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INTERNAL FIT AND MARGINAL ADAPTATION OF CAD/CAM LITHIUM DISILICATE ENDOCROWNS FABRICATED WITH CONVENTIONAL IMPRESSION AND DIGITAL SCANNING PROTOCOLS. AN IN-VITRO STUDY

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ABSTRACT

Aim: To evaluate the internal and marginal adaptation of computer aided design/computer aided manufacturer fabricated lithium disilicate endocrowns restoring endodontically treated maxillary molars and produced by conventional impression and digital scanning protocols.

Materials and methods: Thirty freshly extracted maxillary molars were prepared to receive endocrowns. Teeth were divided into two groups: conventional impression (n=15) and digital scanning (n=15). After restorations designing on CAD/CAM software, endocrowns were milled from Amber® mill lithium disilicate blocks. The internal gap was assessed by replica technique and stereomicroscope selecting 32 measurements for each restoration while, the mean marginal gap was assessed by stereomicroscope before and after cementation and thermocycling. Internal gap values were analyzed by Independent t-test, One Way ANOVA test for different landmark comparison, Tukey`s Post Hoc test for multiple comparisons, and Repetitive One-Way ANOVA test for marginal gap values before and after cementation.

Results: Statistically significant difference in gap values was recorded between different impression protocols and regions ($p < 0.05$). digital scanning displayed significantly smaller gaps than conventional impression in all regions ($p < 0.001$). The largest gap was at pulpal floor in both groups. Marginal gap after cementation was larger than before cementation in both groups ($p < 0.0001$)

Conclusions: Digital scanning protocol produced endocrowns with superior internal and marginal adaption than those produced with conventional impression protocol. Pulpal floor showed the highest gap values in all tested regions while, margin showed the lowest gap. Cementation and thermocycling increased the marginal discrepancies but still within the clinically acceptable range.

KEYWORDS: Endocrowns, CAD/CAM, marginal adaptation, internal fit, conventional impression.

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INTRODUCTION

Over two decades ago, the monolithic monoblock ceramic protocol also known as endocrown was introduced as a viable treatment option to restore compromised endodontically treated teeth. (1) Retention of an endocrown restoration is gained through the extension to the tooth pulp chamber, utilizing its larger surface area to acquire strong adhesive bonding to the compromised tooth structure. (2) Through this monolithic monoblock ceramic protocol, adhesion occurs between the sole interface between the restoration and the tooth structure, this reduces the chances of adhesive failure of the restoration and facilitates the reduction of unwanted stress concentration that used to develop with the conventional post and core treatment protocol due to the use of different materials with their different individual properties.(3) Endocrown restoration is usually indicated in teeth with limited inter-arch space and teeth with severely curved, short, or resorbed roots. Roots with broken instruments or perforations during endodontic instrumentation are also an indication as it will be problematic in construction of post and core restoration. (1,3) Many literatures discussed the advantages of endocrowns that were represented in improved mechanical performance and overall durability of the restored teeth in addition to high aesthetics and less overall chairside and laboratory steps than conventional restorations for endodontically treated teeth. (4-6) For many years, conventional impression technique utilizing elastomeric impression material was successfully used for the construction of fixed dental restorations. However, final impression accuracy was significantly influenced by many factors such as the impression material itself, impression technique, mixing technique and impression tray used in addition to the disinfection technique and the protocol for transfer to and from the dental lab. Moreover, despite the advances in impression materials, some of the material's shortcomings still persists which is usually associated with patient's discomfort such as unpleasant taste, odor or nausea. (7) Recent advances in computer aided imaging, computer aided design and computer aided manufacturing (CAI/CAD/CAM) allows stepping over the shortcomings of conventional impression technique by providing a well-fitting, highly aesthetic restoration with fewer clinical and laboratory steps, faster fabrication time and lower cost. (8)

Internal and marginal adaptation of indirect restorations can be severely influenced by poor-quality conventional impressions. Al-Dabbagh RA (1), stated that open margins alone are not directly correlated with marginal microleakage. However, marginal and internal adaptation are one of the crucial factors determining the long-term functional success of a restoration. (7-9) In addition to promoting plaque retention and periodontal inflammation, ill-fitting restorative margins will also lead to the development of secondary caries and eventually complete failure of the indirect restoration. (9,10)

The marginal and internal adaptation of indirect restorations can be affected by several factors including restoration material, cement, design, impression technique, and fabrication protocol.(11) Several previous studies investigated the marginal fit of endocrown restoration and reported clinically acceptable internal and marginal adaptation that was comparable to conventional full coverage crowns irrespective of the preparation design, impression protocol, fabrication technique or ceramic material used for endocrown construction. (11-20)

A consensus about a definite maximum clinically acceptable marginal gap is unavailable in literature, however value range between 50 and 200 mm was suggested in most. (9,20) Nonetheless, the threshold suggested by McLean and von Fraunhofer for maximum acceptable marginal gap to be 120µm is the one used in the majority of these literature. (21)

Previous studies have produced varying results upon evaluating the internal and marginal fit of fixed dental prosthesis fabricated from conventional impressions and digital techniques. A significant number of these studies reported superior marginal and internal fit was established with digital scanning method over conventional impression, (22-24) while some other studies concluded that there was no significant difference between the two techniques. (25,26) Moreover, variations in the digital scanner and the scanning technique utilized to create the virtual model which is either by direct intraoral scanning or by cast digitization are other influencing factors that were continuously reported. (27) However, there is still lack in literature that provide a detailed comparative evaluation of the internal and marginal adaptation of endocrowns fabricated by different impression techniques and different workflow. Therefore, the purpose of this in vitro study is to evaluate the internal and marginal adaptation of CAD/CAM fabricated lithium disilicate endocrowns restoring endodontically treated maxillary molars and produced by conventional impression and digital scanning protocols.

