BULLETIN OF STOMATOLOGY AND MAXILLOFACIAL SURGERY
Volume 21, Issue 11

DOI: 10.58240/1829006X-2025.21.11-150

REVIEWARTICLE

MARGINAL AND INTERNAL FIT OF ENDOCROWNS FABRICATED WITH DIFFERENT RESTORATIVE MATERIALS

Mohammed Anwar Taher[1], Abdulkareem Ramadhan Almezouri [2]
[1] B.D.S., Assistant professor Department of Conservative Dentistry, Duhok University, Duhok, Iraq
[2] BDS, MSc, PhD Department of Conservative Dentistry, Duhok University, Duhok, Iraq
***Corresponding Author:** Mohammed Anwar Taher, Department of Conservative Dentistry, Duhok University, Duhok, Iraq; e-mail: mohammedbadi790@gmail.com

Received: *Oct 17. 2025;* ***Accepted:*** *Nov 27, 2025;* ***Published:*** *Dec. 6,2025*

ABSTRACT

Objectives: Objectives of this study is to evaluate and compare the *marginal and internal fit* of endocrowns fabricated from three CAD/CAM restorative materials—zirconia, lithium disilicate, and resin composite—using a standardized digital workflow.

Methods: A sound mandibular first molar was endodontically treated and prepared with a standardized butt-joint endocrown design (2 mm occlusal reduction, 4 mm intracoronal depth). The tooth was scanned using an intraoral scanner, and 30 identical resin models were fabricated using a 3D printer. Endocrowns were designed in CEREC CAD software with a 0 µm marginal spacer and 50 µm internal spacer, then milled from zirconia (IPS e.max ZirCAD®), lithium disilicate (IPS e.max CAD®), and resin composite (Tetric CAD®), each group (n = 10). Zirconia and lithium disilicate restorations underwent post-milling sintering and crystallization firing in dedicated dental furnaces (Programat S1 1600® for zirconia and Programat CS6® for lithium disilicate) according to the manufacturers' protocols, while composite restorations (Tetric CAD®) required no additional firing. Marginal and internal gaps were assessed using the Triple Scan Method (TSM) with a Medit i700 scanner and analyzed with Medit Crown Fit software. Statistical analysis was performed using one-way ANOVA and Fisher's LSD test (α = 0.05).

Results: For marginal fit Tetric CAD group exhibited the best marginal fit (73.7 ± 32.3 µm) followed by E-max CAD (115.8 ± 47.3 µm), and ZirCAD group showed the worst fit (134.9 ± 59.4 µm), with a significant difference (p = 0.017) among them. Pairwise comparison revealed a significant difference between ZirCAD and Tetric (p = 0.021). For internal fit the Tetric CAD group exhibited the best overall internal fit (76.9 ± 16.19 µm), followed by ZirCAD group (89.9 ±49.81), and E-max CAD showed the worst internal fit (114.1 ± 37.49 µm), with significant differences (p = 0.005) among them, also significant differences were observed in cervical region (p = 0.009), axial region (p = 0.011), while pulpal fit (p = 0.249) showed no statistically significant difference.

Conclusion: Within the limitations of this in-vitro study, the resin composite endocrowns (Tetric CAD) demonstrated superior marginal and internal adaptation compared with lithium disilicate (IPS e.max CAD) and zirconia (IPS e.max ZirCAD) restorations. These findings suggest that resin composite materials may provide a more accurate internal and marginal fit when fabricated through a fully digital CAD/CAM workflow.

Keywords**:** Endocrown; Marginal fit; Internal fit; CAD/CAM; Zirconia; Lithium disilicate; Resin composite

1.INTRODUCTION

Endocrowns provide a conservative restorative option in an endodontically treated posterior tooth, which consists of the union between the crown and post/core as one single unit that is adhesively bonded to the pulp chamber.

The lasting of these restorations is mainly dependant on marginal and internal adaptation the restoration and prepared surfaces controlling long-term retention, sealing and stress distribution. A poor adaptation may result in microleakage, cement solubility, secondary caries and restoration failure that highlights the significance of an accurate fit for clinical longevity of endocrowns[1,2.]

