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Comparison of the Marginal Fit of E-max CAD Endocrown Restorations Conducted by using intraoral and extraoral scanners: In Vitro Study

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A R T I C L E I N F O.

Keywords:
CAD/CAM, Endocrown, Extraoral scanner, Intraoral scanner, marginal fit..

Abstract

Background: Marginal Fit is one of the detrimental factors for the success and survival of dental restorations including endocrowns. Impression material and technique may affect the fitting of the final restoration**.** Therefore**,** this in vitro study was conducted to assess the marginal fit of endocrown restorations restoring endodontically treated molars fabricated by intraoral and extraoral scanner.

Methods: Thirty-two lower first molars were endodontically treated, prepared to receive endocrowns in a standardized way, they equally divided into 2 groups (n=16) according to the impression technique; direct scanning using intraoral scanner (IOS) (omnicam AF), digitalization of conventional impression by extraoral scanner (EOS) (INEOS X5). Endocrown restorations were designed using InLab CAD SW and milled from E-max CAD blocks using 5 axis milling machine. Cementation was done using dual cured self-adhesive cement. After 1-week the samples were subjected to 10,000 cycles of thermocycling. With an isomet, samples were sectioned buccolingually. Marginal fit was assessed using stereomicroscope under X20. The data was collected and statically analyzed.

Results: No significant difference was found between IOS (61.2μm) and EOS (60.39μm) in terms of marginal gap distances.

Conclusion: Both impression techniques exhibited marginal gap readings within clinically acceptable criteria.

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1 Introduction

Over twenty years ago, the field of adhesive dentistry witnessed advancements that facilitated the restoration of endodontically treated teeth by the utilization of a monolithic monoblock ceramic technique, commonly referred to as the endocrown. The monolithic monoblock ceramic protocol enables a strong adhesive bonding between the restoration and the tooth structure by extending to the tooth pulp chamber, utilizing its larger surface area. This approach ensures that just one interface is formed, increasing adhesion at that specific location. [1] This phenomenon results in a decrease in the occurrence of restorative adhesive failure and a reduction of undesired stress concentration at the interface. The advantages associated with the use of endocrowns in the restoration of teeth that have undergone endodontic treatment have been extensively

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discussed in scholarly literature. The advantages encompassed aesthetics, reduced chairside, laboratory procedures, enhanced mechanical properties and overall longevity of the repaired teeth. [2]

For a long time, elastomeric impression material and the conventional impression technique were effective methods of creating fixed dental restorations. Nevertheless, numerous variables, such as the type of impression material, the technique that was utilized to take the impression, the method used to mix the substance, the specific impression tray utilized, as well as the disinfection process and the procedures involved in transferring the impression to and from the dental laboratory, significantly influenced the overall accuracy of the final impression.[3] Moreover, despite the progress made in impression materials, still remains certain limitations associated with these materials, mostly with patient discomfort, including unpleasant taste, Oduor. The latest advancements in Computer-Aided Impression / Design / Manufacturing (CAI/CAD/CAM) have made it possible to address the limitations of conventional impression techniques. These advancements offer the benefits of producing restorations that fit well, have high aesthetic appeal, require less clinical and laboratory procedures, can be fabricated more rapidly, and are more cost-effective. [4]

The marginal fit of indirect restorations may be significantly affected by conventional impressions of low quality. Marginal fit is a critical factor that plays a crucial part in determining the prolonged functional efficacy of a restoration. [5] Inadequate adaptation of restorative margins might ultimately lead to full failure of the indirect restoration, as well as promote plaque accumulation and inflammation of the periodontal tissues. The marginal fit of indirect restorations may be influenced by various factors such as the restoration material, cement, design, impression technique, and fabrication protocol. Irrespective of the specific design of the preparation, the protocol for taking impressions, the technique for fabricating, or the ceramic material employed in the construction of endocrowns, previous studies examining the marginal fit of these restorations has consistently demonstrated a level of marginal fit that is deemed clinically acceptable and comparable to that of conventional full coverage crowns.[6] However, most studies in this field employ the 120 microns barrier proposed by McLean and von Fraunhofer as the maximum marginal gap deemed clinically acceptable.[7]