The null hypotheses for this study were that there would be no difference in the internal and marginal adaptation between the two techniques as well as no difference would be found in internal adaptation of endocrowns in different regions within the endocrown preparation. Moreover, there would be no difference in margin adaptation of endocrowns before and after cementation and thermal aging.

MATERIALS AND METHODS

The research proposal for this study has been registered and exempted by Institutional Review Board Organization IORG0010868, Faculty of Oral & Dental Medicine, Ahram Canadian University. Registration number: IRB00012891 #14.

The PICO for this study was:

P: Endodontically treated molars.

I: Endocrowns fabricated with digital scanning.

C: Endocrowns fabricated with conventional impression.

O: Primary outcome: Internal Fit, Secondary outcome: Marginal adaptation.

Sample size for this study was calculated depending on a previous study by Lee *et al* (28)**,** as reference. According to this study, the minimally accepted sample size was 9 per group, when the response within each subject group was normally distributed with standard deviation 8.3, the estimated mean difference was 11.9, when the power was 80 % & type I error probability was 0.05. Sample size was increased to 15 samples per group to allow for sufficient number of samples in each study group.

A total of thirty freshly extracted human maxillary first molar teeth were collected from the department of oral and maxillofacial surgery, Ahram Canadian university. The inclusion criteria were: intact, caries and crack free teeth with complete root formation, while the exclusion criteria were teeth with carious lesions, coronal restorations, incomplete root formation, cracks, perforations or fractures. The sizes of the selected molars were measured by digital caliper (Mitutoyo IP 65, Kawasaki, Japan) to verify that they all were nearly similar mesiodistal and buccolingual dimensions at cemento-enamel junction with maximum deviation in dimension of 10%. To remove all external plague and any depositions, all teeth were subjected to ultrasonic cleaning followed by storing in distilled water with 0.1% thymol at room temperature (Caelo, Hilden, Germany) till use.

A custom-made cylindrical mold was used for specimen fixation to mount the teeth in acrylic resin blocks for support during endodontic treatment, endocrown preparation and testing procedures. Custom mold was filled with self-cure acrylic resin (Acrostone, Egypt) then teeth were inserted up to 2mm below CEJ to allow for proper visibility of restoration margin during construction and final testing.

Endodontic Treatment

Conservative access cavity was performed for each tooth using large round diamond bur (endo-access, No. 856; Intensiv SA, Switzerland) in high speed contra-angle followed by pulp extirpation and endodontic instrumentation using a combination of manual stainless-steel K-files 8, 10 & 15 (Dentsply Maillefer, Ballaigues, Switzerland) for negotiation of root canal and rotary Ni-Ti files (Protaper Universal 21mm, Dentsply Sirona, Switzerland) for complete cleaning and shaping of the canals following the crown-down technique. Copious irrigation with 5.25% sodium hypochlorite and recapitulation were carried out between each of the instrumentation. After the final flush and proper dryness of the canals with sterile paper points, root canals were obturated using thermo-plasticized gutta-percha (DiaDent Group International, Seocho-dong, South Korea) and resin-based sealer (AdSeal, Metabiomed, Korea) using cold lateral compaction technique, followed by complete removal of excess gutta-percha from the tooth pulp chamber to the level of 1mm apical to the orifice in each canal using round diamond bur (801,012; Intensiv SA, Switzerland). Finally, all canal orifices were filled with bulk-fill flowable composite (SDR flow; Dentsply Sirona, Bensheim, Germany) to the level of pulp chamber in order to seal all undercuts and remove areas of irregularities.

Teeth Preparation for Endocrowns:

Teeth preparation was done in accordance with the recommendation of Pissis P. (3) For better control over the reduction amount, silicon index was fabricated from hard duplication silicon material (Elite Double 22 Fast, Zhermack-Germany) for each tooth prior to reduction. 80µm grit flat end tapered diamond bur (4137-856-025, Microdont, USA) mounted on high-speed handpiece was used to prepare a standardized central retention. Cavity that extends in the pulp chamber 6mm deep from the central grooves and with 8° divergent axial walls allowing removal of any axial undercuts. Occlusal surfaces of all teeth were reduced by 2mm in axial direction using diamond wheel bur (3054-024-21.0, Microdont, USA) making sure to orient the flat end of the bur with the tooth long-axis to create a 360° butt-joint surface. The final finishing of the preparation was done using fine-grit 30-40µm tapered diamond bur (4137F-856-025-L1 8.0-L2 21.0. Microdont, USA) to ensure smoothening and rounding of all sharp internal line angles.

All specimen preparations were performed by the same operator and checked by digital caliper for verification of axial wall thickness of 2mm (± 0.2 mm) and cavity depth of (4mm ± 0.2 mm). Samples were finally checked by 3D CAD/CAM software; PrepCheck (version 4.5, Sirona Dental Systems GmbH, Bensheim, Germany) for predetermined cavity depth, wall thickness and axial taper. All samples exceeding 0.2mm discrepancy were excluded.

Endocrown Fabrication

Based on the impression protocol, the thirty maxillary first molar teeth were arbitrarily divided into two groups: conventional impression group (n=15) and digital scanning group (n=15).

