Keywords
Endocrown; lithium disilicate; marginal adaptation; microstructure; premolar; preparation depth; CAD/CAM.

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Effect of Lithium Disilicate Ceramic Microstructure and Intracoronal Depth on the Circumferential Marginal Fit of Maxillary Premolar Endocrowns

Abstract

Objectives: To evaluate whether lithium disilicate ceramic microstructure and intracoronal preparation depth influence the circumferential marginal fit of maxillary premolar endocrowns.

Methods: Twenty-eight extracted human maxillary first premolars were randomly allocated to four groups ($n = 7$): IPS e.max CAD or Amber Mill at 2-mm or 4-mm intracoronal depths. After standardised endodontic treatment, digital fabrication, adhesive cementation and thermocycling, marginal gaps were measured at 12 circumferential sites. Crystalline phase abundance and crystal morphology were assessed by X-ray diffraction and scanning electron microscopy, respectively. One-way and two-way analyses of variance with Tukey post hoc testing were applied ($p < 0.05$).

Results: Material and depth significantly affected marginal gap ($p = 0.004$ and $p < 0.001$, respectively), with no interaction ($p = 0.906$). Amber Mill at 4 mm produced the lowest mean gap (52.8 ± 5.7 µm), whereas IPS e.max CAD at 2 mm produced the highest mean gap (74.6 ± 7.9 µm). Amber Mill showed a denser distribution of shorter crystals and fewer marginal machining defects. All group means were below 120 µm.

Conclusions: Restorative material and intracoronal depth independently influenced the marginal behaviour. Amber Mill showed an overall lower marginal gap and fewer edge defects, while the 4-mm preparation improved overall seating without altering the bulk phase abundance or crystal morphology.

Clinical Relevance: Both ceramics achieved mean marginal gaps below 120 µm under the tested conditions. Material-specific machinability and preparation geometry may improve marginal quality, but preservation of sound dentine and long-term clinical validation remain essential.

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Introduction

After tooth loss, the soft tissues that make up the alveolar ridge cover the remaining tissues in the mouth. The alveolar

The restoration of endodontically treated teeth remains one of the most important challenges in restorative dentistry, particularly when extensive coronal tooth structure has been lost. Teeth that have undergone root canal treatment frequently present with reduced fracture resistance as a result of previous caries, large restorations, trauma, and endodontic access cavity preparation. In addition, the loss of internal dentine support and reduction in cuspal stiffness may compromise their biomechanical behaviour under functional loading. Consequently, endodontically treated teeth are more susceptible to crack propagation, cusp fracture, and failure than vital teeth [1].

These challenges become more critical in premolar teeth, especially maxillary first premolars. In contrast to molars, premolars possess narrower cervical dimensions, smaller pulp chambers, thinner remaining cuspal walls, and are exposed to both vertical and lateral occlusal forces during mastication. Such anatomical and functional features may negatively influence the retention, stability, fracture resistance, and long-term prognosis of indirect restorations [2]. Therefore, the rehabilitation of endodontically treated premolars requires restorative strategies that preserve remaining tooth structure while providing adequate retention, strength, and marginal integrity.

Traditionally, severely damaged endodontically treated teeth have been restored using post-and-core systems followed by full-coverage crowns. Although such restorations may provide acceptable clinical outcomes, post placement often requires additional removal of radicular dentine, which may weaken the root structure and increase the risk of perforation or vertical root fracture. Moreover, conventional post-and-core crowns may involve multiple clinical stages and greater technique sensitivity. These limitations have encouraged the development of more conservative adhesive restorative alternatives [3].

The endocrown concept has emerged as a minimally invasive treatment option for restoring endodontically treated posterior teeth. Endocrowns are monolithic restorations that utilise the pulp chamber walls as a source of macromechanical retention while relying on adhesive resin cement for micromechanical and chemical bonding. Unlike conventional post-retained crowns, endocrowns preserve radicular dentine and simplify restorative procedures. With advances in adhesive dentistry and computer-aided design and computer-aided manufacturing (CAD/CAM) systems, endocrowns have become increasingly popular in contemporary restorative practice [4-6].

Although endocrowns were initially recommended mainly for molars because of their broader occlusal tables and larger pulp chambers, their use in premolars has attracted increasing attention. However, premolar teeth remain more demanding candidates because of a reduced bonding surface area and less favourable stress distribution. Consequently, findings obtained from molar studies cannot always be directly extrapolated to premolar restorations, highlighting the need for premolar-specific investigations [1,5,6].

Among the factors influencing the long-term success of indirect restorations, marginal adaptation is considered one of the most critical. A marginal discrepancy between the restoration and tooth preparation may expose the luting cement to oral fluids and bacteria, resulting in cement dissolution, bacterial microleakage, plaque accumulation, recurrent caries, periodontal irritation, marginal staining, and eventual restoration failure. Therefore, precise marginal integrity is essential for biological compatibility and restoration longevity [7,8].