Previous studies have yielded diverse results when evaluating the marginal fit of fixed dental prostheses manufactured by conventional impressions and digital fabrication techniques. [8] Numerous research have stated that digital scanning yields restorations with improved the marginal fir in comparison to conventional impression techniques, but contrasting findings have been reported by other investigations, which have found no noticeable difference between the two approaches. Furthermore, the impact of variations in the digital scanner and the scanning technique employed for generating the virtual model, either direct intraoral scanning or cast digitization, was discussed as a significant influencing factor. [8]

There is currently a deficiency in the literature about a sufficient comparative analysis of the marginal fit of endocrowns made using different impression techniques. Hence, the objective of this in vitro study was to evaluate the marginal adaptability of lithium disilicate endocrowns produced using conventional impression and extraoral scanner and a digital intraoral scanner.

The null hypothesis of the study: there will be no difference in the marginal fit of endocrown restoration fabricated by intraoral scanner and extraoral scanner.

2 Materials and Methods

2.1 Ethical Approval

Informed consent was obtained from patients to collect 32 human lower first molars that were acquired through the October University for Modern Sciences and Arts' Department of Oral Surgery Outpatient Clinic, Faculty of Dentistry. The research ethics committee approved this research (number ETH3632).

2.2 Sample size calculation

A power analysis was designed to have enough power to test the null hypothesis that there will be no statistically significant difference in the marginal fit of endocrown restoration fabricated by intraoral scanner and extraoral scanner. Using an alpha (α) level of 0.05 (5%), a beta (β) level of 0.20 (20%), i.e. power=80% and an effect size (d) of (0.72) calculated based on the results of Ng et al. [9] The anticipated sample size (n) was found to be a total of (32) samples, Sample size calculation was performed using G*Power version 3.1.9.2.

2.3 Samples selection

The process of tooth selection was guided by a predetermined set of criteria for inclusion and exclusion.

Inclusion Criteria:

The inclusion criteria included the following requirements: The teeth should possess intact structure, free of any cracks, fractures, or previous dental restorations.

Exclusion Criteria:

The exclusion criteria were: Carious teeth, anterior and bicuspid teeth, restored, cracked, fracture, root canal treated teeth, pulp stone, calcified canals or restorations. Additionally, they should exhibit consistent dimensions in terms of both length and width, with an acceptable range of variation between 0.5 to 1mm. Furthermore, the teeth should be easily accessible for the purpose of root canal therapy.

The teeth underwent a disinfection process and were subsequently stored at room temperature in distilled water, with regular weekly changes of the water throughout the duration of the study.

2.4 Samples preparation

Two equal groups (16/group) of lower 1st molars were randomly assigned to E-max endocrown impression techniques. The process of randomization is facilitated through the utilization of a computer-based random number generator, specifically obtained from the website www.random.org. Two millimeters below the CEJ, a double layer of softened modeling wax is wrapped around the tooth roots. The teeth were all set in type IV cylinder stone **(Fig. 1)** to facilitate safe handling during the Biogeneric copy scanning process. **(Fig. 2)**

Figure 1. Tooth inserted in stone cylinder.

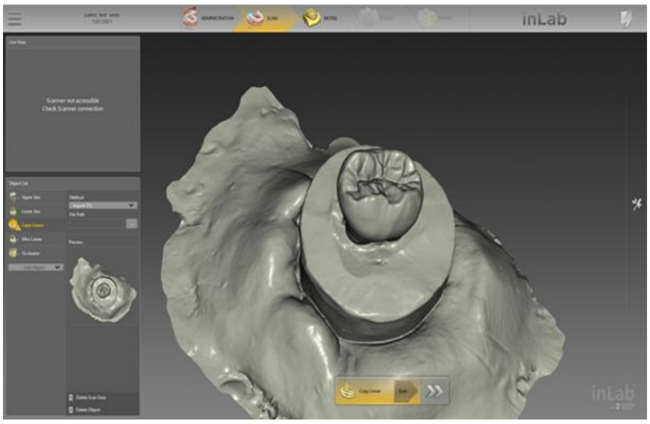

Figure 2. Biogeneric copy scanning of the sample.