For conventional impression group (n=15), light-polymerizing acrylic resin (Megatray; Megadent Ltd) was utilized to fabricate a custom impression tray specifically for this study. In order to maximize the mechanical retention of impression material to the custom tray, two holes were drilled at each side of the tray followed by application of tray adhesive. One-step impression was taken by using polyvinyl siloxane soft-putty and extra-light (Panasil; Kettenbach GmbH & Co) according to the manufacturer’s instructions After removal, all impressions were evaluated under 4.0x magnification loups (Univet, Italy), followed by immediate pouring with type IV dental stone (Fuji-Rock EP; GC Europe) which was left to set for 40 minutes before separating the stone models from its respective impressions and inspection under 4.0x magnification loups for any porosities or discrepancies. All stone models were then scanned using OmniCam intraoral scanner (CEREC AC; Dentsply Sirona GmbH, Bensheim, Germany) to obtain the virtual models for restorations designing. **(Figure 1)**

For the digital scanning group (n=15), all the prepared teeth were scanned directly using Omnicam intra oral scanner. The design of all endocrown restorations in both groups was accomplished by the CEREC 3D software (version 4.5, Sirona Dental Systems GmbH, Germany). Standardized restoration design with similar occlusal surface anatomy and occluso-gingival height was ensured for all endocrown restorations by using bio-generic reference feature in CEREC software. The cement space was set on CAD/CAM software to be 50µm internally and 0µm at the margin to ensure precise restoration seating and minimize marginal discrepancies. (2,19) **(Figure 2)**

All endocrown restorations were milled from lithium disilicate CAD/CAM blocks Amber® mill (HASS, Korea) with 4-axis wet milling and grinding machine MCXL (Dentsply Sirona, Bensheim, Germany). After milling was complete, sprues were cut and sprue area was finished with diamond finishing stones. No further occlusal surface or margin modifications were done for the milled samples. Afterwards, all the milled specimens were crystallized and glazed in Programat P3010 ceramic

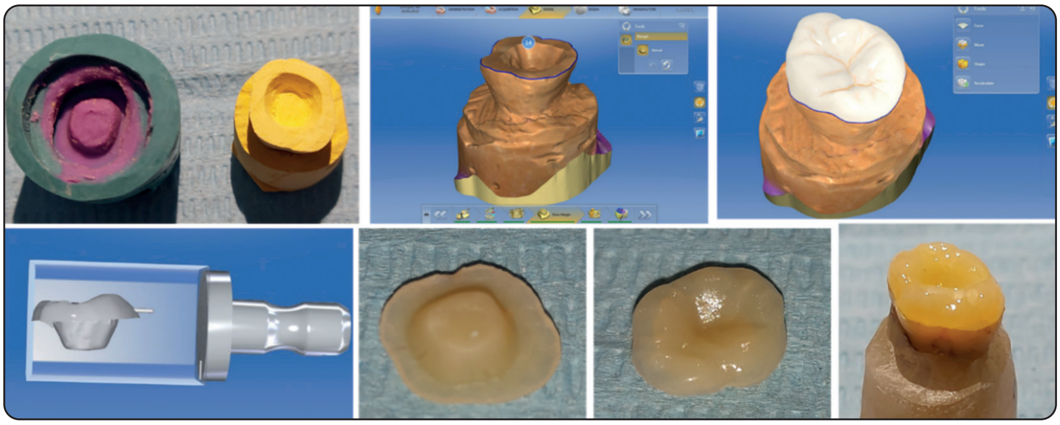

Fig. (1): Endocrowns fabrication by conventional impression

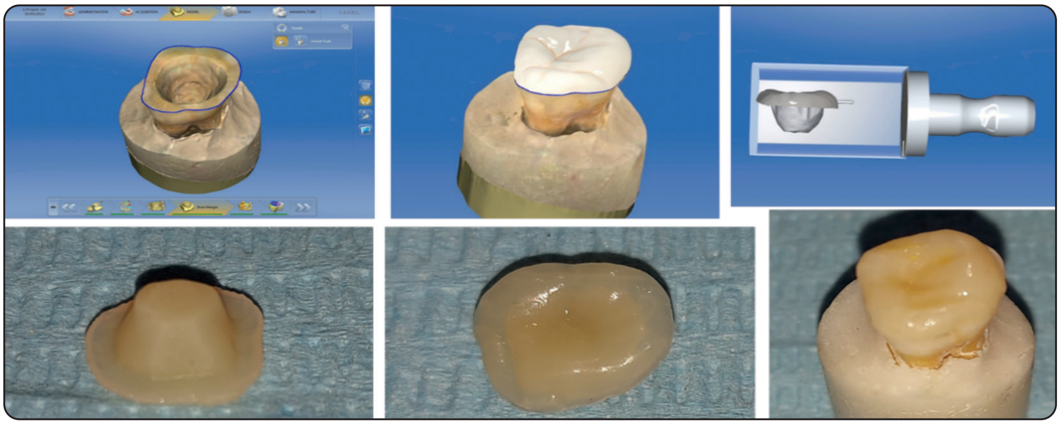

Fig. (2): Endocrowns fabrication by digital scanning furnace (Ivoclar Vivadent Inc., New York, USA) following the crystallization and glazing parameters provided by the manufacturer. Finally, the occlusal and intracoronal thicknesses of all specimens were checked and verified using the digital caliper.

Measurement of internal and marginal fit before cementation:

To assess the internal fit; replica technique was used.**(19)** each endocrown was filled with a light green, light-body polyvinyl siloxane (Panasil® Initial contact; Kettenbach GmbH & Co) impression material and seated in a direction along the long axis of each corresponding tooth then, a five kilograms load was applied vertically using a specially designed loading device in order to ensure full restoration seating, standardize the load for all samples and simulate the loading that will be applied during restoration cementation. The load was maintained for a total of five minutes till complete setting of the light-body material. Endocrown was then removed from the abutment tooth then, dark green heavy-bodied polyvinyl siloxane (Panasil® Tray Heavy; Kettenbach GmbH & Co) was injected over the light-body in order to stabilize it upon removal. After complete polymerization of the heavy-body material, each replica was cut into four equal quarters using a sharp surgical blade (No11) from the center in a buccolingual and mesiodistal direction then, each quarter slice was cut again to produce a 2mm thick slice specimen with parallel walls that was verified under 4x magnification loups in order to ensure a proper vertical perpendicular view of each specimen under the stereomicroscope platform. The discrepancy between the tooth and the endocrown was represented by the light-green colored layer, which was examined with stereomicroscope (Leica MZ6, Leica Microsystems, Switzerland) at a magnification of 20x. Images were captured with high definition digital camera for analysis (Leica MC190 HD, Leica Microsystems, Switzerland), then viewed using the image analysis software (Image Pro-plus V.6). For accurate measurement of internal fit, each slice was divided into 3 main regions of importance where two readings were taken for each region: internal marginal gap (M1, M2), axial wall (A1, A2), and pulpal floor (P1, P2) in addition to the one reading for each of the two line-angles: axio-margin (Am) and axio-pulpal (AP). A total of 32 measurements were obtained for each sample (8 measurement for each slice) by the same operator. A database (Microsoft Excel 2016; Microsoft Corp) was used to save all measurements for internal fit in Micrometers (μm). **(Figure 3)**

