (C), total-etch (TE), self-etch (SE), and universal (U) adhesive groups. A silicone replica was made and longitudinally sectioned with the abutment for measuring adhesive thickness and gaps at different points (EF: external finish line, IF: internal finish line, AW: axial wall, CT: cusp tip, OI: occlusal incline plane, and CO: center of occlusal surface) under a stereomicroscope. Data were analyzed using a two-way ANOVA and multiple comparisons test.

**Results:** Regarding adhesive thickness, adhesive types and measuring points showed significant interaction. The TE group had a significantly higher adhesive thickness, especially in concave areas (IF and CO). The TE group also showed significantly wider gaps at the CT, OI, and CO and a significantly narrower gap at the EF, IF, and AW. The AW had the narrowest internal gap in all groups. The marginal gap increased in all experiment groups compared with the control but remained clinically acceptable (<120 µm).

**Conclusions:** The marginal gap increased significantly when the adhesive was applied after the final impression. High-viscosity adhesive produced a thicker adhesive layer, especially at the IF, causing marginal and internal gap increases.

**Keywords:** dentine sealing, digital impression, internal gap, marginal gap, zirconia crown

## Introduction

Postoperative sensitivity after final cementation is one of the most common complications of full coverage fixed restorations.[1] As a large area of dentine is exposed during the tooth preparation process, failure to cover it or a gap present under the crown after cementation may cause this problem. In 1992, Pashley *et al.,*[2] introduced a technique involving bonding agent application after tooth preparation to establish a fully cured hybrid layer for sealing dentinal tubules to reduce post-operative sensitivity and increase bond strength of restoration, known as the immediate dentine sealing (IDS) technique.[2,3] This technique also has a positive impact on the longevity and retention of the fixed restoration.[3-5] Dentine bonding agents enhance bond strength at the dentine–resin interface[4], thereby improving adhesion to resin cement[3-5], which is commonly used for cementing zirconia crowns due to its ability to provide both micromechanical retention and chemical bonding when used with appropriate surface treatments and primers.[6] Furthermore, IDS also offers advantages for patient satisfaction by decreasing post-operative sensitivity during the provisional period and reducing the need for anesthesia during permanent cementation in the final visit.[7,8]

The ideal time to seal dentine is immediately after tooth preparation; however, this approach is not widely employed in routine procedures, as the abutment for a crown typically already provides sufficient resistance and retention form, thus leading to tooth sensitivity during provisionalization or after permanent cementation.[9] Dentine sealing after impression-taking is sometimes delayed since sensitivity occurs in later visits.[3] Furthermore, dentine sealing causes a fully cured adhesive layer to form a complete hybrid layer, preventing enormous pressure from being exerted on the dental pulp during final cementation.[10,11]

Various dentine bonding systems available in the market can be used to seal dentine.[12] They vary in the composition of the adhesive material, application procedures, and indications for use.[12] Many studies recommended three-step total-etch and two-step self-etch for dentine sealing due to their clinical effectiveness in achieving high bond strength.[13] Moreover, universal adhesives, a recent development, have versatile multimodal and multipurpose uses in clinical practice. Recent studies suggested that using universal adhesives as dentine sealing materials improved bond strength and reduced dentine permeability.[14,15] Some adhesive systems produce a relatively thicker adhesive layer than others (approximately 60-80 µm on smooth and convex surfaces and 200-300 µm on concave surfaces).[4,16]

In the fabrication of indirect restorations, space for the cement layer is intentionally prepared.[17] For zirconia crowns fabricated using CAD/CAM technology, cement space can be set in the software[18] based on the model obtained from the impression. When adhesive applied after taking the final impression, various dental adhesive systems may yield different thicknesses of adhesive layers, potentially interfering with the seating of the restoration and resulting in an unacceptable marginal gap.[19,20]

The recommended clinically acceptable marginal gap for long-term success is less than 120 µm.[21-23] Excessive marginal discrepancy causes the exposure of luting cement to the oral environment, leading to cement dissolution, roughness, microleakage, secondary caries, pulpal lesions, and periodontal problems.[24]

Nevertheless, if dentine sealing material must be applied after taking the final impression, the marginal gap should remain within the clinically acceptable range. Therefore, this study aimed to investigate the effect of applying dentine sealing material after taking the final impression on the marginal and internal gaps of zirconia crowns and the thickness of three dental adhesives *in vitro*.

## Materials and Methods

### *Specimen preparation*

The use of human tissue was approved by the Human Experimentation Committee (No. 1/2024), Faculty of Dentistry, Chiang Mai University. Forty human caries- and restoration-free molars were extracted and stored in a 1% chloramine T trihydrate solution for a week and then placed in grade 3 distilled water until use.

The cusps on the occlusal surface of the tooth samples were flattened using a carborundum disc on the trimmer until no grooves were visible. The tooth was then embedded in the center of a silicone mold with the occlusal surface placed downward, as the designed abutment was located at the center of the block. The silicone mold was fabricated from a high-viscosity polyvinyl siloxane (PVS) impression material (Express XT Putty Body; 3M ESPE, Neuss, Germany) using the Celtra Duo ZLS block (Dentsply Sirona, Hanau-Wolfgang, Germany) as the template. The dimension of the block was 18x14x12 mm. A mixture of low-viscosity epoxy resin (Chem Builder Co. Ltd., Chonburi, Thailand) was poured into the silicone mold to embed the tooth sample. The epoxy resin was left to set for 24 hours. The shaft of a used Celtra Duo ZLS block was attached to the base of the epoxy resin block using epoxy glue (Quick Epoxy Steel; Alteco Chemical Pte. Ltd., Tuas Avenue, Singapore) (Figure 1).