This started with the development of CAD/CAM techniques, which have liberated restorative dentistry from the artist: now high precision and reproducibility is available also for "artistically challenged" people. Three of the CAD/CAM materials most commonly used, zirconia, lithium disilicate and laboratory composite have different physical and mechanical properties. Zirconia provides excellent strength and fracture efficiency but has reduced translucency, lithium disilicate balances esthetics and bonding capability with acceptable strength, while laboratory composites supply dentin-like elasticity that could enhance stress absorption under occlusal loading [3,4].

Both marginal and internal adaptation are influenced by the restorative material choice along with the digital design parameters, milling accuracy, and postmilling treatments such as sintering or crystallization. By using optimised chairside CAD/CAM treatment procedures and a well-adjusted spacer dimension clinically acceptable adaptation values could be achieved, mostly below 120 µm[5]. However, discrepancies still exist among materials due to inherent differences in microstructure, hardness, and machining response[6].

Therefore, this study aimed to evaluate and compare the marginal and internal fit of endocrowns fabricated from zirconia (IPS e.max ZirCAD®), lithium disilicate (IPS e.max CAD®), and resin composite (Tetric CAD®) using a standardized digital workflow. The null hypothesis proposed that no significant difference would exist among the materials in terms of marginal and internal adaptation.

MATERIAL AND METHODS

Sample Selection and Preparation

A sound human mandibular first molar extracted for periodontal reasons was selected as the master specimen. Radiographic and stereomicroscopic inspection confirmed intact structure, complete root formation, and absence of caries or cracks. The tooth was cleaned ultrasonically, debrided of calculus, and stored in 0.1 % thymol solution until use[7].

Root canal treatment was performed using the **ProTaper Next** rotary system (Dentsply Sirona, Germany) with X2 and X3 files for mesial and distal canals, respectively, at 300 rpm and 2 N·cm torque. Irrigation consisted of 5.25 % NaOCl, 17 % EDTA, and distilled water, followed by drying with paper points. Obturation was completed using AH Plus sealer (Dentsply Sirona) and gutta-percha via the single-cone technique. The orifices were sealed with liquid dam material and stored at 37 °C for 24 h in incubator. The access cavity was cleaned of sealer remnants using 70 % ethanol for 7 s and air-polished with calcium carbonate for 10 s at 3.5 bar to ensure optimal surface cleanliness[7].

The specimen was embedded in acrylic resin and oriented with a dental surveyor. Resin was poured into cylindrical molds 25 x 20 mm, and the root placed 2 mm below the cemento-enamel junction. The tooth was prepared with complete butt-joint endocrown design, 2mm occlusal reduction and 4mm pulp-chamber depth under 4.5× magnification using diamond burs and water spray. The line of preparation was an 8° taper and the internal angles were rounded for enhanced stress distribution [8,9,10].

Digital Modeling and Sample Replication

The prepared tooth was scanned with a TRIOS 5 intraoral scanner (3Shape, Denmark), and the STL file was edited in Exocad DentalCAD 3.1 Rejika to verify margin continuity. Thirty identical resin replicas were printed using the SprintRay Pro S DLP 3D printer and Die and Model 2 Gray resin. The additive process performed with 50 µm layer thickness and 76 µm XY resolution for dimensional accuracy. Post-processing involved washing in 99 % isopropyl alcohol, air-drying, and final curing in a SprintRay Pro Cure 2 unit at 60 °C for 10–15 min to ensure full polymerization[11].

Group organization and CAD/CAM Design

Thirty resin models were randomly assigned to three groups (n = 10 each): **Group A:** Zirconia (IPS e.max ZirCAD®), **Group B:** Lithium disilicate (IPS e.max CAD®), **Group C:** Resin composite (Tetric CAD®).

Figure 1. Design of endocrown by CEREC CAD software

All models were scanned with CEREC Omnicam® (Dentsply Sirona) intraoral scanner built into the CEREC CAD software. The endocrowns were uniformly designed and the occlusal morphology reconstructed by means of biogeneric model algorithm. A 0 µm marginal and a 50 µm internal spacer were established for adaptation space and

Mohammed Anwar Taher, Abdulkareem Ramadhan Almezouri. Marginal and internal fit of endocrowns fabricated with different restorative materials Almezouri. Bulletin of Stomatology and Maxillofacial Surgery.2025;21(11)150-157 doi:10.58240/1829006X-2025.21.11-150

cement space[12]. The same design file was applied to all groups in order to minimize geometry difference. (Fig 1)

CAM Fabrication

All restorations were milled with a CEREC MC XL four-axis unit.

