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Effect of Preparation Depth on the Marginal and Internal Adaptation of Computer-aided Design/Computer-assisted Manufacture Endocrowns

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Clinical Relevance

Computer-aided design/computer-assisted manufacture endocrown restorations have a clinically acceptable marginal accuracy; however, increasing the intraradicular extension of the crown may have a reverse effect on the marginal and internal fit of the restorations.

SUMMARY

The aim of the study was to evaluate the effect of preparation depth and intraradicular extension on the marginal and internal adaptation of computer-aided design/computer-assisted manufacture (CAD/CAM) endocrown restorations. Standardized preparations were made in resin endodontic tooth models (Nissin Dental), with an intracoronal preparation depth of 2 mm (group H2), with extra 1- (group H3) or 2-mm (group H4) intraradicular extensions in the root canals (n=12). Vita Enamic polymer-infiltrated ceramic-network material endocrowns were fabricated using the CEREC AC CAD/CAM system and were seated on the prepared teeth. Specimens were evaluated by microtomography. Horizontal and vertical tomographic sections were recorded and reconstructed by using the CTSkan software (TView v1.1, Skyscan).The surface/void volume (S/V) in the region of interest was calculated. Marginal gap (MG), absolute marginal discrepancy (MD), and internal marginal gap were measured at various measuring locations and calculated in microscale (µm). Marginal and internal discrepancy data (µm) were analyzed with nonparametric Kruskal-Wallis analysis of variance by ranks with Dunn's post hoc, whereas S/V data were analyzed by one-way analysis of variance and Bonferroni multiple comparisons (α=0.05). Significant differences were found in MG, MD, and internal gap width values between the groups, with H2 showing the lowest values from all groups. S/V calculations presented significant differences between H2 and the other two groups (H3 and H4) tested, with H2 again showing the lowest values. Increasing the intraradicular extension of endocrown

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restorations increased the marginal and internal gap of endocrown restorations.

INTRODUCTION

Endocrowns are considered alternative restorations for severely damaged endodontically treated posterior teeth.[1-3] Initially proposed by Pissis,[4] they were then described by Bindl and Mörmann[5] as adhesive restorations consisting of the entire core and crown as a single unit (ie, monobloc). Endocrowns strictly follow the rationale of minimally invasive preparations owing to a decay-oriented concept. They are anchored to the internal portion of the pulp chamber and on the cavity margins, thus obtaining macromechanical retention provided by the axial opposing pulpal walls and micro-retention/chemical bonding attained with the use of adhesive cementation.[6]

The precise dimensions of the central intrapulpal retention cavity are not clearly determined. Especially in cases of excessive loss of tooth structure, where only 1- to 2-mm of intact tooth structure above the dentinoenamel junction is left, the need for further intraradicular extension might be a prerequisite. The utilization of the available space inside the pulp chamber adds to the stability and retention of the restoration.[2] The deeper the pulp cavity and resulting intracoronal extension, the greater the surface area that can be utilized for adhesive retention and transmission of masticatory forces.[6]

Endocrown restoration is made available through computer-aided design/computer-aided manufacturing (CAD/CAM) technology, which provides the possibility for chairside design and fabrication. Despite the advantages of in-office CAD/CAM systems and software, there are limitations in the optical depth of field of the intraoral scanning camera.[7] This may lead to reduced impression capacity of the crown, pulp chamber, and part of the canal, with potential discrepancies in marginal fit and cavity adaptation of the restorations.

Marginal and internal adaptation of indirect restorations are both very important parameters that may affect the periodontal status and longevity of the restorations.[8] Increased marginal discrepancies are related to increased exposure of the luting material to the oral environment, leading to chemomechanical degradation of the cement and the adhesive interface between the tooth structure, luting agent, and esthetic indirect restoration.[9] Internal fit is another key factor related to the long-term stability of esthetic indirect restorations. The cement interface has been described as a crack initiation area.[10,11] Increased interfacial space and resin cement thickness may create increased polymerization shrinkage and interfacial stresses, resulting in decreased strength of the tooth-restoration interface.[10,12] A sufficient three-dimensional (3D) fit of the restoration has been considered mandatory to obtain maximum mechanical support of all-ceramic restorations from the tooth structure.[13] Intrapulpal extension of endocrowns may influence the retention and the adaptation of the restoration.[7] Presently, there are limited data available on the marginal internal adaptation[14] and no information about the effect of the intrapulpal extension on the fit of the endocrown restorations. Therefore, the intent of the present study was to evaluate the effect of cavity preparation depth and intraradicular extension on the marginal and internal fit and of resin-ceramic CAD/CAM endocrown restorations. The null hypothesis assumed that there is no statistically significant difference in marginal and internal fit between the different intraradicular preparation depths.