The tooth specimen was prepared for abutment of the zirconia crown using a dental milling machine (CEREC Primemill MCXL; Dentsply Sirona, Bensheim, Germany). The 3D abutment design created in 3D design software (SolidWorks 2023 SP3.0; Dassault Systèmes SolidWorks Corp., Waltham, MA, USA) on the computer was modified from the work of Fernández-Estevan *et al.*[25] The abutment preparation design comprised a rounded rectangular shape with a height of 4 mm, a convergence angle of 6°, and a shoulder with a rounded internal line angle finish line with a depth of 1 mm (Figure 2). The dimensions of the abutment were designed according to the tooth preparation guidelines recommended by Goodacre *et al.*,[26] to ensure proper resistance and retention form. The specimen blocks were milled using a step bur 12S (Dentsply Sirona, Bensheim, Germany) and 12S cylinder-pointed bur (Dentsply Sirona, Bensheim, Germany). Prior to milling, the machine detected and calibrated the block position. If the block dimensions were accurate, the software initiated the milling process, producing preparations with consistent positioning across specimens. To reduce errors in the size of the abutment preparation, the burs were replaced after milling 10 specimens (90% usage as displayed in the milling software). Only intact specimens were included in the study. Any samples exhibiting pulp exposure due to anatomical variations were excluded.

One abutment was randomly selected to represent all prepared abutments for digital impression-taking using an intraoral scanner (CEREC Primescan; Dentsply Sirona, Bensheim, Germany). A zirconia crown was designed in computer-aided design/computer-aided manufacturing (CAD/CAM) software with parameters set for a cement space of 80 µm and a crown thickness of 1 mm at the margin and 2 mm at the axial and occlusal surfaces. The zirconia crown was milled from a Cercon® ht disc (Dentsply Sirona, Hanau-Wolfgang, Germany) using a dental milling machine (CEREC InLab MC X5; Dentsply Sirona, Bensheim, Germany), then sintered and glazed according to the manufacturer's guidelines (Figure 3).

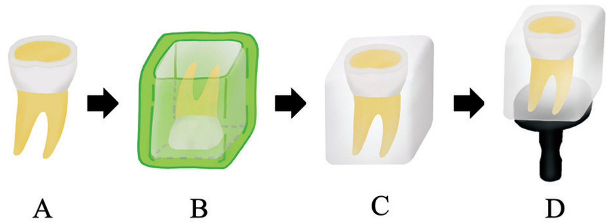


**Figure 1:** Embedding the tooth in epoxy resin procedure (A) The occlusal surface of the tooth was flattened; (B) A silicone mold was fabricated using putty PVS. The flattened tooth was positioned at the center of the mold base, since the designed abutment was centrally located, and epoxy resin was then poured into the mold; (C) The epoxy resin was left to set for 24 hours, then removed it from the mold; (D) The epoxy block was attached to the shaft of a used ceramic block.

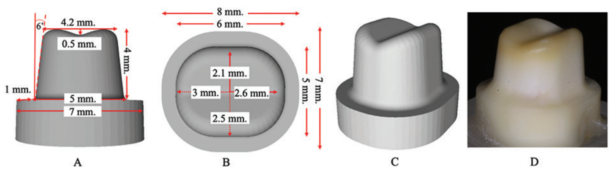


**Figure 2:** The abutment was designed on a computer using SolidWorks software. (A) Dimensions of the abutment in the proximal view; (B) Dimensions of the abutment in the occlusal view; (C) A 3D design of the abutment was created; (D) The abutment was milled from a 3D design using a milling machine.

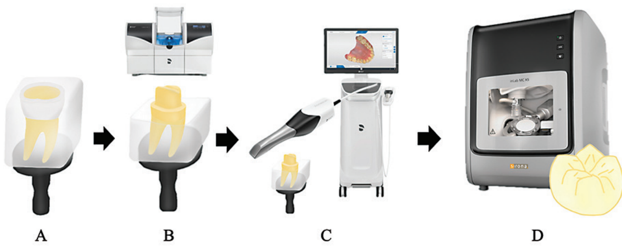


**Figure 3:** Specimen preparation procedure. (A) The occlusal surface of the tooth was flattened and embedded in epoxy resin, then attached to the shaft; (B) The machine calibrated the block position before milling, and the tooth block was milled into an abutment for a zirconia crown; (C) The abutment was scanned and designed for a zirconia crown; (D) The crown was fabricated by a milling machine.

### *Dentine sealing procedure*

Forty abutments were randomly and equally allocated into four groups as follows:

- **Group 1: No dentine sealing (Control; C)** No dentine sealing material was applied on the prepared abutment surface.
- **Group 2: Total-etch adhesive (TE)** The prepared

surface was etched with 37.5% phosphoric acid for 15 seconds followed by rinsing with water for 20 seconds and gentle air-drying for 5 seconds. The primer (OptiBond FL Prime; Kerr Corporation, Orange, CA, USA) was applied with a light rubbing action for 15 seconds and dried with mild airflow for 5 seconds. The dental adhesive (OptiBond FL Adhesive; Kerr Corporation, Orange, CA, USA) was applied on the primed surface, avoiding the external finish line, followed by gentle air-blowing for 5 seconds, and then polymerized with a curing light for 20 seconds on each surface.