– **Zirconia** endocrowns were dry-milled, sintered in **Programat S1 1600®** using the "P6 Speed Crown" program (up to 1500 °C for 2.55 H), and glazed at 850 °C for 10 min13.

– **Lithium disilicate** restorations were wet-milled, crystallized in a **CEREC SpeedFire®** furnace at 840 °C for 7 min and glazed at 760 °C14.

– **Tetric CAD** endocrowns were wet-milled, finished with the **Tetric CAD Polishing Kit®**, and did not require sintering (Ivoclar Vivadent AG)15.

Sprue was removed by a diamond wheel under water coolant, and restorations were inspected for passive fit before measurement. Fig 2.

Figure 2. Fabricated endocrown

Measurement of Marginal and Internal Fit

The Medit i700 intraoral scanner (Medit Link v 3.2.1; Medit, Seoul, Republic of Korea) equipped with blue-light technology was employed to determine the marginal gap and internal fit of the fabricated endocrowns. All scans were conducted by a single trained operator under controlled room temperature and humidity to ensure consistency and eliminate operator variability.

The assessment followed the **Triple-Scan Method (TSM)** described by **Holst et al. (2011)**, a non-destructive 3D protocol widely recognized for its precision in fit evaluation. The technique involves scanning the prosthesis, the prepared abutment, and the seated (cemented) prosthesis, generating three distinct digital datasets—data crown, data abutment, and data seated—that are subsequently aligned to calculate the cement space between surfaces. This method provides reliable and repeatable measurements, with previous studies reporting an intraclass correlation coefficient of $r = 0.981$, confirming high reproducibility[16,17].

At first stage, the internal and external surfaces of both endocrown and prepared tooth incorporated in resin were scanned to have them as the data crown and the data abutment. A third scan (seated data) was recorded for the endocrown once seated to determine the final adaptation. The data was exported as STL files, which are compatible with other CAD software. this file format enables data to be transferred digitally without loss of dimension, and digital communication between the clinical scanner and laboratory CAD software[18,19].

The Medit Link v 2.4.4 platform was used for 3D analysis through the Medit Crown Fit v 1.1.1.61 module. Within the software's compare tool, the data seated file was designated as the reference dataset, and the data crown file as the target. Automatic alignment was performed using the occlusal surface landmarks; when misalignment occurred, manual correction was carried out by selecting corresponding reference points on both datasets. This superimposition allowed visualization and quantification of the cement gap across the entire restoration interface[19].

For quantitative analyses, three symmetrical planes were created in each sample: mesiodistal (MD), buccolingual (BL) and a pair of oblique cross-sections linking internal cusps of opposite sides of the endocrown (Fig 3). each section was also divided into 4 regions of reference interest: marginal, cervical, axial and pulpal. 15 measurements were made per section2,5,20: one at the marginal edge (M1), two in the cervical area (C1 = center and C2= cervico-axial junction), three on the axial wall (A1–3 equally dividing up the wall into thirds) and three along the pulpal floor (P1–P3 at axiopulpal corners and mid-pulpal region).

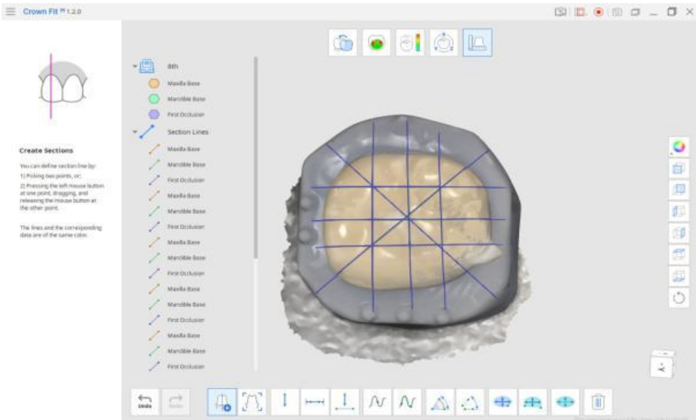

Figure 3. Selected sections in mesiodistal,buccolingual, and oblique directions for marginal and internal adaptation, the section generated in crown by using nonmetrology grade software program (Medit Crown Fit).