METHODS AND MATERIALS

Fabrication of the Master Models

Three acrylic resin first mandibular right molars (Endodontic Tooth Model) were used as the master die models for the three tested groups. All endodontic and restorative procedures were done on the same typodont model (model A12A-200, Nissin Dental, Kyoto, Japan), so teeth were positioned in the same position alternately. One experienced operator made all preparations, took the optical impressions, and designed the restorations.

Endodontic Procedures

An access cavity was prepared on the mounted tooth models with a diamond-coated stainless steel bur, and standardized canal enlargement was performed with an engine-driven rotary NiTi system (ProTaper, Dentsply Maillefer, Ballaigues, Switzerland) using a crown-down technique. Root canals were obturated with a thermo-plasticized gutta percha (Calamus Dual, Dentsply Maillefer, Woodinville, WA, USA). The superior aspect of the gutta-percha material was removed to 3 mm below the orifice of each canal, and then flowable resin composite (Filtek Z350XT flowable, 3M ESPE, St. Paul, MN, USA) was used to fill the canals up to the level of the pulp chamber.

Tooth Preparation for Endocrown

The occlusal portion of the three tooth master die models was trimmed using a model trimmer (3/4 HP

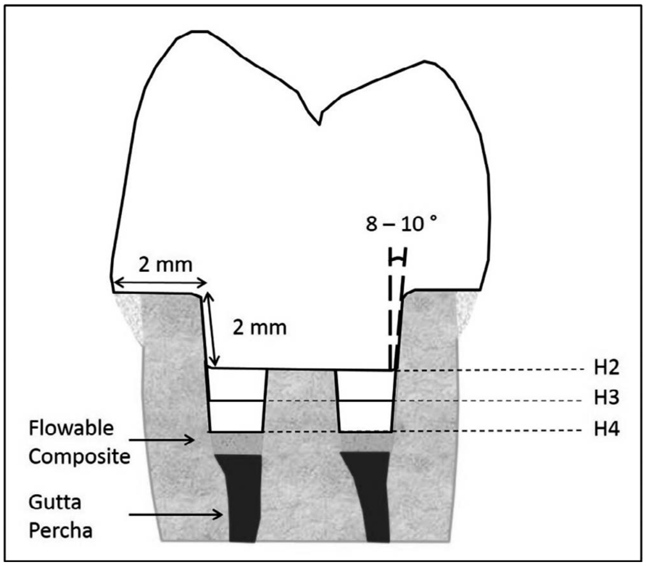

Figure 1. *Diagram of the three types of preparations. Intracoronal height of the preparation was 2.0 mm (group H2). Intacoronal height of 3 mm with an intraradicular extension of 1 mm (group H3) and a 2.0-mm intraradicular extension to reach a total intacoronal height of 4 mm (group H4).*

Wet Model Trimmer, Whip Mix Corporation, Louisville, KY, USA) to reach a standardized height of the internal axial walls of the pulp chamber of approximately 2.0 ± 0.2 mm as measured with a Digital Depth Micrometer (Mitutoyo, Aurora, IL, USA).

Cavity preparations were limited to removal of undercut areas of the pulp chamber and alignment of its internal axial walls with an internal taper of 8-10 degrees using a tapered diamond-coated stainless steel bur with a rounded end (G845KR, Edenta, Au St. Gallen, Switzerland) held perpendicular to the pulpal floor. All internal line angles were rounded and smoothed using the same type of bur. The axial walls were prepared from the pulpal side to provide for a standardized cavity wall thickness of 2.0 ± 0.2 mm measured with a digital caliper (Mitutoyo, Aurora, IL, USA).

In one master die model, the intracoronal height of the preparation was kept at 2.0 mm (group H2). A standardized intraradicular extension of 1 mm was performed in the second master die to reach a total intracoronal height of 3 mm (group H3) and a 2.0-mm intraradicular extension in the third master die to reach a total intracoronal height of 4 mm (group H4; Figure 1). The intraradicular extensions were done in the three canals of each master die using a tapered diamond-coated bur with a round edge (845KR, Edenta).