The root canal procedure was performed by a single endodontist utilizing a standardized methodology. Following the treatment, all access cavities were sealed with a temporary resin filling material. These sealed cavities were then immersed in distilled water for a duration of three days at room temperature. This was done to ensure complete setting of the resin sealer. After that the tooth was removed from stone mold by applying heat to eliminate wax around the roots. Followed by mounting of each tooth in epoxy resin block using silicon duplicating material polyvinyl siloxane (PVS) mold former with 2x2 cm dimensions. **(Fig. 3)**

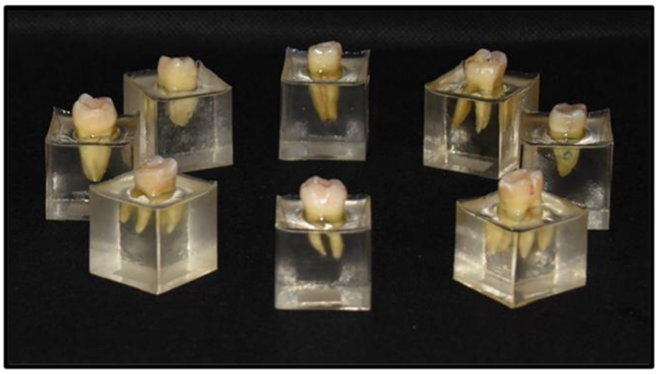

Figure 3. Teeth inserted in epoxy resin blocks

For standardization in this study, all the samples were prepared with the same operator, following the preparation guidelines mentioned in a previous study.[10] Before starting the preparation, a silicon index was fabricated from PVS material for the purpose of standardization of the amount of occlusal reduction, 2 mm depth guide stone used to drill guide grooves, followed by a wheel diamond bur to reduce the occlusal surface along the long axis of the tooth and parallel to the occlusal plane [11,12] which results in a butt joint margin 1 to 2 mm as this type of margin enhances bonding and provides a stable surface that can withstand compressive stresses.[13,14]

In axial preparation, the coronal pulp chamber and endodontic access cavity were made continuously using a tapered flat end inlay stone (medium, fine, super fine in order), with 7^{o} axial wall divergence controlled by the taper of the diamond stones [10], axial wall thickness was verified using digital caliper. The cavity's depth must be at least 3 mm verified using graded periodontal probe.[10] The Orifices of the canals and the floor were sealed, flattened & the undercuts were blocked using flowable Composite.

2.5. Final Impression:

2.5.1 Intra oral scanner group

Direct scanning of the prepared specimens using Powder free intraoral scanner Cerec Omnicam AF Dentsply Sirona CEREC Soft Ware 5.2.4 following the manufacturer instructions.

2.5.2 Extra oral scanner group

For conventional impression taking, a total of 16 custom made special trays were fabricated, final impression was taken using two steps (Zhermack Elite HD+ putty-wash) impression technique. Followed by Pouring of the impression using type IV vacuum mixed dental stone on vibrator, then it left to set until the second day, followed by impression separation and die trimming. Scanning of the plaster model dies was done using Lab scanner (inEos X5 Dentsply Sirona, software 20.0.1)

2.6 Designing and fabrication of the restoration

The final endocrown restoration was designed using InLab CAD SW 22.1.0. The thickness of the spacer was established at 70 microns, while the marginal gap was fixed at 0 microns. The dimensions and occlusal anatomy of the restorations were determined using a biogeneric copy scan. Subsequently, all the restorations were exported to InLab CAM SW 22.0.1. The fabrication of endocrown restorations involved the utilization of monolithic E-max CAD blocks and then further milling utilizing the InLab X5 Dentsply Sirona five-axis milling machine. Crystallization and glazing of restorations were carried out using the Dentsply Sirona MultiMate cube press crystallization furnace, following the instructions provided by the manufacturer.