- **Group 3: Self-etch adhesive (SE)** The Primer (Clearfil™ SE Bond, Primer; Kuraray Noritake Dental Inc., Okayama, Japan) was applied on the prepared surface with a rubbing action for 20 seconds and dried with mild airflow, followed by dental adhesive application (Clearfil™ SE Bond, Bond; Kuraray Noritake Dental Inc., Okayama, Japan), avoiding the external finish line, gentle air-blowing for 5 seconds, and then polymerized with a curing light for 20 seconds on each surface.
- **Group 4: Universal adhesive (U)** The adhesive (3M™ Single Bond Universal adhesive; 3M ESPE, Neuss, Germany) was applied on the prepared surface with a rubbing action for 20 seconds, avoiding the external finish line, followed by gentle air-blowing for 5 seconds, and then polymerizied with a curing light for 20 seconds on each surface.

For Groups 2, 3, and 4, the air-blocking technique was performed after curing the adhesives by applying glycerin jelly (K-Y Lubricating Jelly Sterile; Doppel Farmaceutici SRL, Cortemaggiore, Italy) over the total preparation surface and light-curing for an additional 10 seconds to prevent oxygen-inhibited layer (OIL) formation, then rinsing and air-blowing with a triple syringe.

*Adhesive thickness and marginal and internal gaps measurement*

To measure the marginal and internal gaps for cement, the silicone replica was filled in this space and seated on the abutment. The thickness of the silicone replica represented the space for cement. To produce the replica, low-viscosity PVS (Express XT Light Body; 3M ESPE, Neuss, Germany) base and catalyst were mixed in a 1:1 ratio, filled into the zirconia crown, and seated onto the abutment under a 50 N load with a universal testing machine (Instron Corp., Canton, MA, USA) for 5 minutes. After the material was completely set, the crown was removed from the abutment, with the replica still attached to it. The high-viscosity PVS (Express XT Putty Body; 3M ESPE, Neuss, Germany) was mixed and loaded into an acrylic mold, and then applied on the abutment specimen to stabilize the thin film of the silicone replica. The abutment with the silicone replica was cut longitudinally in the buccolingual direction through the middle of the block using a low-speed cutting machine (Isomet®1000; Buehler, Lake Bluff, IL, USA). One half of the section was randomly selected to measure the thickness of the adhesive and silicone replica under a stereomicroscope equipped with a digital camera at 56X magnification (SZX7 & SZ-ILST LED illuminator stand & E-330 & Olympus, Tokyo, Japan); (Figure 4).

Seven digital images were captured from different areas of the abutment of each specimen for measuring the adhesive thickness (clear to dark brown color in micrographs) and gaps, including the marginal and internal gaps (purple color). Eleven points were selected for measurement: two points at the external finish line (EF), two points at the internal finish line (IF), two points at the center of the axial wall (AW), two points at the cusp tip (CT), two points at the occlusal incline plane (OI), and one point at the center of occlusal surface (CO); (Figure 5). Two values from the EF, IF, AW, CT, and OI of each specimen were averaged to represent the value for that point. ImageJ software (version 1.54 g, National Institutes of Health, Bethesda, MD, USA) was used to measure the adhesive thickness and gaps compared to a standard calibration slide. All measurements were performed by a single operator.

The data of adhesive thickness and gaps on the abutment from six measuring points and three adhesive types were statistically compared using a two-way ANOVA and Tukey's HSD multiple comparisons test with SPSS for MacOS, version 29 (SPSS Inc., Chicago, IL, USA). A $p$-value less than 0.05 was considered significant.

## Results

*Adhesive thickness*

In general, the adhesive tended to accumulate in concave areas such as the internal finish line (IF) and the center of occlusal surface (CO), causing these two points to have a significantly greater thickness than the flat surfaces of AW, CT, and OI; (Figure 6). No adhesive thickness was found at the external finish line (EF) because no

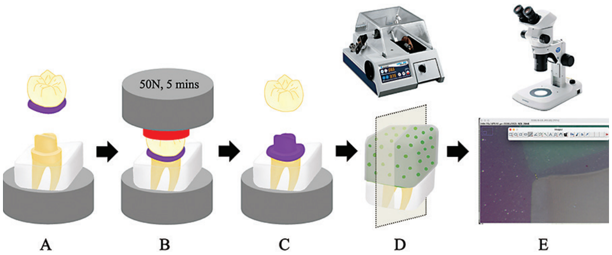


**Figure 4:** Adhesive thickness and gap measurement. (A) A silicone replica was made by loading light-body PVS into the crown; (B) The crown was seated under a 50 N load; (C) The crown was removed; (D) The putty PVS in an acrylic tray was placed to stabilize the silicone replica; (E) The specimen was sectioned in the buccolingual direction to measure the adhesive thickness and gaps under a stereomicroscope.