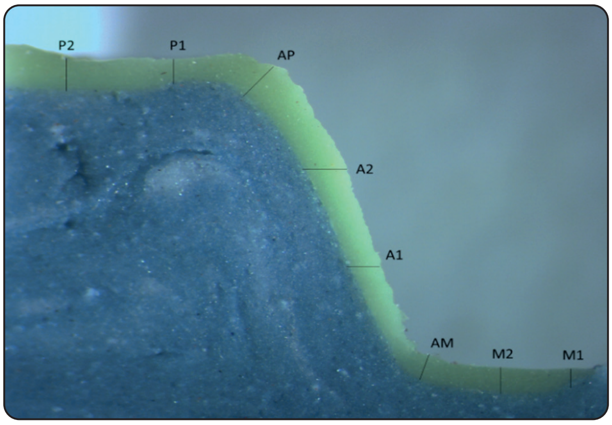

Fig. (3) Positions of the eight measurements on each cross-sectional cut of replica (Magnification 20x).

Initial measurements for the marginal gap were also performed before cementation. Each endocrown was placed on its parallel prepared tooth using a specially designed metal jig to make sure there is full seating and prevents the movement of restoration. For each specimen, four stereomicrographs, one for each surface (mesial, distal, buccal and lingual) were taken by the stereomicroscope at a magnification 40x. Vertical marginal gap was measured between the endocrown cervical margin and the outer end of the tooth butt margin at 3 equidistant points which were lightly marked by blade and measured in stereomicrographs. So, the marginal gap measurements were performed at 12 points for each endocrown. **(Figure 4a)**

Adhesive Cementation of Endocrowns:

In preparation for restorations bonding, all endocrown restorations were immersed in 99% isopropanol in digital ultrasonic cleaner (MCS, Egypt) for 10 minutes. As for the prepared teeth, fluoride-free pumice paste and polishing brush in low-speed hand piece were used to clean all the prepared tooth surface for 15 seconds then it was thoroughly rinsed with distilled water for another 15 seconds.

The intaglio surface of endocrowns was etched with 9.5% hydrofluoric acid (Porcelain etchant, Bisco, USA) for 60 seconds, then rinsed thoroughly with distilled water and dried with oil-free compressed air. A thin layer of silane coupling agent (Porcelain primer, Bisco, USA) was applied with micro-brush to fitting surface for 60 seconds then air dried.

For the prepared teeth surfaces, 37% phosphoric acid etchant gel (Etch-37, w/BAC, BISCO Inc, USA) was applied for 30 seconds, then thoroughly rinsed and air dried. Light cure adhesive bonding agent (All-Bond Universal. BISCO Inc, USA) was applied with micro-brush to the etched teeth surfaces and left for 30 seconds then, air thinned and light cured for 20 seconds using light curing unit (Elipar™, 3M ESPE, USA). Dual-cure adhesive resin cement (BisCem®, Bisco Inc, USA) was applied to the intaglio surface of each endocrown restoration, one restoration at a time and the restoration was seated on its corresponding prepared tooth using static finger pressure followed by axial loading with 5kg using the specially designed loading device for 5 minutes. Initial light curing was done for 2 seconds followed by thorough removal of the excess resin using scaler and finally complete light curing was performed for each surface for 40 seconds. Prior to thermal aging, specimens were stored in distilled water at room temperature for 24 hours.

Thermal aging:

A thermal cycling simulation device (Robota automated thermal cycle; BILGE, Turkey). was used to subject all the study samples to 5000 cycles, at 5° and 55ºC water, with a dwell time bath of 25 seconds and lag time 10 seconds to simulate temperature fluctuations in oral cavity (19).

Measurement of Marginal Fit After Cementation

Vertical marginal gap was re-evaluated after endocrowns cementation and thermal aging using stereomicroscope utilizing the same reference points on each surface at the same magnification (40x). **(Figure 4b)**

Statistical analysis:

All data were collected and tabulated using

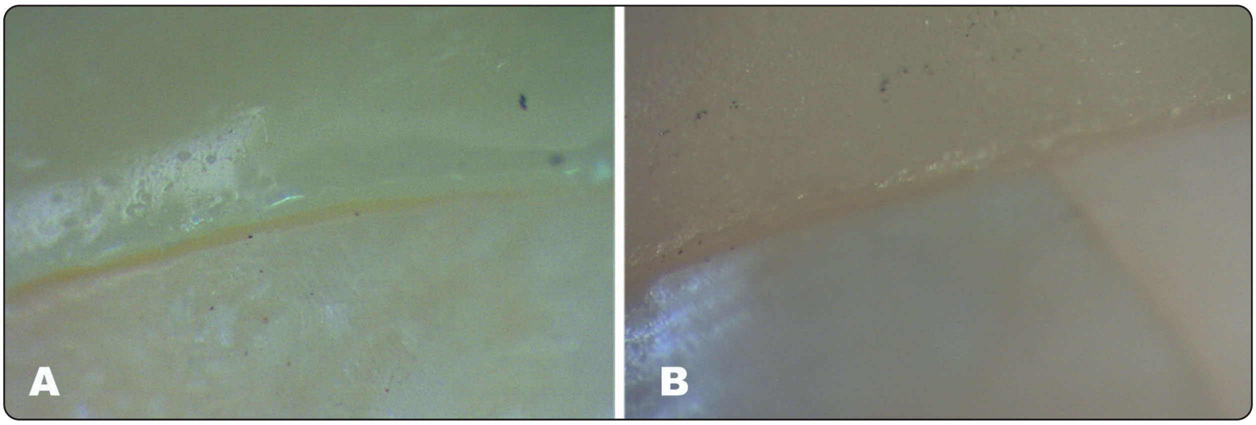

Fig. (4): Stereomicroscope photographs (Magnification 40x) for marginal gap assessment. (a) Before cementation. (b) After cementation.