2.7 Cementation

The intaglio surface of IPS e.max CAD endocrown restorations was etched with 9.5% hydrofluoric porcelain for 20 seconds. washed with water spray for 60 seconds, followed by adequate drying with oil free air and finally immersion in an ultrasonic cleaner. After that, silane was applied to the pretreatment surfaces using a microbrush and given 60 seconds to react.

The dental surfaces underwent treatment by the application of a 37% phosphoric acid gel, applied for 30 seconds on the enamel and 15 seconds on the dentine. Subsequently, a thorough air-water spray lasting 10 seconds was employed to eliminate the etching gel. The etched surface was treated with a bond applicator, whereby a bonding agent was applied. Subsequently, light curing was employed for a duration of 20 seconds. The Breeze™ dual cure resin cement used for cementation, each restoration was seated to its corresponding prepared tooth with light finger pressure, with the aid of customized loading device with consistent occlusal load of 5 kg to standardize the pressure applied during cementation.

2.8 Thermocycling

To simulate artificial aging thermocycling machine (SD Mechatronik Thermocycler, Germany) was used All specimens underwent 10,000 cycles with three rounds in a sequence of each of the following temperatures: 30 seconds at 5 °C, 5 seconds at room temperature, and 30 seconds at 55 °C equivalent to 2 years clinically in the patient mouth. [15]

2.9 Marginal Fit Measurements

Cross section technique was used in this study; for easy and precise sectioning each specimen was marked using ruler and dark marker with 2 mm equidistance vertical lines, also nail polish was used to mark buccal and lingual surface with a special color. The coronal part of the tooth was supported with epoxy resin material using PVC tube as a mold former before sectioning. Each sample was sectioned buccolingually **(Fig. 4)** using Isomet 4000 automated Linear precision saw with 2mm thickness of each slice under copious amount of water coolant (three slices/sample) with three points of measurements at the buccal as well as the lingual surface. After that marginal fit was measured using stereomicroscope under 20x magnification. **(Fig. 5)**

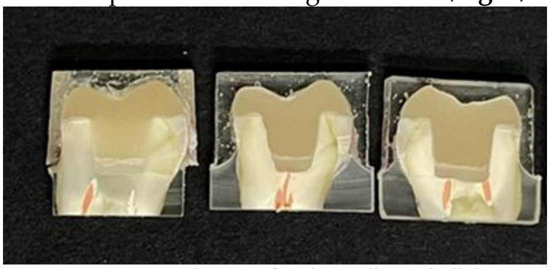

Figure 4. Specimens after buccolingual slicing

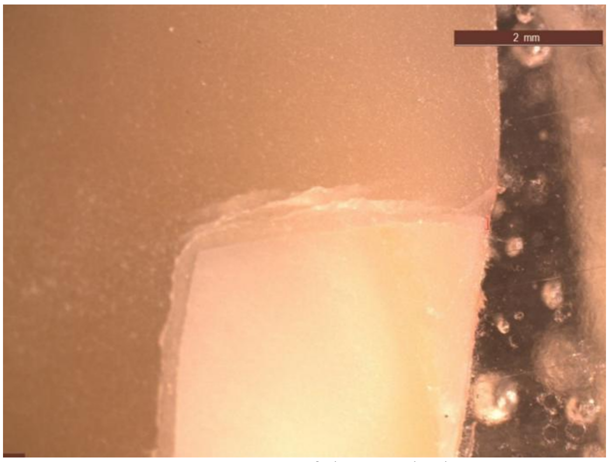

Figure 5. Measurement of the marginal gap.

2.10 Statistical Analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. Repeated measures ANOVA test was used to compare between the two scanners, points of measurement. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at P ≤ 0.05. Statistical analysis was performed with IBM* SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp. Single blinded statistician did all the statistical analysis.