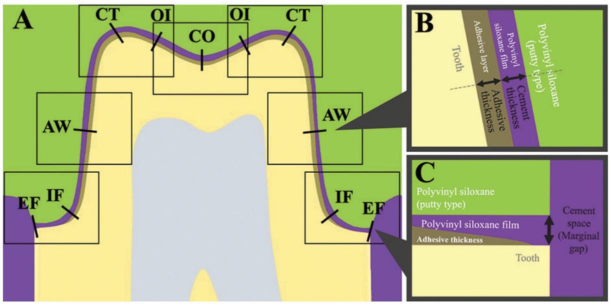


**Figure 5:** (A) Eleven measurement positions from seven images (rectangular frames) taken under a stereomicroscope (56X); external finish line: EF, internal finish line: IF, center of axial wall: AW, cusp tip: CT, occlusal incline plane: OI, and center of occlusal surface: CO; (B and C) Measurement of adhesive thickness and gaps, including the marginal and internal gaps.

adhesive was applied. Among the three adhesive systems, the TE group showed significantly greater adhesive thickness than the SE and U groups for all measurement points. However, there was no significant difference in adhesive thickness between the SE and U groups. The details of the thicknesses of the three adhesive systems at six measuring points are presented in Table 1. The statistical analysis suggested a significant interaction of adhesive types (TE, SE, and U) and measuring points (EF, IF, AW, CT, OI, and CO) regarding adhesive thickness ($p<0.001$).

The thickest adhesive was found at the internal finish line (IF) of the TE group, while the thinnest was present at the cusp tip (CT) of the U group. The second thickest point of the TE group was at the center of occlusal surface (CO), while the remaining points, including AW, CT, and OI, showed thinner adhesive with no significant differences among them. Similarly, the CO and IF points of the SE and U groups showed thicker adhesive than the AW, CT, and OI points.

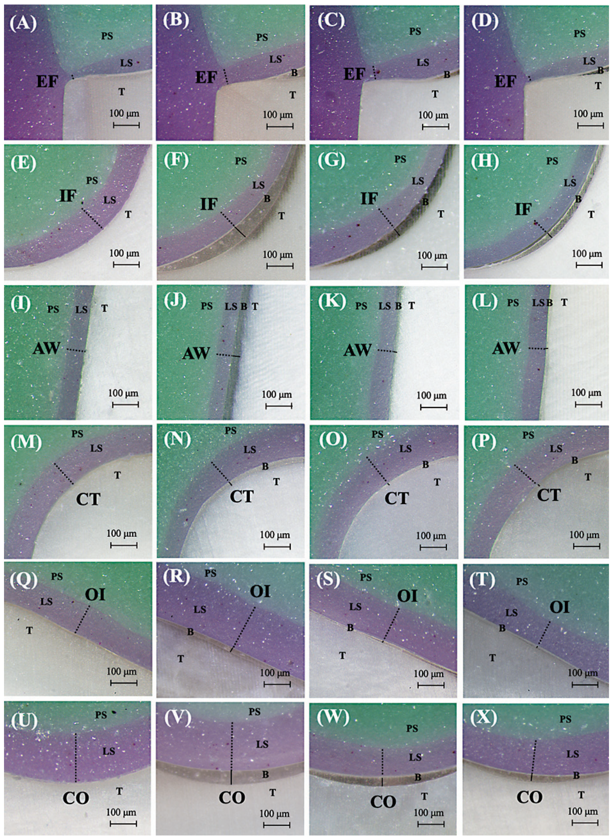


**Figure 6:** Examples of stereomicroscope micrographs (magnification 56x) of adhesive thicknesses (solid lines) and gaps (dashed lines) measured in each position of the C group (A, E, I, M, Q, and U), TE group (B, F, J, N, R, and V), SE group (C, G, K, O, S, and W) and U group (D, H, L, P, T, and X).

*Abbreviations: PS: putty PVS, LS: light-body PVS, B: bonding, T: tooth, EF: external finish line, IF: internal finish line, AW: center of axial wall, CT: cusp tip, OI: occlusal incline plane, CO: center of occlusal surface.*

### *Marginal gap and internal gap*

The marginal gap at the external finish line (EF) of the TE group was significantly wider than that of the SE and U groups, followed by the control group, with no significant difference between the SE and U groups. At the IF and AW points, the gaps of the TE group were significantly thinner than those of the SE and U groups, and the control group yielded the widest gaps, with no significant difference between the SE and U groups. At the cusp tip (CT) and the occlusal incline plane (OI), the TE group showed significantly larger gaps than the other groups, while no significant difference at the center of

**Table 1:** Mean adhesive thickness and standard deviations (µm) of the experimental groups at different points.

| Points | Mean ± standard deviation of adhesive thickness (µm) | | |
|---|---|---|---|
| | Total-etch (TE) | Self-etch (SE) | Universal (U) |
| IF | $105.26\pm14.26^{b,C}$ | $39.54\pm9.06^{a,B}$ | $37.41\pm7.65^{a,B}$ |
| AW | $29.62\pm3.27^{b,A}$ | $22.22\pm3.08^{a,A}$ | $20.24\pm3.87^{a,A}$ |
| CT | $20.90\pm3.37^{b,A}$ | $17.98\pm1.87^{a,A}$ | $17.46\pm2.23^{a,A}$ |
| OI | $23.76\pm2.33^{b,A}$ | $19.42\pm2.74^{a,A}$ | $17.75\pm3.35^{a,A}$ |
| CO | $77.09\pm13.43^{b,B}$ | $42.32\pm10.65^{a,B}$ | $35.25\pm11.39^{a,B}$ |

$^{a,b,c}$*Within a row, different superscript letters indicate statistically significant differences among the points (p<0.05) based on Tukey's HSD.*
$^{A,B,C,D}$*Within a column, different superscript letters indicate statistically significant differences among the groups (p<0.05) based on Tukey's HSD.*

occlusal surface (CO) for all groups.