Microsoft Excel (version 365). Statistical analysis was performed with SPSS 16 ® (Statistical Package for Scientific Studies), Graph pad prism & windows excel. Exploration of the given data was performed using Shapiro-Wilk test and Kolmogorov-Smirnov test for normality which revealed that the significant level (*P*-value) was insignificant as *P*-value > 0.05 which indicated that the hypotheses were rejected, and the concluded data originated from normal distribution (parametric data) resembling normal Bell curve. Sample size (n=15/group) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level.

Accordingly, in internal gap values comparison between different groups was performed by using Independent t-test, comparison between different landmarks was performed by using One Way ANOVA test, followed by Tukey`s Post Hoc test for multiple comparisons. In marginal gap values, comparison between different groups was performed by using One Way ANOVA test while comparison between before and after cementation was performed by using Repetitive One-Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons.

RESULTS

All descriptive data are presented as minimum, maximum, median, mean & standard deviation for both internal gap and marginal gap before and after cementation and thermocycling.

I. Internal gap values

For the conventional impression group, descriptive statistics showing minimum, maximum, median, mean & standard deviation of internal gap values measured in micrometers (µm) in **Table (1)**. There was a significant difference between all landmarks as *P <0.05*, with the highest gap value being in the pulpal floor (P2) (138.39± 6.65), and the lowest being in the margin (M1) (53.04± 3.50), multiple group comparisons revealed significant difference between all landmarks as means have different superscript letters as *P <0.05*, except means with the same superscript letters, there was statistically insignificant difference between them (M1 and M2), (M2 and AM), (A1 and A2), (A1 and A2) and between (AP and P1) as *P>0.05*.

For the digital scanning group, there was a significant difference in internal gap values between all landmarks as P <0.05, with the highest value being in the pulpal floor (123.37± 4.39), and the lowest

TABLE (1): Distribution of internal gap thickness (μm) at different regions in conventional impression group

Region	**landmark**	**Mean**	**SD**	**95% CI**		**Median**	**Minimum**	**Maximum**	**One Way ANOVA *P-value***
				Lower	**Upper**				
Margin	**M1**	53.04 ^{a}	3.50	51.97	54.11	52.37	46.07	59.04	<0.0001*
	M2	62.40 ^{ab}	4.72	61.01	63.93	61.07	56.76	74.85	
Axio-margin	**AM**	70.93 ^{b}	4.08	69.70	72.15	70.80	61.63	78.11	
Axial wall	**A1**	82.85 ^{c}	5.77	81.13	84.61	82.14	70.04	92.31	
	A2	90.72 ^{c}	5.88	88.81	92.51	90.56	76.75	100.70	
Axio-pulpal	**AP**	128.49 ^{d}	10.73	125.19	131.89	127.62	110.51	147.23	
pulpal floor	**P1**	122.00 ^{d}	10.86	118.73	125.40	120.43	102.40	144.07	
	P2	138.39 ^{e}	6.65	136.30	140.45	138.64	126.43	148.98	

Significant difference as P < 0.05

Mean with the same superscript letters were insignificantly different as P > 0.05

Mean with different superscript letters were significantly different as P < 0.05

being in the margin (M1) (39.98± 3.82), multiple group comparisons revealed significant difference between all landmarks as means have different superscript letters as *P <0.05*. **Table (2)**

Independent t-test comparison between conventional and digital scanning groups revealed significant difference between the two groups as internal gap values in conventional impression was significantly higher than digital scanning in regions (M1, M2, AM, AP and P2) *P< 0.05*. **(Table 3 and Figure 5)**

II. Marginal gap values

Comparison between conventional and digital techniques **(Table 4 and Figure 6)** revealed significant difference between digital and conventional impression techniques in marginal gap values in both before and after cementation and thermocycling (*P < 0.05)*.

II. Effect of impression protocol on internal and marginal gap value:

Multiple comparison showed that, there was

TABLE (2): Distribution of internal gap thickness (*μ*m) at different regions in digital scanning group

Region	landmark	Mean	SD	95% CI		Median	Minimum	Maximum	One Way ANOVA *P- value*
				Lower	Upper				
Margin	**M1**	47.31 a	3.01	46.38	48.24	46.80	42.07	53.02	<0.0001*
	M2	55.94 b	2.58	55.16	56.73	56.07	51.09	60.07	
Axio-margin	**AM**	65.59 c	3.14	64.63	66.61	65.61	59.81	73.55	
Axial wall	**A1**	78.17 d	2.43	77.37	78.87	77.99	74.92	82.37	
	A2	90.03 e	4.25	88.78	91.33	89.16	83.14	98.17	
Axio-pulpal	**AP**	103.75 f	4.08	102.55	105.08	103.13	98.78	114.86	
pulpal floor	**P1**	115.74 g	4.42	114.43	117.08	116.32	106.54	123.42	
	P2	123.37 h	4.39	122.02	124.63	123.23	113.73	131.84	

Significant difference as P <0.05
Mean with the same superscript letters were insignificantly different as P > 0.05
Mean with different superscript letters were significantly different as P < 0.05

TABLE (3): Mean values, standard deviations, and group comparison of internal gap thickness (μm) in both study groups at various landmarks