Table 1. Descriptive statistics and results of repeated measures ANOVA test for comparison between marginal fit [gap distance (µm)] of the two scanners

Point of Measurement	Intra-oral scanner (n = 16)		Extra-oral scanner (n = 16)		P-value	Effect size (Partial Eta squared)
	Mean	SD	Mean	SD		
Buccal margin	63.43	7.52	58.97	11.94	0.217	0.05
Lingual margin	62.33	7.7	58.44	9.74	0.219	0.05
Overall	61.2	10.08	60.39	8.86	0.536	0.013

* The mean difference is significant at the 0.05 level.

3 Results

3.1 Comparison between scanners

No statistically significant discrepancy observed in the overall marginal gap distances between the two scanners. **Table 1. (Fig. 6)**

The intraoral scanner revealed a larger marginal gap (63.43µm) at the buccal margin in comparison to the extraoral scanner (58.97µm), although this difference was not found to be statistically significant.

For IOS lingually (62.33µm), there was no significant difference compared to extraoral scanner (58.44µm).

3.2 Comparison between points of measurement

There was no statistically significant disparity observed in the marginal gap distances between the buccal and lingual margins when comparing intra-oral and extra-oral scanners.

Comparing the buccal (63.43 µm) and lingual (62.33µm) marginal gaps, intra-oral scanners showed no significant difference. There was no discernible difference between the margins at the buccal (58.97 µm) and lingual (58.44µm) for the extraoral scanner.

Irrespective of the type of scanner utilized, there was no statistically significant distinction observed among the measurement sites.

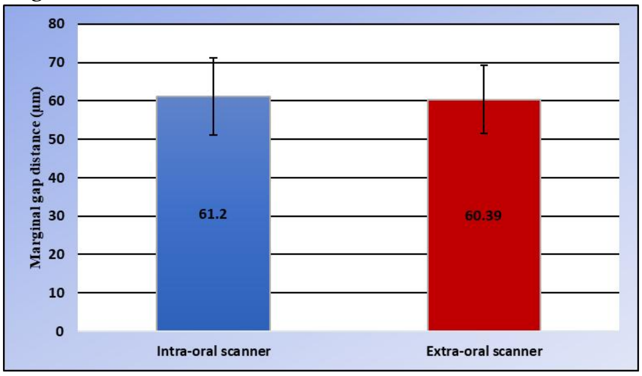

Figure 6. Bar chart representing mean and standard deviation values for marginal fit of the two scanners

4 Discussion

The increasing popularity of minimally invasive restorations, which aim to conserve tooth structure, has resulted in the emergence of an alternative restorative approach characterized by less invasiveness, minimal tooth preparation requirements, and the preservation of the integrity of remaining teeth. One potential alternative for dental restoration is the utilization of an endocrown, which involves the insertion of an internally extending restoration within the pulp chamber, as opposed to the conventional approach of drilling into the canal for post placement. [16-19]

The long-term success of indirect adhesive restorations mostly relies on their internal and marginal adaptability. Many variables, including impression protocol, preparation design, material type, scanner type, milling machine type, cement space, cementation procedure, selection of cement type, and measuring method, have been found to have an impact on both marginal and internal errors. [17] Thus, this Invitro investigation compared intraoral and extraoral scanning methods while holding all other variables constant between specimens.

In this study, human natural teeth were used as the bonding substrate to evaluate the tooth-cement-restoration complex and its ability to closely replicate the clinical scenario. [20]

Biogeneric copy of all the teeth were done before preparation to restore the tooth after reduction to its original anatomical shape, width, and height. To ensure standardization in this study, all samples were prepared by the same operator, adhering to the preparation guidelines outlined in previous studies. [10,21,22] The decision to use a 90° butt margin design was supported by Taha *et al.* [23], who highlighted that the type of finish line may affect the vertical marginal gap.