Endocrown Fabrication

Scanning and designing procedures were repeated for each restoration, resulting in the fabrication of 12 restorations for each group (n=12, according to pilot study results and power analysis). Teeth were air-dried for 10 seconds and evenly covered with antireflection powder (CEREC Optispray, Sirona, Bensheim, Germany). The scanning procedure was done in a standardized way using a digital scanner (CEREC Bluecam, Sirona) with the tip of the scanner always resting at the center of the occlusal surface of the distal adjacent tooth to maintain the same distance between the camera and the prepared tooth models in all the scans. Three scans of the prepared master die were taken for each restoration: one scan with the camera parallel to the occlusal surface and two scans at 30 degrees buccally and lingually to the long axis of the tooth, respectively.

After scanning, contrasting powder was removed using air-water spray for 20 seconds, and each master die sample was evaluated under a stereomicroscope attached to a digital camera (Zeiss, Oberkochen, Germany) for remnants of the contrasting powder, which had to be vigorously washed out by water and dried for complete removal. Endocrowns were designed using a software package (CEREC 3D, version 4.0, Sirona Dental Systems GmbH, Bensheim, Germany) to have similar occlusal anatomy, dimensions, and occluso-gingival height by using the biogeneric reference option in the software. The spacer thickness was set to 0 mm both at the margins and the internal fitting surface of the crowns. Endocrowns were fabricated from polymer-infiltrated ceramic network material (Vita Enamic, Vita Zahnfabrik, Bad Säckingen, Germany) using the CEREC AC system. Each crown was tried for fit on the master models.

Microtomography Testing and Statistics

Adaptation of the restorations was investigated by computerized x-ray microtomography (micro-XCT). A compact desktop system for nondestructive high-resolution x-ray microscopy and microtomography (1072 micro-CT, Skyscan, Kontich, Belgium) was used to obtain a 3D reconstruction of the inner microstucture of the object of interest (endocrown and master die) from 2D x-ray shadow projections. For all three different groups, the master die was positioned precisely within the x-ray beam into a special socket, and the restorations were seated individually, secured in place, checked for fit, and scanned. The scanner operated under the following conditions: W source, 100-KV accelerating voltage,

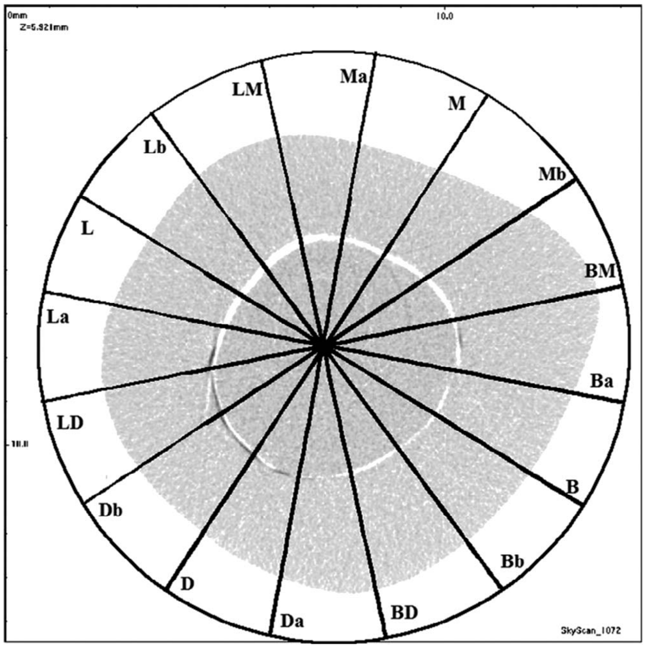

Figure 2. *Circle with eight diameters positioned equally onto a 2D sagittal image.*

98-μA beam current, 14.16-μm pixel size, 180° rotation at 0.45° step, 1.9-second exposure time per step, and 1-mm Al filter. Horizontal tomographic sections were recorded and reconstructed (2D and 3D) by using CT-analyzer software (CTan, Skyscan, Kontich, Belgium).