The fit of CAD/CAM restorations is affected by multiple variables, including scanner precision, software design parameters, milling accuracy, cement spacer settings, preparation geometry, restoration thickness, cementation technique, and restorative material properties. Among these factors, material composition and microstructure are particularly important because they directly influence machinability, marginal edge stability, chipping tendency, crystallisation behaviour, and dimensional accuracy after processing [9].

Lithium disilicate ceramics are among the most widely used CAD/CAM materials for indirect adhesive restorations because they combine favourable aesthetic properties, high flexural strength, fracture toughness, and reliable bonding capability. IPS e.max CAD is one of the most established lithium disilicate CAD/CAM ceramics and has been extensively investigated in both laboratory and clinical studies. It is supplied in a partially crystallised state to facilitate milling and subsequently undergoes crystallisation firing to produce its final microstructure. After firing, IPS e.max CAD consists predominantly of elongated interlocking lithium disilicate crystals embedded within a glassy matrix. This crystalline architecture contributes to crack deflection, improved strength, and favourable optical properties [10,11].

Amber Mill is a newer-generation lithium disilicate CAD/CAM ceramic designed to provide controllable translucency through prescribed firing protocols. Published characterisation studies have demonstrated firing-dependent changes in its microstructure and optical behaviour and have also shown that contemporary lithia-based CAD/CAM ceramics differ in elemental composition, surface morphology, flexural strength and optical properties [12,13]. These material-specific differences may influence machinability, marginal edge integrity and dimensional behaviour after crystallisation.

Despite belonging to the same ceramic family, IPS e.max CAD and Amber Mill should not be considered identical materials. Differences in industrial processing, thermal behaviour, crystal growth kinetics, pigment systems, and final microstructure may influence their marginal adaptation and clinical performance. Therefore, direct comparison between these two materials is clinically relevant, particularly when precision fit is considered a treatment priority [11-13].

X-ray diffraction (XRD) and scanning electron microscopy (SEM) provide complementary information for interpreting such material-dependent behaviour. XRD identifies the crystalline phases present after heat treatment, whereas SEM permits direct assessment of crystal dimensions, crystal distribution and machining-related edge defects. Integrating these analyses with marginal-gap measurements may therefore help distinguish whether an observed fit difference is accompanied by a different phase constitution, crystal morphology or marginal damage pattern [12,13].

Another important variable affecting endocrown performance is preparation depth. Intracoronal extension into the pulp chamber may increase the internal bonding surface area, improve seating guidance, enhance anti-rotational resistance, and contribute to better restoration stability. Conversely, excessive preparation depth may sacrifice sound dentine and weaken the remaining tooth structure. Determining the effect of preparation depth on marginal adaptation is therefore essential for balancing conservative preparation principles with restorative success [2,14].

Evidence directly relevant to the present comparison remains fragmented. Rocca et al. [2] evaluated IPS e.max CAD endocrowns in premolars with 2- and 4-mm endo-core lengths and reported comparable post-fatigue marginal integrity for both endocrown designs. Nassar [15] evaluated Amber Mill endocrowns in maxillary molars using a twelve-point stereomicroscopic protocol and found clinically acceptable marginal gaps after cementation and thermocycling. Kassem et al. [16] directly compared IPS e.max CAD and Amber Mill endocrowns, but focused on fracture resistance and found no significant difference between those two materials.

Taken together, these studies do not resolve the combined material-depth effect on circumferential marginal adaptation in maxillary premolar endocrowns and do not explain whether material-dependent fit is accompanied by differences in crystalline phase composition, crystal morphology or marginal machining defects. The present study therefore integrates two clinically used lithium disilicate systems, two intracoronal preparation depths, twelve-point marginal mapping, XRD phase analysis and SEM microstructural assessment within one comparative design.

The present in vitro study was therefore designed to evaluate the effect of two lithium disilicate CAD/CAM restorative materials, IPS e.max CAD and Amber Mill, and two intracoronal preparation depths (2 mm and 4 mm) on the crystalline phase composition, SEM microstructure, marginal machining defects and marginal adaptation of endocrown restorations fabricated for endodontically treated maxillary first premolars.

Problem Statement

The restoration of endodontically treated maxillary premolars remains clinically challenging because these teeth often present with reduced structural integrity, limited coronal tissue, smaller pulp chambers, and unfavourable biomechanical loading. Although endocrowns offer a conservative restorative option, their long-term success depends greatly on accurate marginal adaptation.

Poor marginal fit may lead to luting cement dissolution, bacterial leakage, recurrent caries, marginal staining, periodontal inflammation, and restoration failure. Marginal adaptation may be influenced by restorative material properties and preparation design.