The two-way ANOVA showed a significant interaction between adhesive types (C, TE, SE, and U groups) and measuring points (EF, IF, AW, CT, OI, and CO points) regarding the gaps ($p<0.001$). The mean and standard deviation of the gaps are shown in Table 2. The multiple comparisons test suggested that the application of dentine sealing materials in this experiment significantly increased the gaps at some points compared to the control. For the control, the gaps were thinnest at the external finish line (EF) and widest at the center of occlusal surface (CO). The results of the SE and U groups were quite similar to those of the control group, while the TE group at the EF, IF, and AW points had significantly narrower gaps than at the CT, OI, and CO points.

## Discussion

This study found that applying dentine adhesives after impression-taking significantly increased the marginal gap at the EF point, particularly in the total-etch (TE) group. While the maximum marginal gap exceeded 50 µm and could be detected with a dental explorer(27), it remained within the clinically acceptable threshold of 120 µm.(23) Despite this increase, the gaps are unlikely to compromise clinical outcomes, though long-term effects on restoration longevity should be further investigated.(28)

The adhesive layer was found to be thickest in concave regions (IF and CO), likely due to gravitational pooling during application.(29) This aligns with previous findings(4,16,30) showing that the adhesive tended to be thicker in the concave areas of the preparation. On the other hand, the adhesive thickness was not significantly different on flat surfaces (AW and OI) and convex surfaces (CT) across all adhesive groups. Among the adhesives, the TE group using Optibond FL showed the highest viscosity, attributable to its 48% filler content.(31) In contrast, SE and U adhesives (10-11% filler)(32,33) formed thinner layers. Since the detailed compositions of the adhesives were not published by the manufacturers, it was difficult to compare the viscosity of these adhesives. The different types of monomers and solvents contained in each adhesive system might also affect the viscosity.(34) The different viscosity

**Table 2:** Means and standard deviations of gaps, including the marginal and internal gaps (µm), of the control and experimental groups at different points.

| Points | Mean ± standard deviation of gaps (µm) | | | |
|---|---|---|---|---|
| | Control (C) | Total-etch (TE) | Self-etch (SE) | Universal (U) |
| EF | $17.94\pm1.76^{a,A}$ | $61.69\pm7.89^{c,A}$ | $27.45\pm3.92^{b,A}$ | $23.82\pm3.60^{b,A}$ |
| IF | $138.62\pm9.27^{c,C}$ | $45.17\pm13.38^{a,A}$ | $97.63\pm14.76^{b,C}$ | $101.50\pm10.26^{b,C}$ |
| AW | $91.08\pm2.97^{c,B}$ | $53.18\pm8.45^{a,A}$ | $65.02\pm8.00^{b,B}$ | $66.71\pm10.07^{b,B}$ |
| CT | $148.15\pm12.58^{a,CD}$ | $196.30\pm28.22^{b,B}$ | $133.42\pm13.31^{a,D}$ | $130.16\pm16.56^{a,D}$ |
| OI | $158.08\pm19.17^{a,D}$ | $186.63\pm21.92^{b,B}$ | $143.79\pm25.67^{a,DE}$ | $149.33\pm22.22^{a,DE}$ |
| CO | $195.89\pm15.85^{a,E}$ | $185.65\pm47.62^{a,B}$ | $164.74\pm36.70^{a,E}$ | $157.03\pm35.47^{a,E}$ |

$^{a,b,c}$*Within a row, different superscript letters indicate statistically significant differences among the points (p<0.05) based on Tukey's HSD.*
$^{A,B,C}$*Within a column, different superscript letters indicate statistically significant differences among the groups (p<0.05) based on Tukey's HSD.*

of the adhesives also affected their pooling, even when air-thinning was applied.[30]

Many factors affect the marginal fit of fixed restorations, including the finish line configuration and cement space. Regarding the finish line configuration, zirconia restorations require proper material thickness, with a recommended tooth reduction of 1 mm at the finish line.[35] A shoulder with a rounded internal line angle, which was the horizontal finish line chosen in this study, ensured sufficient thickness without causing over-contour of the restoration and provided better occlusal seating than a vertical finish line, feather edge, or shoulder-less preparations.[36,37] However, the horizontal finish line produced a wider marginal gap than a vertical finish line, even with the crown seated properly.[36] The narrower gaps at IF and AW could also affect crown seating since they reduced the venting of cement, resulting in a wider internal gap in the occlusal areas (CT, IO, and CO), especially in the TE group, where the crown would not be perfectly seated. When cement cannot escape from the inside, thicker cement can be found in the occlusal area, which affects the marginal gap.[38] In this case, the crown could have a hyper-occlusion and increased marginal gap after try-in, which can usually be seen in the clinic.