For the evaluation of the marginal fit, the marginal gap (MG) and the absolute marginal discrepancy (MD) were determined according to the criteria stated by Holmes and others.[15] Measurements of both MG and MD were made at 16 selected landmarks after computed reconstruction (TView version1.1, SkyScan) of eight vertical cuts (jpeg files) of the scanned specimens. For this reason, a circle was drawn with eight diameters equally distributed from each other, at the same image position of every scanned specimen. One diameter of the circle was directed from the middle of the buccal and the lingual surface, whereas another perpendicular to the latter was directed from the middle of the mesial and the distal surface. The center of the circle was placed over the midpoint of the mesio-distal and bucco-lingual diameter (Figure 2). Therefore, the number and the orientation of the slices were standardized for all specimens. Images produced were transferred to Photoshop CS2 digital image editing software (Adobe Systems Incorporated, San Jose, CA, USA) and measurements were performed under the same magnification using digital image editing software (Image J software, National Institute of Health, Bethesda, MD, USA), with a reduction ratio of the given size of the pixel of 14.16 μm (Figure 3a). For each specimen, 16 MG and 16 MD measurements were obtained. All values, either for overextended or underextended margins, were gathered as positive values (Figure 3b). For the analysis of the data, landmarks B, Ba, and Bb, L, La, and Lb, M, Ma, and Mb, and D, Da, and Db (Figure 2) were merged together as Bl, Ll, Ml, and Dl, respectively, due to their symmetric location.

Internal adaptation was calculated by measurements taken from nine internal landmarks on each obtained cross-section: two (C1 and C2) on the cervical seats (C), oriented in the middle of the cervical seat; four (A1, A2, A3, and A4), on the axial walls (A), 400 μm from the axio-cervical and the axio-

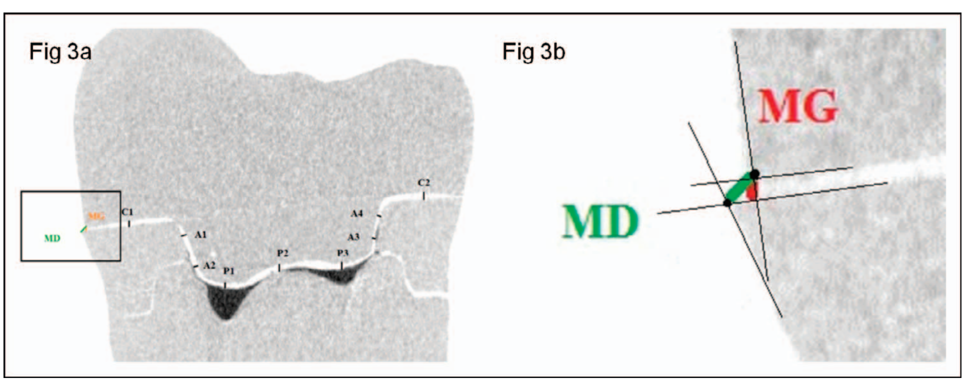

Figure 3. *(a) Vertical cut of a coping on the master die showing the measuring locations: MG; MD; cervical seat area C (C1, C2), at the midpoint of the cervical seat floor; axial wall A (A1, A4), 400 μm pulpal to the axio-cervical line angle; axial wall A (A2, A3), 400 μm occlusal to the axio-pulpal line angle; intrapulpal wall P (P1, P3), the deepest point above the orifice; intrapulpal wall P (P2), the top of the bulkiest intrapulpal floor area. (b) Closer view of the marginal area MD (the distance between contact point of the tangential lines between prepared and unprepared surface of the master die near to the margin and the contact point of the tangential lines between the inner and outer surface of the restoration near to the margin and MG (the distance of the vertical projection of the margin of the die to the inner surface of a hyperextended endocrown or the distance of the vertical projection of the margin of a hypoextended endocrown to the inner prepared surface of the die).*

Table 1: *Mean, SD, and Median Values of the Marginal and Internal Gaps (μm) at the Measured Points*

N	Measuring location	H2				H3				H4			
		Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%
192	MG	40.6 (4.1)	40.5^{aA}	28.9	49.3	48.9 (13.8)	43.9^{bA}	29.8	63.4	59.4 (9.6)	56.4^{cA}	43.7	70.5
192	MD	65.9 (12.1)	46.9^{aB}	33.3	80.5	76.2 (12.0)	61.8^{bB}	38.4	97.7	77.6 (5.9)	65.8^{bA}	47.2	97.5
192	C (C1, C2)	150.3 (48.2)	141.5^{aC}	117.6	179.3	169.5 (77.56)	155.2^{aC}	119.0	196.5	161.8 (45.7)	155.1^{aB}	126.9	197.4
384	A (A1, A2, A3, A4)	93.2 (45.7)	89.5^{aD}	59.5	125.9	113.7 (57.9)	104.1^{bD}	70.5	148.3	121.8 (79.7)	103.7^{bC}	79.7	146.2
288	P (P1, P2, P3)	129.6 (55.5)	122.6^{aC}	85.1	169.2	135.5 (59.5)	129.9^{abC}	99.2	162.1	152.3 (65.5)	150.4^{bB}	105.7	182.9