Region	Landmark	Conventional Impression group		Digital Scanning group		Independent t-test	
		M	SD	M	SD	*t value*	*P value*
Margin	**M1**	53.04	3.50	47.31	3.01	3.29	0.001*
	M2	62.40	4.72	55.94	2.58	3.72	0.001*
Axio-margin	**AM**	70.93	4.08	65.59	3.14	3.28	0.004*
Axial wall	**A1**	82.85	5.77	78.17	2.43	2.36	0.02
	A2	90.72	5.88	90.03	4.25	0.31	0.76
Axio-pulpal	**AP**	128.49	10.73	103.75	4.08	6.81	0.001*
pulpal floor	**P1**	122.00	10.86	115.74	4.42	1.91	0.051
	P2	138.39	6.65	123.37	4.39	5.91	<0.0001*

**Significant difference* as P <0.05*

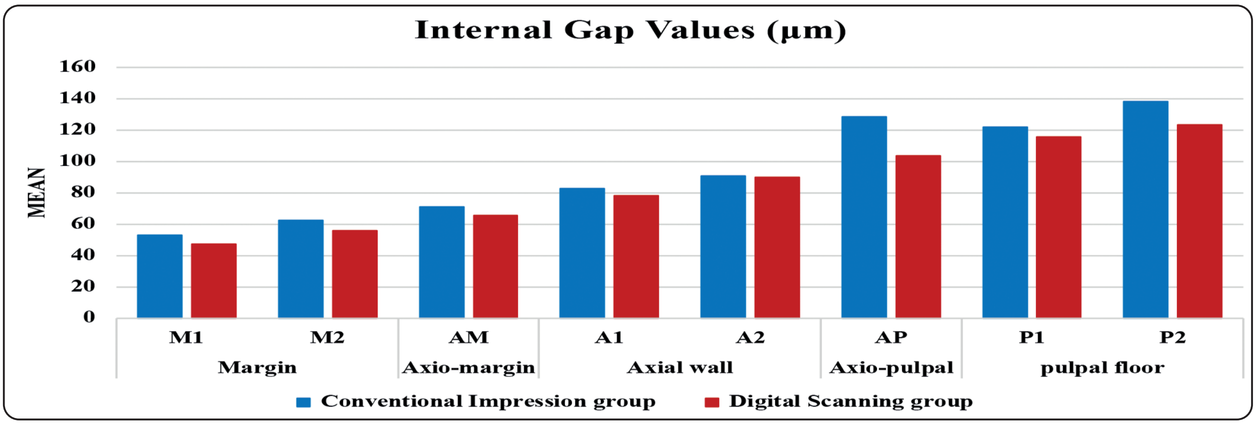

Fig. (5): Bar chart showing comparison between internal gap values in conventional impression group & digital scanning group.

a significant difference in the mean internal gap between the two impression protocols. There was also a significant difference in the marginal gap values between before and after cementation and thermocycling in both conventional and digital impression protocols *P <0.05*. While, there was insignificant difference in the marginal gap values between conventional and digital protocols before cementation or between conventional; and digital protocols after cementation and thermocycling *P > 0.05*. **Figure (7)**

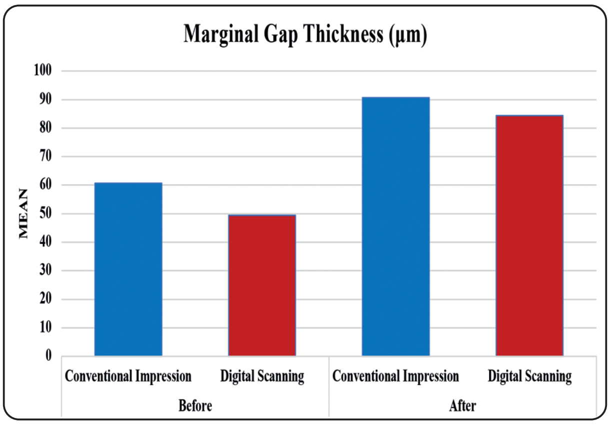

Fig. (6): Bar chart showing Mean of marginal gap thickness (µm) in different study groups before and after cementation and thermocycling

TABLE (4): Mean values, standard deviations of marginal gap thickness (µm) in both groups before and after cementation and thermocycling

Time	Group	Mean	Standard Deviation	95% Confidence Interval		Median	Minimum	Maximum	*P-value*
				Lower	Upper				
Before cementation	**Conventional Impression**	60.67 ^{b}	5.65	59.64	61.72	60.07	48.65	72.34	<0.0001*
	Digital Scanning	49.42 ^{a}	5.51	48.37	50.41	49.84	35.06	59.18	
After cementation & thermocycling	**Conventional Impression**	90.66 ^{b}	4.15	89.96	91.38	91.00	79.09	99.63	<0.0001*
	Digital Scanning	84.38 ^{d}	4.34	83.64	85.22	83.95	73.88	97.11	

Significant difference as P <0.05

Mean with the same superscript letters were insignificantly different as P > 0.05

Mean with different superscript letters were significantly different as P < 0.05

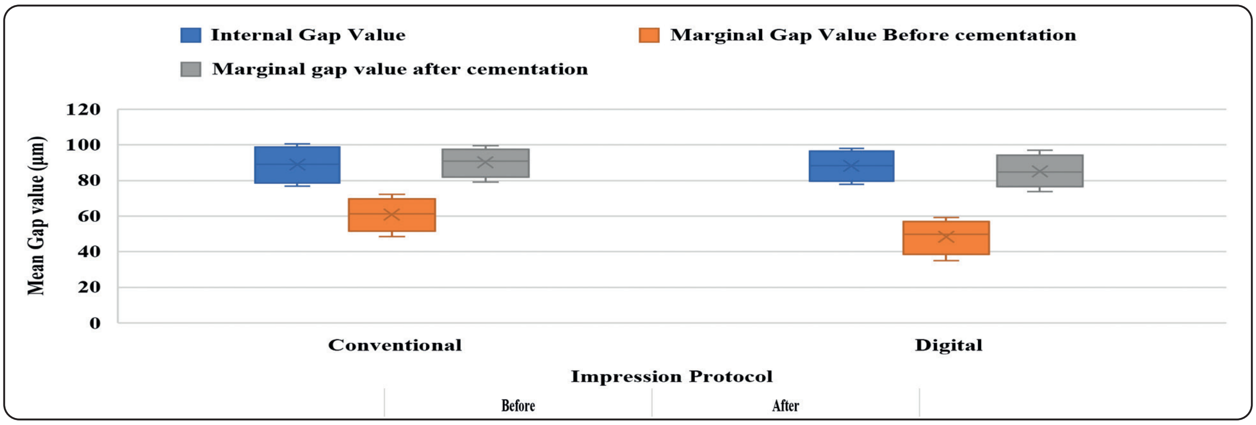

Fig. (7): Boxplot showing the effect of impression protocols on the internal and marginal gap values.