Numerous studies have evaluated the precision of digital scans and consistently found them to be highly accurate. [24,25] In this study, the CEREC CAD/CAM system was employed to standardize the STL language and minimize errors. [26] All impressions were taken by the same operator to maintain standardization. The final impressions for the intraoral scanner group were obtained using the Omnicam AF IOS, a powderless video imaging scanner with active triangulation technology, known for its high precision and accuracy according to prior studies. [27,28]

For the first group, direct scanning with the intraoral scanner was chosen because digital impressions obtained via intraoral scanners are as accurate, or even superior, compared to extraoral scanners. [25] For the second group, final impressions were made using the two-step putty/light-body technique, which is well-documented as an accurate method in the literature. [29,30] To avoid dimensional discrepancies, all conventional impressions from the second group were promptly poured using type IV extra-hard vacuum-mixed stone, and the resulting dies were scanned using an InEos X5 CAD/CAM scanner. This scanner, featuring a five-axis rotatable arm and blue light technology, is highlighted in the literature for its superior performance compared to other scanners. [31,32]

The decision to utilize direct cast digitization was based on findings by Abduljawad and Rayyan, who reported that endocrowns fabricated through direct digitization of the tooth using IOS or cast digitization with IOS or EOS showed statistically insignificant differences in mean marginal gap, while impression scanning yielded inferior marginal fit. They justified that direct scanning could show potential errors. [19,33]

Monolithic lithium disilicate E-max ceramics were used for the fabrication of endocrown restorations due to their high mechanical strength, excellent bonding ability, and compatibility with acid etching. Combined with adhesive systems and resin cements, these materials provide enhanced durability, high esthetics, and superior marginal fit, largely attributable to their needle-like microstructure that limits crack propagation.[19]

In this study, lithium disilicate E-max CAD was used instead of E-max Press to eliminate potential errors that might occur during the fabrication process and to reduce human factors. [34] A 5-axis milling machine was utilized for the fabrication of the restorations, as the type of milling device significantly influences the adaptation of restorations, particularly for complex shapes such as endocrowns with deep grooves and internal angles. [35]

The etch-and-rinse technique was selected because it is considered the gold standard. This method removes the smear layer, allowing the adhesive resin to penetrate deeply and form resin tags, which enhance adhesion quality and ultimately improve the durability and longevity of the restoration. [36]

Cementation was performed using auto-mixed, dual-cured, self-adhesive resin cement. This approach reduces the number of application steps, shortens clinical treatment time, and minimizes technique sensitivity by reducing procedural errors. Dual-cured resin was chosen because it can be cured through both chemical and light activation. [37] This type of cement is particularly beneficial when the ceramic is too thick or opaque to allow light transmission, as is often the case with endocrown restorations. In such scenarios, light curing seals the margins, and chemical polymerization ensures complete curing in deeper areas. [23,37]

A customized loading device was employed to apply a 5 kg occlusal load during cementation, ensuring complete seating of the restoration and standardization of the load applied during the procedure. [38]

Thermal aging was included as an essential component of the in vitro study to simulate clinical conditions and assess the restorations under realistic scenarios. Thermocycling enhances the solubility and dissolution rate of cement at the restoration margins and can influence marginal gap values [(39)]. These effects result from differences in the thermal expansion properties of the cement, tooth, and restorative materials [(40)]. Each specimen underwent 10,000 cycles of thermocycling at temperatures of 5°C and 55°C, equivalent to two years of clinical service. [15]

The marginal fit of the restorations was measured directly under a stereomicroscope after cementation using the direct sectional measurement method. Specimens were sectioned buccolingually with an Isomet diamond saw into slices with a thickness of 2 mm, as specified in previous studies. [38] The advantages of this technique include the ability to measure the gap in various regions along the restoration-cement interface, providing precise and accurate results. However, its limitations include the destruction of samples and the inability to perform measurements intraorally. As a result, this study was conducted in vitro. To protect the ceramic material and prevent damage during sectioning, the coronal part of the tooth was mounted in epoxy resin. [41]