Within a row, the same lowercase superscript letters show mean values with no statistically significant difference ($p>0.05$). Within a column, the same uppercase superscript letters show mean values with no statistically significant difference ($p>0.05$).

pulpal lines angles, respectively; and three (P1, P2, and P3) on the intrapulpal wall (P), P1 and P3 oriented on the deepest area of the orifices and P2 oriented in the middle of the bulkiest area of the intrapulpal wall (Figure 3a). In total, 72 measurements were made for each specimen.

The surface/void volume ratio (S/V) in the region of interest (ROI) was calculated using special software (TView, Skyscan). The ROI was set 100 μm from the margin inside the cavity.

Statistical Analysis

Analysis of the data was performed regarding the preparation depth and the measured location. All statistical computations were carried out with the SigmaPlot (ver. 12.3) software package (Systat Software, Inc., San Jose, CA, USA). Saphiro-Wilk's test and Levene's test were performed to verify departures from basic assumptions about variance and normality. All marginal and internal discrepancy data (μm) were analyzed with nonparametric Kruskal-Wallis analysis of variance by ranks with Dunn's post hoc, because normality tests failed. S/V data were analyzed by one-way analysis of variance (ANOVA) and Bonferroni multiple comparisons. A 95% (α=0.05) level of significance was used for all comparisons.

RESULTS

A summary of the results of the descriptive statistical analysis of the marginal and internal discrepancies on the measured areas (MG, MD, C, A, and P) for all the groups is listed in Table 1.

Overall median MG widths of 40.5, 43.9, and 56.4 μm were revealed for H2, H3, and H4 preparation depth groups, respectively, all being significantly different ($p<0.001$). No significant difference was identified within any of the three groups tested in respect to the different groups of landmarks measured (Table 2).

The MD evaluation showed significantly lower ($p<0.001$) median gap values for H2 compared with H3 and H4 (Table 1). No significant difference existed between H3 and H4. Statistically significant differences were revealed in the various landmarks tested ($p=0.007$; Table 3). Within each preparation depth group, Ll, LD, and LM values were lower than the ones measured at the rest of the landmarks, with differences not being significant in all cases.

Endocrowns fabricated for the H2 group presented overextension or underextension of the margin in 30% of the measurements, whereas over- or underextended margins were identified in 26.25% and 25% of the measurements for H3 and H4 groups,

Table 2: *Mean, SD, and Median Values of the MG Evaluated in Different Landmarks*

N	Landmarks (LM)	H2				H3				H4			
		Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%
36	Bl (B, Ba, Bb)	42.6 (19.7)	35.2^{A}	25.4	57.5	55.1 (27.3)	49.1^{A}	31.7	84.6	60.3 (22.8)	56.4^{A}	49.3	66.5
36	Ll (L, La, Lb)	38.0 (18.3)	35.2^{A}	28.2	37.8	33.7 (8.7)	29.8^{A}	27.9	42.3	58.4 (43.3)	37.6^{A}	29.3	94.4
36	Ml (M, Ma, Mb)	42.9 (8.6)	38.7^{A}	40.3	49.3	44.8 (19.8)	43.3^{A}	25.4	64.7	80.52 (46.9)	81.9^{A}	35.2	126.1
36	Dl (D, Da, Db)	45.7 (8.3)	47.0^{A}	42.8	49.3	59.3 (21.4)	56.4^{A}	42.3	84.6	69.5 (40.5)	56.4^{A}	47.5	119.6
12	BD	53.2 (11.5)	49.8^{A}	44.6	63.6	62.3 (19.8)	56.6^{A}	45.8	81.7	75.3 (14.9)	75.2^{A}	63.8	86.9
12	LM	36.8 (12.9)	32.9^{A}	26.2	49.3	58.1 (36.7)	57.8^{A}	26.6	89.8	40.7 (9.1)	42.3^{A}	31.7	48.8
12	BM	29.2 (10.2)	23.3^{A}	21.2	40.2	31.1 (22.3)	35.2^{A}	10.4	50.0	59.4 (7.8)	57.2^{A}	53.1	66.9
12	LD	30.6 (7.8)	28.2^{A}	24.6	37.7	52.1 (11.8)	51.7^{A}	41.2	63.0	51.1 (7.7)	56.4^{A}	42.6	56.8

Within a column, the same uppercase superscript letters show mean values with no statistically significant difference ($p>0.05$).