M1 represented the *absolute marginal distance (AMD)*—the vertical gap between the most extended point of the crown margin and the external finishing line of the preparation. **C1** and **C2** quantified the cervical discrepancies; **A1–A3** the axial discrepancies; and **P1–P3**

the pulpal discrepancies (fig 4). Each endocrown yielded 120 measurement points, resulting in 3600 total measurements across all 30 specimens (15 points × 8 sections × 30 restorations). The measured cement gap represented the virtual luting space between the restoration's internal surface and the tooth substrate, thereby reflecting the marginal and internal adaptation precision of each material[2,5].

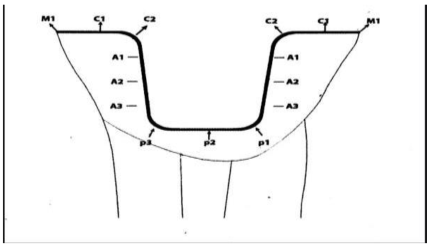

Figure 4. Schematic representation of measurement positions for marginal and internal fit. black line represents cement analog layer; M1: AMD. C1 and C2: cervical discrepancies. A1, A2, and A3: axial discrepancies. P1 and P2, and P3: pulpal discrepancies.

RESULT

Table 1. Descriptive statistic, one-way anova and pairwaise comparison of marginal gap regarding restorative materials Marginal: Gap Comparison Between Restorative Materials (µm)

Marginal: Gap Comparison Between Restorative Materials (µm)								
Region	N	Mean ±SD			P	Pairwise Comparison		
		Zirconia	E-max	Tetric		Zirconia / E-Max	Zirconia / Tetric	E-Max / Tetric
Marginal	10	134.9 ±59.4	115.8 ±47.3	73.7 ±32.3	0.017	0.65	0.021	0.137

Table (1) Represents the mean gap between the marginal area of different Restorative materials (three groups). The best fit belongs to Tetric group with a mean gap of (73.7 ±32.3 µm). conversely the worst fit belongs to Zirconia group with a mean gap of (134.9 ±59.4µm), with a statistically significant difference (p-value) of 0.017 by using ANOVA test. As shown in fig (5).

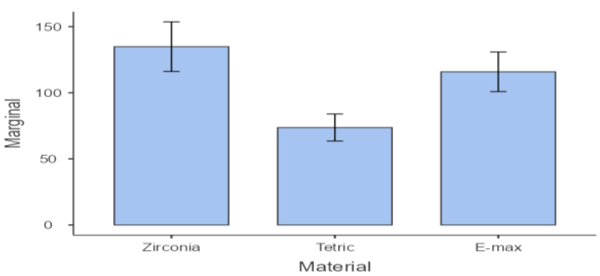

Figure 5. Marginal mean gap regarding restorative materials

The right side of the table represents the pairwise comparison between the three restorative materials within the marginal area. Significant differences were found between Zirconia – Tetric (p = 0.021), but there was no statistically significant difference found among the other pairs.

Table 2. Descriptive statistic and one-way anova of internal gap regarding restorative materials

Internal Regions: Gap Comparison Between Materials (µm)					
Area	N	Mean ±SD			P
		Zirconia	E-max	Tetric	
C	10	115.8 ±61.1	136.6 ±42.74	83.4 ±20.57	0.009
A	10	55.9 ±24.5	71.5 ±19.91	45.2 ±13.18	0.011
P	10	97.9 ±68.7	134.3 ±54.01	102.2 ±20.65	0.249
Internal	10	89.9 ±49.81	114.1 ±37.49	76.9 ±16.19	0.005

Table (2) Represents the mean Internal gap of the different Restorative materials (three groups) at three (3) different areas and the mean internal gap.