The cement space set in the software, including the radial spacer and occlusal spacer, would be filled with permanent cement during crown insertion. Many studies[39-41] have recommended a range of cement space in CAD/CAM from 30 to 200 μm to achieve a good marginal fit. In this study, the cement space for the zirconia crown was set at 80 μm, according to the manufacturer's recommendations.[42] It should not be too wide to prevent the excessive thickness of resin cement, which might cause polymerization shrinkage and a large number of voids, compromising the shear bond strength of the restoration.[43-46] However, insufficient cement space hinders the escape of cement, leading to poor crown seating.[47]

Ideally, the sum of the internal gap and adhesive thickness should be equal to the cement space set in the software. In the control group, even no adhesive was applied, the gaps were found to be wider than the set cement space in all areas. Furthermore, regarding the internal gap, the AW showed the narrowest gap in the control and all adhesive groups but was comparable to the IF in the TE group, while the occlusal area showed the widest gap in all groups. This difference was consistent with other studies.[47-49]

The difference in the internal gap in the AW and occlusal area could result from errors in the optical scanning process and the shrinkage of the pre-sintered zirconia block. During the processing of the 3D model after scanning, the sharp angle on the abutment was transformed into smoother and more continuous surfaces while the software generated the point cloud. This is one of the internal inaccuracies of the technique.[18] The machined zirconia block typically shrinks by approximately 25% during the sintering process.[50] However, the 3D model from the software estimation may not be sufficient to cover the actual shrinkage.[47] Increasing the cement space, particularly at the AW of the abutment (radial spacer in the software), might help solve this issue without further increasing the cement thickness at the occlusal region.

The sum of the measured adhesive thickness and the thickness of the silicone replica represented the total distance between the crown restoration and tooth surface or the sum of the adhesive and gap. Difference dental adhesives caused an increase in the sum of the adhesive and gap, as the TE group showed a greater sum of adhesive and gap than the SE, U, and C groups. The thickness of the adhesive in the TE group might have hindered the flow of cement more than other adhesives in the experiment, increasing the probability of incomplete crown seating, as evidenced by the larger marginal gap.[38] Spohr *et al.,*[16] also found that the sum of adhesive and gap in the occlusal region of crown preparation of the group in which adhesive was applied was greater than that of the group without adhesive.

Based on this study's results, dentine sealing after taking a digital impression with an intraoral scanner significantly increased the marginal gap within the limit of clinical acceptance (< 120 μm), together with significantly increased internal gaps. Especially in the TE group, the adhesive had high viscosity and less ability to flow and spread on the surface due to strong intermolecular forces;[51] thus, it tended to accumulate more in the concave areas, which enhanced molecular cohesion, than in the convex areas. In the case of the application of a high-viscosity adhesive, increasing the air-blowing or preheating process[52] might be helpful for thinning and spreading the adhesive by increasing molecular motion and enhancing fluidity.[53] However, it is challenging to control the thickness of the dental adhesive applied to a scanned abutment. Therefore, although the marginal gaps observed in this study remain within clinically acceptable, the author does not recommend this approach. Furthermore, it may also affect occlusion due to incomplete seating of the crown.(54) If it must be performed, high-viscosity adhesives should be avoided.

Dentine sealing can be performed at various clinical stages: immediately after tooth preparation, after the provisional cementation of a temporary restoration, or after digital impression-taking but before the temporary restoration, as done in this experiment. The technique in which the dental adhesive is applied to freshly cut dentine before impression-taking or before fabricating a temporary restoration is called IDS, whereas in the delayed dentine sealing (DDS) technique, the dentine is sealed after it has been contaminated by the impression material or temporary restoration. IDS offers the advantages of stronger bond strength(3), while DDS helps to reduce tooth sensitivity.(55) However, the technique used in this experiment might not fully fit the criteria for IDS or DDS. The use of the silicone replica method in this study aimed to preserve the crown; as a result, permanent cementation of the crown was not needed, and sectioning the specimen was not necessary.(56-59) Although adhesive application was carefully controlled in this *in vitro* study, clinical conditions may differ. Challenges such as limited visibility, subgingival margins, or adhesive overextension beyond the finish line can lead to uneven application, which may affect crown seating and marginal adaptation.

## Conclusions

The application of dentine sealing material after abutment scanning influenced the marginal and internal gaps of the zirconia crown. The marginal gap of all dentine sealing groups increased significantly but remained clinically acceptable. The internal gaps of the occlusal region were wider than those of the other areas. The high-viscosity bonding adhesive produced the thickest adhesive layer, especially at the internal finish line (IF), which caused the widest marginal gap, especially in the total-etch (TE) group.

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## Conflicts of Interest

The authors declare no conflicts of interest.