Table 3: *Mean, SD, and Median Values of the Absolute MD Evaluated in Different Landmarks*

N	Landmark (LM)	H2				H3				H4			
		Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%	Mean (SD)	Median	25%	75%
36	BI (B, Ba, Bb)	42.2 (27.2)	35.2^{A}	25.4	57.5	113.5 (53.5)	99.6^{A}	58.1	159.0	71.9 (31.9)	65.8^{AB}	51.7	77.5
36	LI (L, La, Lb)	58.9 (43.3)	37.6^{A}	29.2	94.5	44.7 (41.9)	33.8^{B}	28.2	42.9	59.9 (39.3)	56.1^{A}	38.7	91.0
36	MI (M, Ma, Mb)	80.5 (46.9)	81.9^{B}	35.2	126.1	55.7 (36.5)	49.3^{AB}	29.9	65.0	91.6 (53.3)	79.7^{AB}	47.9	151.4
36	DI (D, Da, Db)	99.5 (80.5)	73.6^{B}	43.8	191.6	91.3 (49.54)	85.8^{AB}	43.3	146.6	71.9 (33.6)	47.5^{A}	47.0	85.5
12	BD	53.3 (11.5)	49.8^{AB}	44.6	63.6	106.2 (52.1)	92.7^{AB}	58.8	160.2	75.3 (14.9)	75.2^{AB}	63.8	86.9
12	LM	56.5 (41.3)	42.3^{AB}	28.2	91.8	66.6 (36.3)	63.4^{AB}	43.4	98.2	40.7 (9.0)	42.3^{A}	31.7	48.8
12	BM	63.2 (34.1)	73.0^{B}	29.4	92	75.9 (6.6)	75.9^{AB}	20.9	159.6	148.8 (35.7)	134.6^{B}	126.3	178.3
12	LD	30.6 (7.8)	28.2^{A}	24.6	37.7	52.1 (11.8)	51.7^{AB}	41.2	63.0	60.2 (16.7)	56.4^{AB}	49.6	72.7

Within a column, the same uppercase superscript letters show mean values with no statistically significant difference ($p>0.05$).

respectively (Table 4). Comparison of MG and MD values in each group revealed a significant difference in groups H2 and H3, with MD values being higher in both cases ($p<0.001$).

In the evaluation of internal gaps (Figure 3a), for the cervical seat measuring points (C1 and C2), there was no significant difference between the three tested groups ($p=0.258$). At the axial measuring locations (A1, A2, A3, and A4), group H2 exhibited significantly lower median gap width values compared with the other two groups H3 and H4 ($p<0.001$). The intrapulpal gap width measured at three points (P1, P2, and P3) was significantly wider for H4 compared with H2 ($p=0.011$). No significant difference was identified among groups H2 and H3 and among H3 and H4, respectively. Significant differences existed between the various measured positions within all groups, with median values measured in axial walls (A) being significantly lower than the ones measured in cervical seat (C) and the intrapulpal floor (P), but significantly higher than the gap width values measured at the marginal area (MG and MD), in all preparation groups ($p<0.001$; Table 1).

S/V calculation (Table 5) showed significant differences among the three groups. H4 showed higher mean values (46.99 ± 2.01) than H2 (39.33 ± 3.83) but not significantly different than H3 (44.69 ± 2.89; $p=0.005$).

Table 4: *Percentages of Over- and Underextended Restorations at the Marginal Area in Different Preparation Depths Groups*

Preparation type	N	Overextension, %	Underextension, %	Equal, %
H2	160	12.5	17.5	70
H3	160	13.75	12.5	73.75
H4	160	6.25	18.75	75

DISCUSSION

The aim of this study was to evaluate the marginal and internal fit of endocrown restorations with different intraradicular extension using micro-XCT. The null hypothesis assuming that there would be no significant difference between the groups tested should be rejected.