IPS e.max CAD is a well-established lithium disilicate ceramic, whereas Amber Mill is a newer-generation lithium disilicate material introduced with modified firing and translucency protocols. However, limited evidence exists comparing the marginal adaptation of these two materials in premolar endocrowns, and direct evidence linking their XRD phase profiles and SEM crystal morphology to marginal machining defects is scarce. Furthermore, the influence of preparation depth on marginal fit and marginal edge quality remains unclear.

Therefore, uncertainty remains regarding the most favourable combination of restorative material and preparation depth for achieving optimal marginal adaptation and whether differences in ceramic microstructure and machining-related marginal damage help explain the observed fit.

Aim of the Study

To evaluate the influence of two CAD/CAM lithium disilicate restorative materials (IPS e.max CAD and Amber Mill) and two intracoronal preparation depths (2 mm and 4 mm) on ceramic microstructure, marginal machining defects and the marginal adaptation of endocrown restorations fabricated for endodontically treated maxillary first premolars.

Objectives of the Study

General Objective

To compare the microstructure and marginal adaptation of maxillary premolar endocrowns fabricated from IPS e.max CAD and Amber Mill at different preparation depths.

Specific Objectives

1.To compare the marginal adaptation of IPS e.max CAD and Amber Mill endocrowns at 2-mm and 4-mm intracoronal preparation depths.

2.To evaluate the effect of increasing intracoronal preparation depth from 2 mm to 4 mm on marginal adaptation and identify the best-performing material-depth combination.

3.To characterise and compare XRD-detected crystalline phase abundance and SEM crystal morphology between the tested materials and preparation depths.

4.To compare SEM-detected marginal machining defects among the experimental groups and interpret them alongside circumferential marginal-gap values and clinical acceptability.

Null Hypotheses

1.There is no significant difference in marginal adaptation between IPS e.max CAD and Amber Mill endocrowns.

2.There is no significant effect of intracoronal preparation depth, or material × depth interaction, on marginal adaptation.

3.There are no significant differences in XRD-detected crystalline phase abundance or SEM crystal morphology according to restorative material, preparation depth or their interaction.

4.There are no significant differences in SEM-detected marginal machining defects according to restorative material, preparation depth or their interaction.

Materials and Methods

This in vitro study investigated the effect of restorative material and intracoronal preparation depth on the ceramic microstructure, marginal machining defects and marginal adaptation of endocrown restorations fabricated for endodontically treated maxillary first premolars. Twenty-eight extracted sound premolars were selected, cleaned, standardised, mounted in acrylic resin and randomly allocated into four equal groups (n = 7): A1 (IPS e.max CAD, 2 mm), A2 (Amber Mill, 2 mm), B1 (IPS e.max CAD, 4 mm), and B2 (Amber Mill, 4 mm). The 2- and 4-mm depths were selected because both endo-core lengths have previously been evaluated in IPS e.max CAD premolar endocrowns [2]. The two ceramics were selected because IPS e.max CAD and Amber Mill had previously been directly compared in endocrown fracture testing [16], whereas their circumferential marginal adaptation and microstructural characteristics across both depths had not been examined in the same premolar model.

All specimens received standardised root canal treatment followed by butt-joint endocrown preparation with 8–10° axial divergence. Digital impressions were obtained using a laboratory scanner. Restorations were designed with standardised spacer settings and milled according to the manufacturers' recommendations. The internal surfaces were etched with hydrofluoric acid, silanised, and cemented using dual-cure resin cement.

Following cementation, all specimens underwent thermocycling for 1,000 cycles between 5°C and 55°C, with a dwell time of 30 seconds. Marginal adaptation was assessed using a stereomicroscope at ×80 magnification. A twelve-point circumferential protocol comprising three equidistant points on each of the buccal, palatal, mesial and distal surfaces was used, consistent with the measurement distribution previously reported for Amber Mill endocrowns [15]. The mean of the twelve readings represented the marginal-gap value for each specimen. XRD was used to identify and quantify the relative abundance of lithium disilicate ($Li_2Si_2O_5$), lithium phosphate (Li_3PO_4), cristobalite and quartz among the detected crystalline phases. Calibrated SEM micrographs were analysed for crystal length, crystal width, aspect ratio and crystal density per 100 µm². The restoration margins were also examined by SEM to quantify marginal chips per millimetre, maximum chip depth and the percentage of defective marginal area.

Statistical analysis included Shapiro-Wilk normality testing and Levene's test for homogeneity of variance. One-way ANOVA followed by Tukey post hoc testing was used for overall group comparisons of the marginal gap. Two-way ANOVA was used to evaluate the main effects of restorative material and preparation depth and their interaction on marginal gap, XRD phase abundance and SEM outcomes. Effect size was expressed as eta-squared for the one-way analysis. Statistical significance was set at $p < 0.05$.

Figure 1. Representative of Amber Mill and IPS e.max CAD endocrown restorations.