Within Cervical area the best fit belongs to Tetric with a mean gap of (83.4 ±20.57 µm) conversely the worst fit belongs to E-max with a mean gap of (136.6 ±42.74 µm) with a statistically significant difference (p-value) of 0.009 by using ANOVA test. Within Axial area the best fit belongs to Tetric with a mean gap of (45.2 ±13.18µm) and the worst fit belongs to E-max with a mean gap of (71.5 ±19.91µm) with a statistically significant difference (p-value) of 0.011 by using ANOVA test. Within Pulpal area the best fit belongs to Zirconia with a mean gap of (97.9 ±68.7 µm), conversely the worst fit belongs to E-max with a mean gap of (134.3 ±54.01µm). However, by using ANOVA test no statistically significant difference were found between groups for this area.

The mean internal gap represents the average gap of the Cervical, Axial, and Pulpal Areas. The best fit among the averages belong to Tetric with a mean gap of (76.9 ±16.19 µm), Conversely the worst fit belongs to E-max with a mean gap of (114.1 ±37.49µm) with a statistically significant difference (p-value) 0.005 by using ANOVA test. As shown in fig 6.

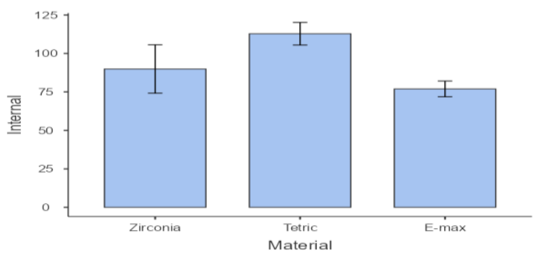

Figure 6. Internal mean gap regarding restorative materials

Table 3. pairwise comparison of internal mean gap regarding restorative materials

Pairwise Comparison of Internal Groups LSD (Least Significant difference)				
Materials		Area		
		C	A	INTERNAL
Zirconia	E-Max	0.83	0.49	0.29
Zirconia	Tetric	0.43	0.83	0.87
E-Max	Tetric	0.04	0.05	0.02

Table (3) represents Fisher's LSD (Least Significant difference) pairwise comparison among the groups at The Cervical, Axial and mean Internal gap.
Within the Cervical area significant differences were found between E-max – Tetric (p=0.04). but there was no statistically significant difference found among the other pairs.
Within the Axial area significant differences were found between E-max – Tetric (p=0.05). but there was no statistically significant difference found among the other pairs.
Within the internal Area significant differences were found between E-max – Tetric (p=0.02). but there was no statistically significant difference found among the other pairs.
The marginal and internal fit are important aspects for the clinical success and durability of endocrown restorations. Poor adaptation can result in cement dissolution, microleakage, bacterial ingress along the tooth–restoration interface and nonuniform stress distribution in the luting resin that risks degradation of restoration retention and fracture resistance[2,21].
while an optimal internal fit provides uniform cement thickness and better load transfer to the underlying tooth structure. Clinically, the acceptable range for marginal gaps in CAD/CAM endocrowns is generally 50–120 µm, whereas internal gaps up to 200 µm are considered acceptable if uniformly distributed[22,23,24]. Shin et al. (2017) reported lithium-disilicate endocrowns exhibiting marginal gaps between 99 µm and 120 µm, confirming that values within this range remain clinically acceptable. maintaining both marginal and internal gaps within these clinically accepted limits is essential for ensuring the long-term stability and functional reliability of endocrown restorations [5,13].
In the present study, the Tetric CAD endocrowns demonstrated the best marginal adaptation (73.7 ± 32.3 µm), whereas zirconia (IPS e.max ZirCAD) showed the largest marginal discrepancy (134.9 ± 59.4 µm). When compared to previous study the Tetric CAD value lies within the clinically acceptable range (≤120 µm), while the zirconia group marginally slightly exceeds the 120 µm[25,26].
The superior marginal fit of Tetric CAD over zirconia can be attributed to its distinct material composition, manufacturing process, and mechanical characteristic. As a resin-composite CAD/CAM block, Tetric CAD does not require post-milling sintering or crystallization, eliminating thermal shrinkage and maintaining the precision of its milled margins. Its favorable machinability allows smoother cutting and minimal bur wear, producing cleaner and more accurate finish lines. The material's viscoelastic behavior further aids in reducing chipping and achieving a refined marginal contour. In addition, Tetric CAD's relatively low elastic modulus (approximately 12–20 GPa) enables slight elastic accommodation during cementation, allowing the restoration to seat more completely and achieve closer marginal contact. These factors collectively contribute to its superior marginal precision.
These results are consistent with findings by El Ghoul et al. (2020), Abo El-Farag et al. (2023), and Saad et al. (2025), who observed that resin-based and hybrid CAD/CAM materials generally produce smaller marginal gaps than high-strength ceramics due to easier milling and better seating behavior[2,27,28].
On the other hand, poor marginal adaptation of zirconia (ZirCAD) may be attributed to processing and mechanical rigidity Zirconia restorations are milled in the soft stage or pre-sintered stage and then fired through a high temperature sintering technique, resulting in an approximate 25% volume shrinkage of the pre-sintered state. Also, small errors for sinter compensation, temperature ramp or furnace calibration may cause geometrical distortion or marginal opening. Furthermore, the extremely high stiffness of zirconia (≈200 GPa) does not allow for elastic accomodation during cementation so internal irregularities or peaks will impede complete seating, leading to increased marginal gap. This can account for the higher discrepancy observed in zirconia endocrowns and is consistent with the findings of (Rosentritt et al. (2020), Taha & Hatata (2024) and Kumar et al. 2025), who also showing that zirconia has a higher marginal misfit in comparison to lithium-disilicate and resin materials [13,25,29].
The moderate marginal adaptation of lithium disilicate (IPS e.max CAD) (115.8 ±47.3 µm) found in our study mirrors its intermediate structural and manufacturing behavior, situational between the excellent performance by Tetric CAD and the poorer findings of zirconia. Being a Glass-ceramic material, e.maxCAD is milled in its