DISCUSSION

Internal and marginal adaptation are integral parameters for survival of indirect adhesive restorations. Poor marginal adaptation increases risks of cement dissolution, secondary caries and gingival inflammation. As a ceramic monoblock restoration, endocrown utilizes the axial walls of the prepared tooth's pulp chamber for macro-mechanical retention, while micro-mechanical retention is usually achieved through the resin cement. (3,4) Hence, the mechanical properties of the restoration in terms of retention and fracture resistance are significantly influenced by the internal fit. (2)

Endocrown was selected in this study as a satisfying option for restoration of endodontically treated teeth because it does not need additional tooth structure removal, which is an unavoidable process in post and core restoration. Since it is a minimally invasive procedure, so it inherently protects the established tooth structure. (1)

Different factors such as; impression protocol, preparation design, material type, scanner type, milling machine type, cement space and measuring method have been shown to influence marginal and internal discrepancies (2,5,15,19), so this study was designed to test the effect of conventional and digital impression protocols while considering all other factors equal in all specimens.

The aim of this study was to evaluate the internal and marginal fit of CAD/CAM lithium disilicate endocrowns fabricated with conventional impression and digital scanning protocols. Teeth that have been chosen for this study were of the same size. All specimens were finished by one operator, intracoronal depth of 4mm was checked by periodontal probe and verified by digital caliper. Preparations were finally verified for the pre-set parameters on 3D-CAD/CAM software and adjusted within 0.2mm discrepancy. All conventional impressions for the first study group were poured immediately to avoid any dimensional discrepancies. Moreover, to eliminate manual errors, a precise CAD/CAM scanner and milling machine were used for fabrication of all samples.

The cement space was set on CAD/CAM software to be 50µm (2,19,29) to allow the restoration to set more precisely. Differences of internal gap discrepancies among the in-vitro studies are directly related to the space given to the cementing agent. Anadioti *et al* (30), suggested that the choice of cement space of less than 40µm prevents the complete seating of the restoration. Also, cement gap was adjusted to 0µm at the margin area to ensure proper margin adaptation and to detect any minor discrepancy. (2,19)

Replica technique was used in this study as it is a commonly used, non-destructive method to measure the internal and marginal adaptation. Other techniques for internal and marginal fit assessment are either destructive like cross-sectioning of the samples, or comes with certain risks like cone beam computed tomography (CBCT) where there is risk of unnecessary radiation exposure. (31) Replica technique is known to preserve the restoration and the abutment tooth which enables repeating the assessment of the same specimen if required. In addition, the technique measures the gap in different regions along the restoration-cement space providing precise and accurate results (19) Moreover, this technique has the advantages of being less time consuming with fewer costs than the other methods. Besides, it can be easily applied in clinical practice as it's a non-destructive method. (24) Each replica was sectioned in the same position to examine the differences from a perpendicular perspective.

As replicas only measure the internal aspect of restoration margin, direct viewing under stereomicroscope was used to measure the external vertical marginal gap between the external restoration margin and the outermost periphery of the butt-joint margin. In this study, vertical marginal gap was measured twice, before and after endocrowns cementation and thermocycling. Since stereomicroscope does not integrate any sectioning or destruction of the restorations, it's less destructive and less time consuming than other measuring techniques mentioned previously, while possible errors from sectioning are avoided.(32) However, in this technique it is difficult to repeat the measurements from a corresponding angle and to differentiate the actual marginal gap from its projection.(31) Also, it's challenging to select the most significant points where the marginal opening should be measured and to identify the most apical part of the preparation margin. Moreover, sometimes the restoration and tooth margins tend to appear rounded upon viewing under magnification which makes the measuring process more challenging. (33) To avoid these viewing limitations, all measurements were performed by the same operator. Also, 3-equidistant reference points were selected on each surface of the tooth and marked with blade so they can be used when measurement is repeated after cementation and thermocycling.

Artificial aging is an integral part of any in vitro study involving ceramic materials as it allows for restoration evaluation under clinically simulated conditions. Thermal ageing was known to affect the marginal gap values and to accelerate the cement dissolution at restoration margin. (15,20) In this study, all specimens were subjected to 5000 cycles, at 5° and 55°C water which are equivalent to 6 months of clinical service.

The null hypotheses for this study were rejected because there were significant differences between different regions (marginal, cervical, axial, and pulpal) between the two tested groups (conventional impression and digital scanning) and in the gap measurments within the same group in different regions. Moreover, there were significant differences between the marginal gap values before and after restorations cementation and thermocycling.

For internal gap values; statistical analysis showed significant difference between the conventional impression and digital scanning groups ($P < 0.05$), digital scanning group showed superior adaptation in all regions with the lowest internal gap value at the marginal area M_1 (47.31 ± 3.01µm), while the highest gap value was found in the conventional impression group at the pulpal floor region P_2 (138.39 ± 6.65µm).

To the best of our knowledge, no study has evaluated the internal fit of Amber mill lithium disilicate endocrowns fabricated with conventional impression in comparison with digital scanning techniques on upper first molar. Other in vitro studies reported similar evaluation with diverse experimental designs. (8-12) The results of this study validate those of several other preceding studies.