Table 1. Experimental groups

Group	Material	Depth	n
A1	IPS e.max CAD	2 mm	7
A2	Amber Mill	2 mm	7

Group	Material	Depth	n
B1	IPS e.max CAD	4 mm	7
B2	Amber Mill	4 mm	7

Table 2. Twelve-point circumferential mapping protocol

Surface	Points
Buccal	B1, B2, B3
Palatal	P1, P2, P3
Mesial	M1, M2, M3
Distal	D1, D2, D3

Results

All groups demonstrated mean marginal-gap values below the commonly cited 120-µm clinical threshold [17]. Group B2 showed the lowest mean marginal discrepancy, whereas Group A1 had the highest value. One-way ANOVA confirmed significant overall intergroup differences ($p < 0.001$). Two-way ANOVA identified significant material and preparation-depth effects, with no material-by-depth interaction.

Table 3. Descriptive statistics for marginal gap values

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Group	Mean (µm)	SD	Min	Max	95% CI
A1	74.6	7.9	63.4	88.1	67.3–81.9
A2	66.8	6.8	57.3	79.0	60.5–73.1
B1	61.2	6.1	52.5	71.8	55.6–66.8
B2	52.8	5.7	44.9	64.0	47.5–58.1

Table 4. Shapiro–Wilk normality test

Group	W	p-value	Interpretation
A1	0.961	0.821	Normal
A2	0.955	0.744	Normal
B1	0.948	0.671	Normal
B2	0.963	0.846	Normal

Table 5. Levene's test for homogeneity of variance

Statistic	df1	df2	p-value	Interpretation
1.284	3	24	0.302	Equal variances assumed

Table 6. One-way analysis of variance

Source	SS	df	MS	F	p-value
Between groups	1773.73	3	591.24	13.26	<0.001
Within groups	1070.10	24	44.59	–	–
Total	2843.83	27	–	–	–

Table 7. Two-way analysis of variance for marginal gap values

Source	SS	df	MS	F	p-value
Material	459.27	1	459.27	10.30	0.004
Preparation depth	1313.83	1	1313.83	29.47	<0.001
Material × depth	0.63	1	0.63	0.01	0.906
Error	1070.10	24	44.59	–	–

Table 8. Tukey post hoc pairwise comparisons

Comparison	Mean difference (µm)	p-value	Result
A1 vs A2	7.8	0.156	Not significant
A1 vs B1	13.4	0.005	Significant
A1 vs B2	21.8	<0.001	Significant
A2 vs B1	5.6	0.416	Not significant
A2 vs B2	14.0	0.003	Significant

Comparison	Mean difference (µm)	p-value	Result
B1 vs B2	8.4	0.114	Not significant

Table 9. Ranking of experimental groups according to marginal adaptation

Rank	Group	Interpretation
1	B2	Lowest mean marginal gap
2	B1	Second-lowest mean marginal gap
3	A2	Third-lowest mean marginal gap
4	A1	Highest mean marginal gap

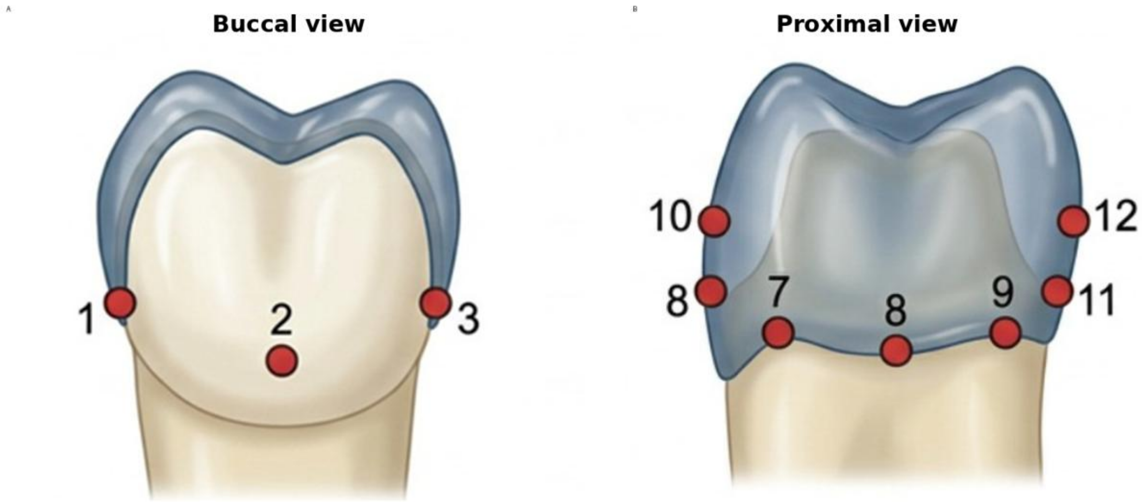

Figure 2. Twelve-point circumferential measurement sites from buccal and proximal views.