partially crystallized blue phase and subsequently undergoes a controlled crystallization firing. This process induces only minimal dimensional change, maintaining good accuracy at the margins while enhancing the material's strength through complete lithium disilicate crystallization. However, its relatively high hardness and brittle microstructure make it less forgiving during milling, make the margins susceptible to minor chipping or over-milling compared with resin-composite blocks. Furthermore, its elastic modulus of approximately 95 GPa allows less seating adaptation than composite materials but more than zirconia, resulting in a moderate degree of marginal discrepancy.[28]
These characteristics explain why lithium disilicate restorations consistently demonstrate a fitting quality that is superior to zirconia but not as precise as resin-based CAD/CAM materials, as similarly reported by El Ghoul et al. (2020), Abo El-Farag et al. (2023), and Saad et al. (2025)[2,27,28].
In the present study, the mean internal gap values among the three CAD/CAM restorative materials were Tetric CAD (76.9 ± 16.19 µm), ZirCAD (89.9 ± 49.81 µm), and IPS e.max CAD (114.1 ± 37.49 µm), showing a statistically significant difference ($p = 0.005$). These results reveal that Tetric CAD achieved the most accurate internal adaptation, than E-max CAD, and zirconia groups

The better internal fit of Tetric CAD could be related to its resin-composite nature and composition, allowing more constant milling and less tool vibration compared with ceramics/brittleness. No post-milling sintering or crystallization process is necessary so that no volumetric change occurs, and the precision of inside surface to cavity fit is preserved. Their results are corroborated by Abo El-Farag et al. (2023) and Saad et al. (2025), who found that the internal gap of hybrid and composite CAD/CAM materials was smaller than that of ceramics because they were highly machinable and had good dimension accuracy. Attia et al. (2024) also reported that resin-matrix composites kept better adaptation after thermomechanical aging and demonstrating an internal stability over time [27,28,30].
This is in contrast to lithium disilicate restorations where larger internal gaps can be attributed to the crystallisation phase of this material, during which there may be restricted thermal contraction or residual stresses effecting the internal dimension. This finding is in agreement with El Ghoul et al. (2020), who observed that ceramic groups, such as lithium disilicate, showed greater internal discrepancies when compared with resin-based groups. On the other hand, Taha and Hatata (2024) found that E-max endocrowns showed greater mean value internal gap when compared to hybrid ceramics stating it is related to the shrinkage as well as microstructure rearrangement during crystallization[2,25].
Overall, the internal gap values obtained in this study fall within the **clinically acceptable range of 80–200 µm**, as described by **Nakamura et al. (2015)** and **Groten et al. (2000)**[24,23].