In the present study, micro-XCT, a nondestructive evaluation method, was used to investigate the marginal and internal fit of the endocrowns. In the literature, a variety of qualitative and quantitative and destructive and nondestructive methods for evaluating the marginal and the internal fit have been applied. Micro-XCT is an alternative technique for 3D evaluation of precementation space due to the ability to acquire 3D relationships between structures of different coefficients of absorption without sample sectioning or chemical fixation. It allows 2D and 3D investigation of the MG, the MD, and the internal fit within the range of a few micrometers at multiple sites and directions.[16-18] Disadvantages of the technique are radiation artifacts and the low capacity of discrimination in cases of insufficient radiographic contrast.[19,20] In the current study, to improve the contrast between the acrylic die and the resin-ceramic endocrowns, the evaluation procedure was done without cementation. Moreover, all restorations of each group were seated on the same

Table 5: *Mean, SD, and Median Values of the S/V Void Ratio*

Preparation type	S/V	
	N	Mean (SD)
H2	12	39.33 (3.83) ^{A}
H3	12	44.69 (2.89) ^{B}
H4	12	46.99 (2.01) ^{B}

Within a column, the same uppercase superscript letters show mean values with no statistically significant difference ($p>0.05$).

prepared die, keeping the conditions of the samples more standardized. Previous studies have concluded that micro-XCT can be a reliable method for further evaluation of the marginal and internal fit of indirect restorations.[16,18,20,21]

Marginal fit or misfit is defined as a combination of gap and extension errors. The MD is an angular combination of the MG and the over- or under-extension errors.[15] Therefore, in the present study, micro-XCT was used to evaluate the MG and the MD as well.

In this study, significant differences among the groups were identified in MG and MD values. Increase of preparation and intraradicullar extension of 1 and 2 mm in groups H3 and H4, respectively, inversely affected marginal fit of the restorations. There is much controversy in the literature regarding the clinical acceptable MG width. Many authors agree that marginal openings below 120 μm are clinically acceptable,[22-24] whereas a maximum gap width of 100 μm is advocated by other researchers.[25] In the present study, mean and median MG values for all tested groups could be considered within the clinically acceptable range.

Many researchers have criticized the marginal and internal fit of CAD/CAM restorations.[20,26] Continuing developments and improvements in CAD/CAM technology have led to marginal adaptation competing with that of the laboratory-fabricated restorations.[27] The majority of the studies evaluating marginal or internal adaptation of esthetic restorations fabricated from the CAD/CAM systems have focused on onlay or crown restorations made of composite or various all-ceramic systems. Therefore, no direct comparisons of the present results can be made. Moreover, comparisons with studies reporting 2D measurements made from physical sectioning should be made with caution. A wide range of marginal gaps has been reported for CAD/CAM-fabricated esthetic restorations. The type of the preparation design,[28,29] the impression method, the CAD/CAM system and the restorative material,[30] and the testing method seem to have an effect on the marginal and internal adaptation of CAD/CAM-fabricated indirect restorations. There are only limited data evaluating marginal and internal adaptation of endocrown restorations. Cook and Fasbinder[14] evaluated the marginal and internal adaptation of chairside CAD/CAM IPS Empress endocrowns on premolars, using different preparation designs at the marginal area and the internal line angles. MG width ranged from 49 to 102 μm, which is in accordance to the results of the present study, whereas the internal gap widths ranged from 139 to 229 μm, which is higher than those reported here (89.5-155.2 μm).[14] The use of premolars instead of molars, a different type of restorative material, and different testing and measuring techniques between the two studies do not allow for direct comparisons. The reported mean MGs for CEREC I intracoronal restorations range from 191 to 308 μm,[31,32] whereas for CEREC 2 intracoronal restorations, the values varied from 59 to 121 μm.[31-33] A mean MG range of 46-162 μm has been reported for all ceramic and composite crowns fabricated with CEREC 3, whereas an MG width of 201 ± 78 μm and up to 116 μm have been shown for Cerec3 and Cerec 3D onlay restorations, respectively.[25,28,34-36]