(34,35) Abduljawad and Rayyan, (2) reported that digitally fabricated endocrown restorations showed superior internal and marginal adaptation over endocrowns obtained with conventional impression when measured by microcomputed tomography (micro-CT), irrespective to the method of digitization; wither it was direct intraoral scanning or indirect cast scanning. Ng *et al.* (34) and Mostapha *et al.* (35) reported that fully digital manufacturing technique of lithium disilicate crowns showed better adaptation than conventional impression on maxillary premolars. These outcomes can be attributed to the fact that no laboratory phases were involved in digital scanning and thus elimination of all possible dimensional changes from impression and die materials. (35) Additionally, as only milled blocks were used in this study, the crystallization of milled lithium disilicate blocks only results in 0.3% shrinkage that doesn't affect the fitting accuracy of endocrowns in comparison to other processing techniques.(36) the results of this study is in disagreement with Schestatsky *et al*, (37) who reported that pressed e-max crowns fabricated from conventional impression had better marginal adaptation than milled e-max crowns done by digital scanning, though the adaptation of milled crowns at the occluso-axial angles was more accurate with digital scanning technique. This study also disagrees with Guess *et al*, (20) who reported that the marginal discrepancies of mandibular molars onlays and partial crowns were neither influenced by the impression protocol wither it was conventional or direct digital scanning nor the manufacturing technique of the restoration. Though, restorations fabricated with conventional impression had smaller internal discrepancies than its corresponding acquired with digital scanning. Inversely other studies found that restorations acquired from conventional impression displayed better fit accuracy than digital scanning complete crowns (38-40) or partial restorations. (23,41) The direct comparison between different studies is limited because they didn't apply a standardized protocol regarding preparation designs, materials used, CAD/CAM systems, fabrication techniques and methods of measurements. (42)

The pulpal floor showed significantly the largest gap in the two tested groups, followed by axio-pulpal angle, axio-margin and finally the marginal gap ($p < 0.05$). However, the axial gaps (A1 and A2) didn't show a significant difference in both groups ($p = 0.02$) **(Table 1).** The largest gap on pulpal floor might be attributed to the restricted optical deepness of a scanning machine leading to inaccurate scanning of the pulpal floor and overshooting near the edges. (19,37)

Clinically acceptable range for ceramic restorations marginal gap was frequently debated in literature. Guess *et al,* (20) suggested that a marginal gap that ranges from 20-150 µm is considered clinically acceptable. While, McLean and von Fraunhofer (21) set a gap threshold of less than 120 µm to be proper marginal fit for long-term survival of dental prostheses. In this study, the lowest mean marginal gap value was (49.42 ± 5.51µm) in digital scanning group followed by (60.67± 5.65µm) for the conventional impression group before endocrown cementation. While the marginal gap values after cementation and thermocycling were (84.38± 4.34 µm) and (90.66± 4.15 µm) for digital and conventional impression protocols respectively.

Statistical analysis in this study showed significant difference in the marginal gap values between the two impression protocols and before and after cementation ($P<0.0001$). Both study protocols produced clinically acceptable margins (19-21,29,30) however, digital scanning group generally had lower marginal gap values than conventional impression group in both before and after cementation, which is the most essential element to prevent microleakage, periodontal affection and secondary caries. (27)

Abduljawad and Rayyan (2), reported significantly higher marginal gap in endocrowns fabricated by conventional impression which could be also attributed to the discrepancy caused by the impression and die material in addition to the presence of human factor for extra laboratory steps that are expected to produce more errors. Our results were also in agreement with Homsy *et al* (23), Sharma *et al* (33), and Shamseddin *et al*. (43) However, Falahchai *et al* (42), reported similar marginal gap values for endocrowns fabricated with conventional and digital impression. Similar results were also reported by other studies like Abdel-Azim *et al* (7), Dauti *et al* (11), and Sakornwimon and Leevailoj (44) where no significant difference was found between intraoral digital scanning and conventional impression in the margin adaptation of full coverage ceramic crowns. This could also be attributed to the difference in preparation design, margin location, number and design as well as the ceramic material and restoration laboratory fabrication protocols used in these studies from the present study.

Cementation and thermocycling had a significant effect on marginal gap values in both study groups, which is similar to the results obtained by Taha *et al*. (15) this significant change in the gap values although still within the clinically acceptable range can be justified by the addition of resin cement film thickness (22 µm) to the equation. Moreover, thermocycling resulted in a degradative effect on the marginal adaptation of the restoration as was frequently reported in literature. This effect was attributed to the presence of thermal expansion difference between the cement, tooth and restoration. These results disagree with Kassem *et al,* (45) who reported that marginal gap values were reduced after cementation and thermomechanical aging. This contradiction could be justified by using hybrid ceramic in the other study, these ceramics are known for their high resiliency that could influence the material dimensional stability and stress transfer under high temperature and pressure loading facilitating smaller gap occurrence after aging of the cemented restorations. (20,27)

One of the limitations of this study was the evaluation of internal fit before cementation of the restoration which disregards the influence of luting cement and the cementation protocol on the internal adaptation and gap width. Another limitation is that the spacer thickness selected for this study was constant. However, altering the spacer thickness for both internal and marginal surfaces of the restoration can influence the resultant internal and marginal gap values.

Additionally, further randomized clinical studies are essential to evaluate the results of this study under clinical situations.

CONCLUSIONS

Within the limitations of the study, both tested impression protocols provided restorations with clinically acceptable internal and marginal gap discrepancies. Digital scanning protocol produced endocrowns with superior internal and marginal adaption than those produced with conventional polyvinylsiloxane impression protocol. Pulpal floor showed the highest gap values in all tested regions in both study groups while, margin showed the lowest gap. Cementation and thermocycling increased the marginal discrepancies in both tested groups but still within the clinically acceptable range. Further investigations are required to test the findings of this study with different preparation and margin designs.

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