Regarding the internal gap between regions, Tetric CAD showed the lowest internal adaptation at cervical (83.4 ± 20.57 µm) and axial areas (45.2 ± 13.18µm), while the zirconia was that with less gap at pulpal floor (97.9 ± 68.7 µm). E-max CAD consistently showed statistically significantly higher gaps in all areas, especially in the cervical and pulpal regions. The improved results of Tetric CAD in the cervical and axial zones may be associated with its reduced elastic modulus and better adaptation to the cavity walls, which allows more homogeneous cement spreading. The pulpal region, however, tended to have higher discrepancies because of its flat horizontal surface and complex geometry of the endocrown chamber which features many line angles that are not suitable to be optically scanned accurately and accordingly seated homogenously. scanner light distortion and lack of depth capture in these areas may result in more measurement scatter and internal misfit, Similar findings were also observed by El Ghoul et al. (2020) and Kumar et al. (2025) agreeing that accuracy of pulpal adaptation is commonly inferior to axial and cervical zones.[2,29]

Limitations and Future Research

This in-vitro study was conducted on standardized resin models, which do not fully replicate the biomechanical behavior, moisture variations, and thermal fluctuations of natural teeth, potentially affecting the generalizability of the results. Only one tooth morphology, one preparation design, and a single spacer setting (0 µm marginal, 50 µm internal) were evaluated, which may not reflect clinical variability. Future research should include natural teeth, multiple cavity designs, different spacer configurations, dynamic loading, and long-term aging. Additionally, micro-CT analysis and larger sample sizes are recommended to enhance accuracy and strengthen clinical translation.

CONCLUSION

Within the limitations of this in-vitro study, resin composite endocrowns (Tetric CAD) demonstrated superior marginal and internal adaptation compared with lithium disilicate and zirconia restorations. Although all materials showed clinically acceptable values, composite endocrowns achieved the most consistent fit. These findings support the suitability of resin-based CAD/CAM materials for improved endocrown accuracy.

DECLARATIONS

Funding
This research received no external funding or financial support.
Conflict of Interest
The authors declare no conflict of interest.
Ethical Approval
This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Medical Ethics Committee.
Acknowledgments
None.