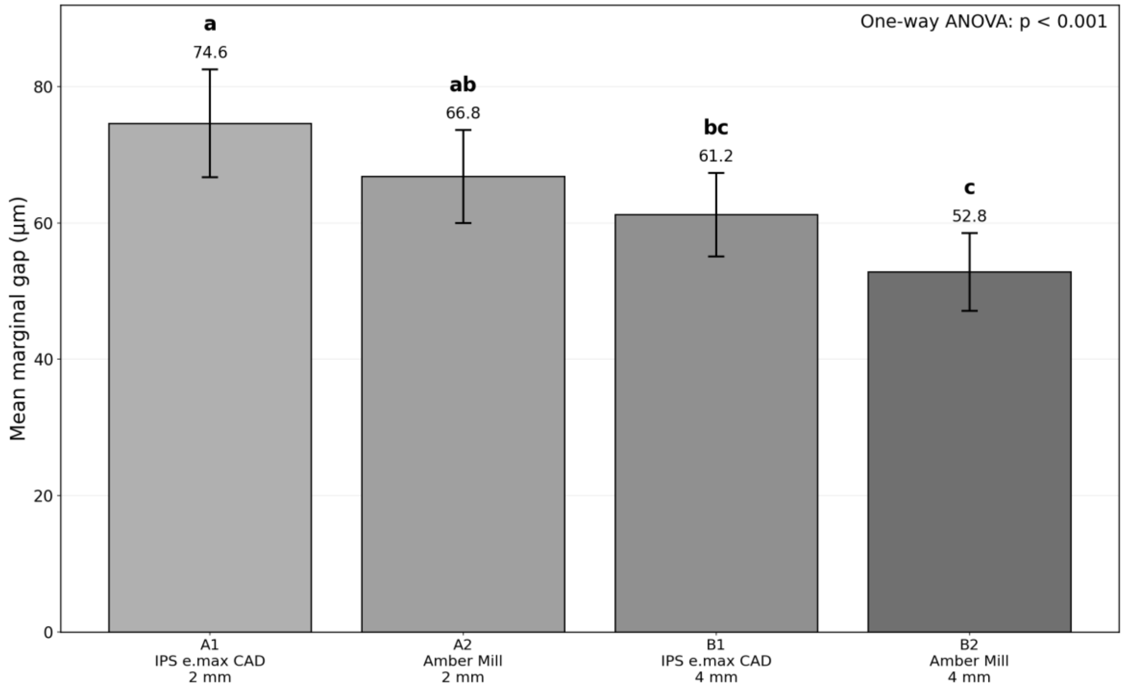

Figure 3. Mean marginal gap values by experimental group. Error bars represent standard deviations. Groups that do not share a letter differ significantly according to Tukey post hoc testing ($p < 0.05$).

Table 10. Clinical interpretation of marginal gap values

Group	Mean gap	Clinical interpretation
A1	74.6 µm	Within the 120-µm threshold
A2	66.8 µm	Within the 120-µm threshold
B1	61.2 µm	Within the 120-µm threshold
B2	52.8 µm	Within the 120-µm threshold; lowest mean

Increasing intracoronal preparation depth from 2 mm to 4 mm produced a significant overall reduction in marginal gap ($p < 0.001$). Amber Mill also showed a significantly lower overall marginal gap than IPS e.max CAD when the two depths were considered together ($p = 0.004$), although the material-by-depth interaction was not significant ($p = 0.906$) and the within-depth Tukey contrasts were not all statistically significant.

X-ray Diffraction Findings

Lithium disilicate was the predominant detected crystalline phase in all four groups. IPS e.max CAD showed a higher relative lithium disilicate abundance, whereas Amber Mill showed higher relative abundances of lithium phosphate, cristobalite and quartz. Two-way ANOVA demonstrated a significant material effect for every detected phase (all $p < 0.001$), while preparation depth and the material-by-depth interaction were not significant. The percentages represent relative abundance among the detected crystalline phases rather than the total crystalline fraction of the glass-ceramic.

Table 11. Relative abundance of crystalline phases detected by XRD (%)

Group	Material and depth	$Li_2Si_2O_5$	Li_3PO_4	Cristobalite	Quartz
A1	IPS e.max CAD, 2 mm	71.2 ± 1.9	14.8 ± 1.0	9.1 ± 0.7	4.9 ± 0.4
A2	Amber Mill, 2 mm	56.4 ± 2.2	22.1 ± 1.3	15.0 ± 1.1	6.5 ± 0.6
B1	IPS e.max CAD, 4 mm	70.6 ± 2.0	15.1 ± 1.1	9.4 ± 0.8	4.9 ± 0.5
B2	Amber Mill, 4 mm	55.9 ± 2.3	22.4 ± 1.2	15.4 ± 1.0	6.3 ± 0.5

Table 12. Two-way ANOVA p-values for XRD phase abundance

Outcome	Material	Depth	Material × depth
$Li_2Si_2O_5$	<0.001	0.496	0.950
Li_3PO_4	<0.001	0.499	1.000
Cristobalite	<0.001	0.321	0.886
Quartz	<0.001	0.605	0.605

Scanning Electron Microscopy: Crystal Morphology

SEM measurements demonstrated material-dependent crystal morphology. IPS e.max CAD exhibited longer, wider and more elongated crystals, whereas Amber Mill had a substantially higher crystal density with shorter and narrower crystals. Material effects were significant for all four measurements (all $p < 0.001$). Preparation depth and the material-by-depth interaction were not significant.