Marginal fit was evaluated using a stereomicroscope, a widely used measurement tool in the literature. [20,40] This method is straightforward, as it does not require sample preparation, gold spattering, or exposure to radiation, unlike electron microscopy and micro-CT. However, stereomicroscopic evaluation poses challenges in differentiating the actual marginal gap from its projection and in consistently repeating measurements from the same angle. [40,42]

Regarding the null hypothesis, it was accepted. No statistically significant differences were observed in marginal gap distances between the two scanners, either at the buccal or lingual margins. Additionally, no significant difference was found in the overall marginal gap distances between the scanners, with mean values **IOS = (61.2μm), EOS = (60.39μm)**. This is likely attributable to the in vitro setting, where factors such as adjacent teeth, cheeks, tongue, and saliva, which might influence scanning accuracy, were absent.

Falahchai *et al.* [43] demonstrated no significant differences in marginal gap values for intraoral scanner and extraoral scanner cast digitized endocrowns, supporting our investigation. The intraoral scanner group had a mean marginal gap of 70 μm, while the conventional group had 74μm the findings are higher than our study but agreed with it. Different scanners and restoration materials make direct comparison challenging.

In agreement with this study, **Dauti *et al.*** [44] found that marginal fit of polymer infiltrated ceramic material fabricated using polyether conventional impression material was similar to trios(3shape) IOS and true definition (3M ESPE) IOS when using micro-CT.

Sakornwimon *et al.* [45] showed no significant difference in margin fit of full coverage ceramic crowns between intraoral digital scanning and conventional impression, supporting our findings. Due to their different study designs, they measured the marginal gap in vivo using zirconia crowns, in addition to using 1-step PVS conventional impressions. Also, the marginal gap was measured using replica apparatus.

In agreement with our study **Abdel-Azim *et al.*** [46] evaluated the marginal fit of e-max CAD crowns fabricated with two digital intraoral scanners with that fabricated with conventional impression technique, the marginal gap results weren't differed significantly, though it was found that conventional impression produced crowns with larger marginal gap, this is mainly due to difference in the study methodology, different intraoral scanners used that need powder application. Also, measurement was done before cementation by direct viewing under x60 stereomicroscope. [47] The study found that both the conventional impression technique and the direct digital scanning method had no significant impact on the marginal differences observed in onlays and partial crowns of mandibular molars.

Abdul Jawad and Rayyan [19] found that regardless of the method of digitization direct intraoral scanning or indirect cast scanning, endocrown restorations made digitally displayed superior marginal adaptation over those made with conventional impressions, which could be attributed to the discrepancy caused by the impression and die.

Nassar *et al.* [40] founded that E-max CAD endocrowns produced using complete digital workflow using Omnicam AF had superior marginal adaption than those produced with conventional impression protocol and indirect cast digitization with the same intraoral scanner, which is in contradiction with the present study. This is maybe due to the difference in impression techniques and different cast digitization methods.

Limitations of the study

This study was conducted in-vitro to allow proper examination of the marginal gap directly under microscope using cross sectional technique, however, thermocycling was done to simulate the clinical condition which is not resemble to the real clinical scenario. Further in vivo studies are advised to evaluate marginal and internal fitting under clinical conditions to determine the effect of moisture and humidity, mouth opening, lighting and surrounding environment, adjacent teeth, and clinical aging.

5 Conclusion

Within the limitations of the study, it was found that:

1. Extra oral scanners produced a restoration with smaller marginal gap compared to intraoral scanners and the difference was statistically insignificant.
2. Both impression techniques produced a restoration with clinically acceptable marginal fit after 2 years of simulated clinical service.
3. Intraoral scanner results in higher numerical gap values.

Authors' Contributions

Hayat Hany (H.H.) conducted the literature search, performed the experimental work, and wrote the in-vitro study.

Rabab Abdullah (R.A.) proposed the study idea and provided guidance throughout the experimental work and the writing process.

Aya Salama (A.S.) contributed to refining the study topic, and revised the manuscript.

Conflict of interest

The authors declare that they hold no competing interests.

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