REFERENCES

1.Dolev E, Bitterman Y, Meirowitz A, (2019). Comparison of marginal fit between CAD-CAM and hot-press lithium disilicate crowns. J Prosthet Dent;121: 124-8.
2.El Ghoul WA, Özcan M, Ounsi H, (2020). Effect of different CADCAM materials on the marginal and internal adaptation of endocrown restorations: an in vitro study. J Prosthet Dent.; 123(1):128-134
3.Hasanzade, M., Moharrami, M., & Alikhasi, M. (2019). Evaluation of Marginal and Internal Adaptation of Endocrowns Fabricated from Three Different CAD/CAM Materials. The European Journal of Prosthodontics and Restorative Dentistry.
4.Tammam, R. (2021). Clinical evaluation of monolithic Zirconia (5Y), Lithium Disilicate and modified PEEK CAD-CAM endocrown materials, 3-year clinical prospective study. Egyptian Dental Journal, 67, 635-650.
5.Shin Y, Park S, Park JW, Kim KM, Park YB & Roh BD (2017). Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study. J Prosthet Dent, 117, 109-115.
6.Al-Dabbagh RA. Survival and success of endocrowns, (2021): A systematic review and meta-analysis. J Prosthet Dent. Mar;125(3):415. e1-415.
7.Devroey S, Calberson F & Meire M (2020). The efficacy of different cleaning protocols for the sealer-contaminated access cavity. Clinical oral investigations, 24, 4101-4107.
8.Bindl, A. and Mörmann, W.H., (2005). Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years—preliminary results. J Adhes Dent ,7(3), pp.321-325.
9.Biacchi GR. And Basting RT., (2012). Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent, 37(2):130-6.
10.Foad AM, Hamdy A, Abd el Fatah G, Aboelfadl A, (2020). Influence of CAD/CAM Material and Preparation Design on the Long-term Fracture Resistance of Endocrowns Restoring Maxillary Premolars. Braz Dent Sci.; 23(4):9p–p.
11.Carnier L., del Hougne M., Schmitter M. et al, (2024). 3D-printed tooth for caries excavation. BMC Med Educ 24, 1243.
12.Sahebi M, Ghodsi S, Berahman P, Amini A & Zeighami S (2022). Comparison of retention and fracture load of endocrowns made from zirconia and zirconium lithium silicate after aging: an in vitro study. BMC oral health, 22, 41.
13.Rosentritt M., Schumann F., Krifka, S. & Preis, V. 2020. Influence of zirconia and lithium-disilicate tooth- or implant-supported crowns on wear of antagonistic and adjacent teeth. Journal of Advanced Prosthodontics, 12(1), pp.1-8.
14.Gold SA, Ferracane JL & Da Costa J (2018). Effect of crystallization firing on marginal gap of CAD/CAM fabricated lithium disilicate crowns. Journal of Prosthodontics, 27, 63-66.
15.Aboelgar YH, Hasan MM, Zakaria ZF, & Ragheb A. (2025). 3D-PRINTED INDIRECT COMPOSITE RESTORATION. Sue Oral and Dental Medicine Journal, 1(1), 50–52.
16.Holst S, Karl M, Wichmann M & Matta R-ET (2011). A new triple-scan protocol for 3D fit assessment of dental restorations. Quintessence international, 42
17.Fasih P, Tavakolizadeh S, Monfared MS, Sofi-Mahmudi A & Yari A (2023). Marginal fit of monolithic versus layered zirconia crowns assessed with 2 marginal gap methods. The Journal of Prosthetic Dentistry, 130, 250. e1-250. e7.
18.Yilmaz B, Marques VR, Donmez MB, Cuellar AR, Lu W-E, Abou-Ayash S, et al (2022). Influence of 3D analysis software on measured deviations of CAD CAM resin crowns from virtual design file: an in-vitro study. Journal of dentistry, 118, 103933.
19.Sarhan MM, Khamis MM, Abdelhamid AM & Ezzelarab S (2023). Evaluation of the virtual cement gap parameter of different CAD software programs in designing a single crown restoration: An in vitro study. The Journal of Prosthetic Dentistry, 129, 777. e1-777. e7.
20.Nagi N, Fouda AM & Bourauel C (2023). Comparative evaluation of internal fit and marginal gap of endocrowns using lithium disilicate and polyether ether ketone materials-an in vitro study. BMC Oral Health, 23, 1-8.
21.Sedrez-Porto, J.A., Rosa, W.L.O., Silva, A.F., Münchow, E.A. & Pereira-Cenci, T. (2016) 'Endocrown restorations: A systematic review and meta-analysis', Journal of Dentistry, 52, pp. 8–14.

22.McLean JW & von Fraunhofer JA (1971) The estimation of cement film thickness by an in vivo technique. British Dental Journal, 131:107–111.
23.Groten, M., Axmann, D., Pröbster, L. & Weber, H. (2000) 'Determination of the minimum number of marginal gap measurements required for practical in-vitro testing', Journal of Prosthetic Dentistry, 83(1), pp. 40–49.
24.Nakamura, T., Saito, O., Fuyikawa, J. & Ishigaki, S. (2015) 'Marginal and internal fit of CAD/CAM ceramic crowns', Dental Materials Journal, 34(1), pp. 46–52.
25.Taha, A, & Hatata N. (2024). Marginal and internal gaps evaluation of endocrown restoration fabricated of different CAD/CAM materials using CBCT: An In vitro study. Advanced Dental Journal, 6(2), 208-215.
26.Dudley J., et al. (2025) Systematic review of marginal gaps of pre-cemented endocrown restorations. BMC Oral Health, 25:110.
27.Abo El-Farag S., et al. (2023) Marginal and internal fit of PEKK, zirconia, and hybrid ceramic endocrowns: an in-vitro evaluation. BMC Oral Health, 23:480.
28.Saad M., et al. (2025) Micro-CT assessment of internal adaptation of CAD/CAM endocrowns fabricated from various materials. Ceramics, 8(4):377–390.
29.Kumar S., et al. (2025) Comparative evaluation of marginal and internal adaptation of different CAD/CAM endocrown materials. Ceramics, 8(2):189–200.
30. Attia A., et al. (2024) Effect of thermomechanical aging on marginal adaptation of hybrid versus ceramic CAD/CAM veneers. MDPI Polymers, 16(7):1450.