Table 13. SEM measurements of lithium disilicate crystal morphology

Group	Crystal length (µm)	Crystal width (µm)	Aspect ratio	Density per 100 µm²
A1	0.93 ± 0.12	0.24 ± 0.04	3.9 ± 0.5	188 ± 20
A2	0.31 ± 0.04	0.14 ± 0.02	2.2 ± 0.3	329 ± 29
B1	0.91 ± 0.11	0.23 ± 0.04	4.0 ± 0.5	191 ± 18
B2	0.30 ± 0.04	0.14 ± 0.02	2.1 ± 0.3	334 ± 31

Table 14. Two-way ANOVA p-values for SEM crystal morphology

Outcome	Material	Depth	Material × depth
Crystal length	<0.001	0.649	0.879
Crystal width	<0.001	0.679	0.679
Aspect ratio	<0.001	1.000	0.527
Crystal density	<0.001	0.677	0.917

Table 15. SEM measurements of marginal machining defects

Group	Marginal chips per mm	Maximum chip depth (µm)	Defective marginal area (%)
A1	6.4 ± 1.2	20.5 ± 3.6	2.9 ± 0.5
A2	3.9 ± 0.9	13.2 ± 2.7	1.7 ± 0.4

Group	Marginal chips per mm	Maximum chip depth (µm)	Defective marginal area (%)
B1	5.5 ± 1.0	17.4 ± 3.1	2.4 ± 0.5
B2	3.0 ± 0.7	10.4 ± 2.2	1.2 ± 0.3

Table 16. Two-way ANOVA p-values for SEM marginal-defect outcomes

Outcome	Material	Depth	Material × depth
Marginal chips per mm	<0.001	0.021	1.000
Maximum chip depth	<0.001	0.014	0.894
Defective marginal area	<0.001	0.005	1.000

Discussion

The present study evaluated the influence of restorative material type and intracoronal preparation depth on crystalline phase composition, SEM microstructure, marginal machining defects and the circumferential marginal adaptation of endocrown restorations fabricated for endodontically treated maxillary first premolars. Significant material and depth effects were observed for the marginal gap, while XRD and SEM demonstrated marked material-dependent differences in phase abundance and crystal morphology. Group B2 (Amber Mill, 4 mm) demonstrated the lowest mean marginal gap and the lowest marginal-defect values, whereas Group A1 (IPS e.max CAD, 2 mm) exhibited the highest values. Importantly, all tested groups remained below the commonly cited 120-µm threshold. These findings indicate that restorative material and preparation depth influence marginal behaviour through partly distinct mechanisms: material was associated with both bulk microstructure and edge integrity, whereas depth influenced seating and marginal damage without measurably altering the bulk phase or crystal morphology.

Marginal adaptation is widely considered one of the most critical determinants of long-term restorative success. Inadequate marginal fit may result in luting cement dissolution, bacterial microleakage, plaque accumulation, recurrent caries, marginal staining, periodontal irritation, and eventual restoration failure [7,18]. Therefore, the lower marginal discrepancy observed in the present study may be clinically advantageous, particularly in premolar teeth restored with adhesive protocols, where long-term sealing is essential.

A principal finding of the present study was the lower overall marginal gap demonstrated by Amber Mill compared with IPS e.max CAD. The Amber Mill groups also showed lower mean values at both preparation depths, although the individual within-depth Tukey comparisons were not all statistically significant. The factorial analysis is therefore the more appropriate basis for interpretation: material had a significant main effect, while the material-by-depth interaction was not significant. Although both materials belong to the lithium disilicate CAD/CAM ceramic family, they should not be regarded as identical restorative systems. Differences in chemical formulation, crystal nucleation kinetics, crystal size distribution, glass-to-crystal ratio and post-crystallisation dimensional behaviour may contribute to the observed material effect.

IPS e.max CAD is supplied in a partially crystallised state that facilitates milling and is subsequently converted to a definitive lithium disilicate microstructure after crystallisation firing. In the present XRD analysis, IPS e.max CAD showed a higher relative lithium disilicate contribution. SEM also demonstrated longer, wider and more elongated crystals, with aspect ratios close to 4.0. This interlocking morphology is consistent with the established crack-deflection mechanism of lithium disilicate ceramics, but the SEM edge analysis showed more marginal chips and deeper defects than Amber Mill under the tested milling and preparation workflow. The presence of a strong bulk microstructure therefore does not necessarily prevent local machining damage at thin restoration margins [10,13].