The effect of measuring location on the MG and MD was evaluated in the present study. Differences of median MG and MD values in the evaluated landmarks were identified as significant only in a few cases. Further measurements with additional samples might be required to draw a more representative conclusion. In the literature, a wide range of marginal space has been described at different measured locations of various all-ceramic system restorations.[24,37] In a recent clinical study, significantly larger MGs were observed at the distal location of CAD/CAM-fabricated metal-ceramic crowns in conjunction with intraoral digital impressions.[36] The lingual site had a significantly lower marginal discrepancy than the mesial, distal, and buccal sites in some other laboratory investigations.[36]

Internal fit has been advocated as an important factor in the retention and favorable clinical performance of indirect restorations. High bond strength has been achieved in conjunction with cement thickness of 50-100 μm, but when MG was raised to 150 μm or more, a significantly higher washout of the cement was shown.[26] Cement space should be uniform and facilitate seating without compromising resistance or retention forms.[38]

In the present study, S/V void ratio was calculated instead of evaluating the absolute volume void to compensate for the 1 mm in depth added intraradicularly in each preparation type tested. According to the results, H2 showed significantly lower S/V than the other two groups, which did not differ significantly. In addition to S/V ratio, internal fit was assessed by evaluating the gap width in 72 measuring locations per tooth. In all groups tested, median values of gap measured at the axial wall (A) were significantly lower than the pulpal (P) and cervical floor seat (C) area. Compared with marginal discrepancy widths (MG and MD), internal gap values (A, P, and C) were significantly higher for all three tested groups. Higher internal gap than marginal gap values have been reported in studies evaluating marginal and internal fit of CAD/CAM-fabricated full coverage or onlay esthetic restorations.[24,28,35,39,40] In most cases, internal gap on the occlusal or pulpal region was presented as higher than on other regions. Kokubo and others[24] attributed this difference to the scanning process, preparation height, luting space, convergence angle, and variations between CAD/CAM systems.

Scanning process, software design, milling, and shrinkage effects have an influence on the fitting accuracy of CAD/CAM restoration. Despite the significant improvements in CAD/CAM technology systems, there might be some clinical problems.[20,41] Optical contrasting powder application procedure, camera misalignment, distance between the camera and the scanned surface, and imaging walls with different orientation in relation to the camera are all possible sources of accuracy problems and dimensional errors.[42.43]

Although the manufacturer information states that the CEREC Bluecam has a depth of field up to 15 mm (CEREC AC Operating Manual, Sirona), which is sufficient to capture deep preparations, increasing the preparation depth in the current study negatively affected the accuracy of the captured image. This effect was clearly manifested in H4 group, as internal gap values increased significantly on the axial and pulpal walls (A and P) that were moved further away from the prism, but not on the cervical seats (C1 and C2), which remained at the same distance from the camera. In addition to this, the increased thickness of the scanning powder in the deepest areas of the canals and the corners could have become a negative input for the optical scans.[44]

Questions regarding the efficacy of the systems to accurately scan in depth and record the pulp chamber and part of the canals in endocrown preparations have been raised.[45] Limited optical depth of field may result in a blurred image of the central retention cavity of the endodontic preparation if the adjacent teeth limit the position of the camera head.[1,42,45]

This *in vitro* study simulates the compromised situation of extensive loss of tooth structure, which does not readily allow for the use of the ferrule effect in crown preparation. CAD/CAM-fabricated endocrowns are relatively new treatment modalities, and information about their long-term clinical performance is limited in the literature. High survival rates for Cerec endocrowns on molars were reported in two different studies after 5 and 12 years of evaluation (90.5%), with no significant difference compared with classic shoulder crowns. Both studies reported higher risk of failure for endocrowns fabricated on premolar teeth.[46,47]

Limitations of the present study include the use of one CAD/CAM system and one restorative material and the spray used for digitizing the specimens. The use of other systems or materials might have resulted in different outcomes. Further research is proposed to investigate the marginal and cavity adaptation of endocrowns and the effect of intraradicular extension on the retention of endocrowns, especially in cases of excessive tooth loss, and to determine whether the results of the current study have an effect on the long-term clinical performance of the restorations.

CONCLUSIONS

Within the limitations of the present *in vitro* study, the following conclusions can be drawn:

1. Intraradicular extension of the endocrown preparation negatively affected both the marginal adaptation and the internal fit of the final restoration.
2. Marginal fit of the three groups tested proved to be significantly better than internal fit evaluated by analyzing the internal gap width in various measuring positions.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the College of Dental Medicine, University of Sharjah, UAE.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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