## References

1. Farias D, Walter R, Swift EJ. Postoperative sensitivity with indirect restorations. J Esthet Restor Dent. 2014;26:100-7.
2. Pashley EL, Comer RW, Simpson MD, Horner JA, Pashley DH, Caughman WF. Dentin permeability: sealing the dentin in crown preparations. Oper Dent. 1992;17(1):13-20.
3. Magne P. Immediate dentin sealing: a fundamental procedure for indirect bonded restorations. J Esthet Restor Dent. 2005;17(3):144-54.
4. Stavridakis MM, Krejci I, Magne P. Immediate dentin sealing of onlay preparations: thickness of pre-cured dentin bonding agent and effect of surface cleaning. Oper Dent. 2005;30(6):747-57.
5. Magne P, So WS, Cascione D. Immediate dentin sealing supports delayed restoration placement. J Prosthet Dent. 2007;98(3):166-74.
6. Özcan M, Bernasconi M. Adhesion to zirconia used for dental restorations: a systematic review and meta-analysis. J Adhes Dent. 2015;17(1):7-26.
7. Cagidiaco MC, Ferrari M, Garberoglio R, Davidson CL. Dentin contamination protection after mechanical preparation for veneering. Am J Dent. 1996;9(2):57-60.
8. Hu J, Zhu Q. Effect of immediate dentin sealing on preventive treatment for postcementation hypersensitivity. Int J Prosthodont. 2010;23(1):49-52.
9. Langeland K, Langeland LK. Pulp reactions to crown preparation, impression, temporary crown fixation, and permanent cementation. J Prosthet Dent. 1965;15:129-43.
10. Maleknejad F, Moosavi H, Shahriari R, Sarabi N, Shayankhah T. The effect of different adhesive types and curing methods on microleakage and the marginal adaptation of composite veneers. J Contemp Dent Pract. 2009;10(3):18-26.
11. Hahn P, Schaller H, Hafner P, Hellwig E. Effect of different luting procedures on the seating of ceramic inlays. J Oral Rehabil. 2000;27(1):1-8.
12. Sofan E, Sofan A, Palaia G, Tenore G, Romeo U, Migliau G. Classification review of dental adhesive systems: from the IV generation to the universal type. Ann Stomatol (Roma). 2017;8(1):1-17.
13. Samartzi TK, Papalexopoulos D, Sarafianou A, Kourtis S. Immediate dentin sealing: a literature review. Clin Cosmet Investig Dent. 2021;13:233-56.
14. Abo-Alazm EAE, Safy RK. Impact of immediate dentin sealing using universal adhesive under simulated pulp pressure on microtensile bond strength of indirect resin composite restorations and dentin permeability. Eur J Dent.

2022;16(3):536-42.
15. Kimyai S, Bahari M, Abed-Kahnamouei M, Ebrahimi-Chaharom ME, Asl-Oskouei MH. Effect of different application strategies of universal adhesive used for immediate and delayed dentin sealing on the microtensile bond strength of self-adhesive resin cement to dentin with and without aging. J Clin Exp Dent. 2023;15(3):e210-6.
16. Spohr AM, Borges GA, Platt JA. Thickness of immediate dentin sealing materials and its effect on the fracture load of a reinforced all-ceramic crown. Eur J Dent. 2013;7(4): 474-83.
17. Wilson PR. Effect of increasing cement space on cementation of artificial crowns. J Prosthet Dent. 1994;71(6):560-4.
18. Luthardt R, Weber A, Rudolph H, Schöne C, Quaas S, Walter M. Design and production of dental prosthetic restorations: basic research on dental CAD/CAM technology. Int J Comput Dent. 2002;5(2-3):165-76.
19. Hibino Y. Influence of types and surface treatment of dental alloy and film thickness of cements on bond strength of dental luting cements. Shika Zairyo Kikai. 1990;9(6): 786-805.
20. Coelho Santos MJ, Navarro MF, Tam L, McComb D. The effect of dentin adhesive and cure mode on film thickness and microtensile bond strength to dentin in indirect restorations. Oper Dent. 2005;30(1):50-7.
21. Sorensen JA. A standardized method for determination of crown margin fidelity. J Prosthet Dent. 1990;64(1):18-24.
22. McLean JW. Polycarboxylate cements: five years' experience in general practice. Br Dent J. 1972;132(1):9-15.
23. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an *in vivo* technique. Br Dent J. 1971;131(3):107-11.
24. Mohaghegh M, Firouzmandi M, Ansarifard E, Ramazani L. Marginal fit of full contour monolithic zirconia in different thicknesses and layered zirconia crowns. J Int Soc Prev Community Dent. 2020;10(5):652-8.
25. Fernández-Estevan L, Millan-Martínez D, Fons-Font A, Agustín-Panadero R, Román-Rodríguez JL. Methodology in specimen fabrication for *in vitro* dental studies: standardization of extracted tooth preparation. J Clin Exp Dent. 2017;9(7):e897-e900.
26. Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent. 2001;85(4):363-76.
27. Rappold AP, Ripps AH, Ireland EJ. Explorer sharpness as related to margin evaluations. Oper Dent. 1992;17(1):2-6.
28. Larson TD. The clinical significance of marginal fit. Northwest Dent. 2012;91(1):22-9.
29. Bannister RD, Roudsari RV, Satterthwaite JD. Film thickness of dentin desensitizing agents on full crown preparations: influence of product and gravity. Oper Dent. 2014;39(6): E241-9.
30. Peter A, Paul SJ, Lüthy H, Schärer P. Film thickness of various dentine bonding agents. J Oral Rehabil. 1997;24 (8):568-73.
31. Kerr Corporation. OptiBond™ FL Bonding Agents [Internet]. 2021 [cited 2025 Jun 22]. Available from: https://www.kerrdental.com/en-fi/dental-restoration-products/optibond-fl-dental-bonding-agents
32. Kuraray Co Ltd. CLEARFIL™ SE BOND resin-based dental adhesive system [Internet]. 2018 [cited 2025 Jun 22]. Available from: https://kuraraydental.com/wp-content/uploads/2018/05/clearfil_se_bond_brochure.pdf
33. 3M Company. 3M™ ESPE™ Single Bond Universal safety data sheet [Internet]. 2020 [cited 2025 Jun 22]. Available from: https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8l00xMY_eMYtGlv70k17zHvu9lx-tD7SSSSSS--
34. Zhang X, Zhang Q, Meng X, Ye Y, Feng D, Xue J, *et al*. Rheological and mechanical properties of resin-based materials applied in dental restorations. Polymers (Basel). 2021;13(17):2975.
35. Rosenstiel SF, Land MF, Fujimoto J. Tooth preparation for all-ceramic restorations. In: Rosenstiel SF, Land MF, Fujimoto J. editors. Contemporary fixed prosthodontics. 5$^{th}$ ed. St. Louis: Mosby; 2016. p. 264-277.
36. Gavelis JR, Morency JD, Riley ED, Sozio RB. The effect of various finish line preparations on the marginal seal and occlusal seat of full crown preparations. J Prosthet Dent. 1981;45(2):138-45.
37. Nemane V, Akulwar RS, Meshram S. The effect of various finish line configurations on the marginal seal and occlusal discrepancy of cast full crowns after cementation-an *in vitro* study. J Clin Diagn Res. 2015;9(8):ZC18-21.
38. Jørgensen KD. Structure of the film of zinc phosphate cements. Acta Odontol Scand. 1960;18(4):491-501.
39. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of CEREC 3 CAD/CAM all-ceramic crowns. Int J Prosthodont. 2003;16(3):244-8.
40. Dauti R, Lilaj B, Heimel P, Moritz A, Schedle A, Cvikl B. Influence of two different cement space settings and three different cement types on the fit of polymer-infiltrated ceramic network material crowns manufactured using a complete digital workflow. Clin Oral Investig. 2020;24(6):1929-38.
41. Zhang Y, Dudley J. The influence of different cement spaces on the marginal gap of CAD/CAM all-ceramic crowns. Aust Dent J. 2019;64(2):167-74.
42. Dentsply Sirona. Clinical guideline for full contour zirconia restorations produced chairside with "CEREC Zirconia" (milling process) [Internet]. 2017 [cited 2025 Jun 22]. Available from: https://www.dentsplysirona.com/content/dam/websites/my-cerec/pdf/Clinical-Guidelines-for-CEREC-Zirconia.pdf
43. Chana HS, Ibbetson RJ, Pearson GJ, Eder A. The influence of cement thickness on the tensile strength of two resin cements. Int J Prosthodont. 1997;10(4):340-4.