Amber Mill, by contrast, exhibited a finer and denser crystal distribution. Its crystals were approximately one-third the length of those measured in IPS e.max CAD, while crystal density exceeded 329 crystals per 100 µm² in both depth groups. XRD showed a lower relative lithium disilicate contribution and higher relative contributions from lithium phosphate, cristobalite and quartz. These compositional percentages describe the distribution among the detected crystalline phases and should not be interpreted as representing the total crystalline fraction. The finer, more densely distributed morphology may have provided a more uniform response to milling at the restoration edge, which is compatible with the lower chip frequency, chip depth and defective marginal area observed in Amber Mill. This explanation remains an association rather than proof of a direct causal mechanism [12,13].

The absence of significant depth effects on XRD phase abundance and SEM crystal morphology was expected because intracoronal depth changes restoration geometry rather than the manufacturer-controlled bulk ceramic composition and crystallisation process. In contrast, depth significantly affected all SEM marginal-defect outcomes. A deeper preparation may provide a more stable insertion path and reduce local interference during seating, thereby limiting stress concentration and edge contact at the margin. The parallel reduction in marginal gap and edge defects at 4 mm supports a geometry-related improvement in seating, although the present design cannot establish which step of the digital, milling or cementation workflow produced that effect.

The present findings complement the direct material comparison reported by Kassem et al. [16], who recorded mean fracture loads of 1483.76 ± 150.34 N for IPS e.max CAD endocrowns and 1430.11 ± 100.39 N for Amber Mill endocrowns, with no significant difference between the two materials. Although fracture resistance and marginal adaptation are distinct outcomes, the comparison indicates that mechanical similarity does not preclude material-dependent differences in seating accuracy. Accordingly, the lower marginal gaps observed for Amber

Mill in the present study should be interpreted as an adaptation advantage under the tested workflow rather than evidence of overall material superiority.

Nevertheless, it should be emphasised that improved marginal adaptation alone does not necessarily indicate complete material superiority. IPS e.max CAD remains one of the most extensively researched and clinically validated lithium disilicate systems, with documented success in crowns, veneers, overlays, and endocrowns. Therefore, clinical material selection should consider multiple variables, including strength, fatigue resistance, translucency, wear behaviour, bonding performance, and long-term survival, in addition to marginal fit [6,11].

Another important finding of the present study was the significant improvement in marginal adaptation associated with increasing preparation depth from 2 mm to 4 mm for both tested materials. The 4-mm groups also exhibited fewer marginal chips, a smaller maximum chip depth and a lower defective marginal area. Deeper preparation may provide a longer path of insertion, improved internal guidance, greater resistance to rotational displacement and more favourable cement escape during restoration seating. However, the non-significant interaction indicates that the depth effect was broadly similar for both ceramics.

Rocca et al. [2] evaluated IPS e.max CAD premolar endocrowns with 2- and 4-mm endo-cores and reported comparable percentages of closed margins between the two endocrown designs and conventional crowns after fatigue loading. The present results extend that evidence by demonstrating lower absolute marginal-gap values at 4 mm than at 2 mm for both tested ceramics. Because Rocca et al. assessed marginal integrity and fatigue survival rather than twelve-point circumferential gap magnitude, the findings are complementary rather than directly equivalent.

From a conservative dentistry perspective, however, preparation depth must be balanced against preservation of remaining tooth structure. While deeper intracoronal extension may improve adaptation, excessive dentine removal may weaken already compromised premolars. This issue is particularly important in maxillary premolars because of their narrow cervical dimensions and reduced residual wall thickness. Consequently, clinicians should aim to achieve sufficient internal depth for retention and seating while preserving structurally important dentine whenever possible.

The present study also provides clinically relevant evidence by focusing specifically on maxillary first premolars. Many previous endocrown investigations have concentrated primarily on molars because of their broader occlusal tables and larger pulp chambers. Premolars represent a more demanding restorative situation because of their smaller chamber volume, steeper cusp inclines and less favourable stress distribution. Available evidence therefore supports tooth-specific evaluation rather than direct extrapolation from molar models [1,2].

The twelve-point circumferential measurement protocol employed in the present study is a methodological strength, although the use of three points per surface has previously been reported for Amber Mill endocrowns by Nassar [15]. In that study, digitally fabricated Amber Mill endocrowns showed a mean marginal gap of 49.42 ± 5.51 µm before cementation and 84.38 ± 4.34 µm after cementation and 5,000 thermal cycles. The Amber Mill groups in the present study also remained within clinically acceptable limits, with mean values of 66.8 ± 6.8 µm at 2 mm and 52.8 ± 5.7 µm at 4 mm after thermocycling. Differences between the studies may reflect tooth type, preparation geometry, scanning workflow, magnification, cementation protocol, and ageing regimen.

All tested groups demonstrated marginal-gap values below commonly accepted clinical thresholds, indicating that both IPS e.max CAD and Amber Mill may be considered clinically acceptable restorative materials under the investigated conditions [5,6]. However, a lower marginal discrepancy may still be preferable because smaller gaps may reduce long-term cement degradation and bacterial penetration.

The strengths of the present study include the comparison of two contemporary lithium disilicate CAD/CAM ceramics, evaluation of two clinically relevant preparation depths, use of a premolar-specific model, thermocycling ageing, comprehensive circumferential marginal assessment, XRD phase characterisation and quantitative SEM analysis of both crystal morphology and marginal machining defects. The principal contribution is the integration of material, depth, microstructure and marginal behaviour within one experimental model, an experimental combination not addressed by the directly relevant studies [2,15,16].

Several limitations should be acknowledged. This investigation was conducted under in vitro conditions and therefore could not fully reproduce oral variables such as saliva, masticatory fatigue, prolonged thermal fluctuation, parafunctional habits and patient-related variability. Although XRD and SEM identified material-dependent features, these analyses demonstrate association and do not establish that any specific phase or crystal dimension directly caused the observed marginal gap. Only marginal adaptation and microstructural or edge-defect outcomes were evaluated; fracture resistance, fatigue survival, internal fit, bond durability and wear were not simultaneously assessed. In addition, only two restorative materials and two preparation depths were included. The relative phase percentages reported by XRD represent the distribution among detected crystalline phases rather than the absolute crystallinity of the whole glass-ceramic.

Future studies should evaluate the long-term thermomechanical performance of Amber Mill and IPS e.max CAD endocrowns under cyclic fatigue loading and should relate specimen-level marginal gaps to quantified SEM edge defects. Three-dimensional assessment using micro-computed tomography is recommended to examine both internal and marginal adaptation. Further work using Rietveld refinement, larger independent XRD samples and repeated SEM fields would strengthen phase and morphology quantification. Prospective clinical trials are also required to validate the long-term behaviour of premolar endocrowns fabricated from contemporary lithium disilicate CAD/CAM materials.

Within the limitations of the present study, both restorative material and preparation depth influenced the marginal adaptation of premolar endocrown restorations. The two materials showed distinct phase profiles and crystal morphologies, and Amber Mill exhibited fewer marginal machining defects and a lower overall marginal gap than IPS e.max CAD. A 4-mm intracoronal extension improved seating and marginal edge quality compared with a 2-mm depth but did not alter the bulk phase composition or crystal morphology. These findings may assist clinicians and researchers in interpreting marginal fit as the combined result of material-specific machinability and preparation geometry rather than material strength alone.

Conclusions

Based on the findings of the present in vitro study, the following conclusions were drawn:

1.Restorative material type and intracoronal preparation depth significantly influenced marginal adaptation, with no significant material-by-depth interaction.

2.Amber Mill showed a lower overall marginal gap and fewer SEM-detected marginal defects than IPS e.max CAD, while the 4-mm preparation improved marginal fit and edge quality in both materials.

3.Amber Mill at 4 mm produced the lowest mean marginal gap and marginal-defect values, whereas IPS e.max CAD at 2 mm produced the highest; all group means remained below 120 µm.

4.XRD and SEM confirmed distinct material-dependent microstructures: IPS e.max CAD showed a higher relative lithium disilicate abundance and longer, more elongated crystals, whereas Amber Mill showed a denser distribution of shorter crystals and higher relative abundances of the detected minor phases.

5.Overall, material-specific microstructure and machinability, together with preparation geometry, contributed to the marginal behaviour of CAD/CAM endocrowns under the tested in vitro conditions.

Clinical Relevance

The findings suggest that both IPS e.max CAD and Amber Mill can produce premolar endocrowns with mean marginal gaps below 120 µm when appropriate digital and adhesive protocols are followed. Amber Mill showed a finer and denser crystal morphology, fewer marginal machining defects and a lower overall marginal gap. A 4-mm intracoronal depth improved seating and edge quality in both materials. These laboratory findings support attention to both material-specific machinability and preparation geometry when planning conservative endocrown restorations.

Limitations

This study was conducted under in vitro conditions and therefore could not fully replicate the oral environment, including masticatory fatigue, saliva, pH fluctuation and patient-related variables. XRD and SEM findings demonstrate associations with material type but do not prove a direct causal relationship with marginal gap. Fracture resistance, fatigue survival, bond durability, wear and three-dimensional internal fit were not assessed. Only two restorative materials and two preparation depths were investigated, and the reported XRD percentages represent relative abundance among detected phases rather than absolute whole-material crystallinity.

Recommendations for Future Research

Future studies should evaluate the long-term thermomechanical behaviour of Amber Mill and IPS e.max CAD endocrowns under cyclic fatigue loading, correlate specimen-level SEM edge defects with marginal-gap measurements, and use micro-computed tomography for three-dimensional internal and marginal fit analysis. More extensive XRD quantification and prospective clinical trials are required to confirm the long-term clinical relevance of the material-dependent microstructural findings.

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