44. Urapepon S. Effect of cement film thickness on shear bond strengths of two resin cements. M Dent J. 2014;34:122-8.
45. May LG, Kelly JR, Bottino MA, Hill T. Effects of cement thickness and bonding on the failure loads of CAD/CAM ceramic crowns: multi-physics FEA modeling and monotonic testing. Dent Mater. 2012;28(8):e99-109.
46. Maneenacarith A. The influence of resin cement thicknesses on shear bond strength of zirconia treated with a universal adhesive: Thammasat University; 2021.
47. Schriwer C, Skjold A, Gjerdet NR, Øilo M. Monolithic zirconia dental crowns: internal fit, margin quality, fracture mode, and load at fracture. Dent Mater. 2017;33(9):1012-20.
48. Souza RO, Özcan M, Pavanelli CA, Buso L, Lombardo GH, Michida SM, *et al.* Marginal and internal discrepancies related to margin design of ceramic crowns fabricated by a CAD/CAM system. J Prosthodont. 2012;21(2):94-100.
49. Coli P, Karlsson S. Precision of a CAD/CAM technique for the production of zirconium dioxide copings. Int J Prosthodont. 2004;17(5):577-80.
50. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24(3):299-307.
51. Zumdahl SS, Zumdahl SA, DeCoste DJ. Liquids and solids. In: Zumdahl SS, Zumdahl SA, DeCoste DJ, editors. Chemistry. 11th ed. Boston: Cengage Learning; 2023. p. 375-424.
52. Magne P, Mori Ubaldini AL. Thermal and bioactive optimization of a unidose 3-step etch-and-rinse dentin adhesive. J Prosthet Dent. 2020;124(4):487.e1-.e7.
53. Ayub KV, Santos GC Jr, Rizkalla AS, Bohay R, Pegoraro LF, Rubo JH, *et al*. Effect of preheating on microhardness and viscosity of 4 resin composites. J Can Dent Assoc. 2014; 80:e12.
54. Cruz MA, Sorenson JA, Johnson WK. Effect of venting and seating techniques on the cementation of complete coverage restorations. Oper Dent. 2008;33(6):690-5.
55. Dionysopoulos D, Gerasimidou O, Beltes C. Dentin hypersensitivity: etiology, diagnosis and contemporary therapeutic approaches-a review in literature. Appl Sci. 2023;13(21):11632.
56. Rahme H, Tehini G, Adib S, Ardo A, Rifai K. *In vitro* evaluation of the "replica technique" in the measurement of the fit of Procera® crowns. J Contemp Dent Pract. 2008;9:25-32.
57. Fathi H, Al-Masoody A, El-Ghezawi N, Johnson A. The accuracy of fit of crowns made from wax patterns produced conventionally (hand-formed) and via CAD/CAM technology. Eur J Prosthodont Restor Dent. 2016;24:10-7.
58. Son K, Lee S, Kang SH, Park J, Lee KB, Jeon M, *et al*. A comparison study of marginal and internal fit assessment methods for fixed dental prostheses. J Clin Med. 2019;8(6):785.
59. Licurci CAA, Lins L, Garbossa M, Canabarro A. A comparative study between replica and cementation techniques in the evaluation of internal and marginal misfits of single crowns. J Prosthet Dent. 2020;127(4):609-16.