

Comparative Analysis of Marginal Adaptation for Zirconia Monolith Crowns Fabricated using Conventional Impression Versus Digital Impression Techniques

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Abstract

This In- vitro comparative study aimed to evaluate and compare the marginal fit of full-contour monolithic zirconia crowns fabricated using conventional and digital impression techniques, as marginal adaptation is a key factor influencing the biological success and longevity of fixed dental restorations. Poor marginal fit can result in plaque accumulation, gingival inflammation, secondary caries, and eventual failure of the prosthesis. Fifteen samples of monolithic zirconia crowns were fabricated in each of three groups resulting in total sample size of 45 (n=45). Group 1 utilized the conventional polyvinyl siloxane impression technique (3M ESPE/Dentsply, USA) with a die model (Neelkanth, India), Group 2 employed digital impressions obtained from Digital Scanner-A (UPCERA, China) with a 3D-printed resin model, and Group 3 used digital impressions from Digital Scanner-B (Medit i600, South Korea) with a 3D-printed resin model. All crowns were fabricated using a standardized CAD/CAM workflow, and Marginal discrepancy was evaluated using a stereomicroscope at 45× magnification and analyzed using image analysis software. Statistical analysis was performed using one-way ANOVA followed by post hoc testing. The results showed that the conventional technique exhibited the highest marginal discrepancy (77–84 µm), whereas both digital techniques demonstrated significantly lower discrepancies (41–47 µm) ($p < 0.005$), with no statistically significant difference between the two digital scanners. Within the limitations of this In- vitro study, digital impression techniques demonstrated superior marginal fit compared to the conventional impression technique.



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Introduction

The advancement of restorative and prosthodontic dentistry emphasizes precision, longevity, esthetics of restoration and patient comfort. Fixed prosthodontic restorations, particularly crowns, require accurate marginal adaptation to ensure long term biological and mechanical success.¹ Inadequate marginal fit may result in microleakage, plaque accumulation, cement dissolution, secondary caries, periodontal inflammation, pulpal pathology, and restoration failure. Elastomeric impression materials such as polyvinyl siloxane have long been regarded as the gold standard because of their accuracy; however, they are technique sensitive, time consuming, and often associated with patient discomfort and gag reflex.^{2,3}

The introduction of digital dentistry has enabled intraoral scanning as an alternative impression technique, allowing direct three-dimensional recording of prepared teeth without impression materials.⁴ Digital impressions improve patient comfort, reduce chairside time, enhance clinical workflow efficiency, and allow immediate visualization and verification of preparation details. Additionally, digital data can be stored, transferred, and reused without dimensional distortion, facilitating seamless integration with CAD/CAM systems. Concurrently, monolithic ceramic crowns, particularly zirconia and lithium disilicate, have gained popularity due to their superior strength, esthetics, and resistance to chippings.⁵⁻⁷

High impression accuracy is essential for monolithic crowns, as even minor discrepancies can compromise marginal integrity and long-term performance. Despite a clinically acceptable marginal gap of 50-120 μm ,^{8,9} Although several studies have compared conventional and digital impression techniques, conflicting evidence exists regarding their accuracy and marginal adaptation outcomes, particularly with different intraoral scanners and fabrication workflows.¹⁰ Therefore, the aim of this study was to evaluate and compare the marginal adaptation of monolithic zirconia crowns fabricated using conventional and

two different digital impression techniques under standardized in-vitro conditions.

Materials and Methods

The present in-vitro comparative experimental study was conducted to evaluate and compare the marginal fit of monolithic zirconia crowns fabricated using conventional polyvinyl siloxane and digital impression techniques at Department of Prosthodontics and Crown & Bridge following Institutional ethical committee guidelines and approval. Fifteen samples ($n=15$) were fabricated for each group, resulting in a total of forty-five samples ($n=45$). Group 1 consisted of monolithic zirconia crowns fabricated using the conventional impression technique with polyvinyl siloxane (PVS) impression material (3M ESPE/Dentsply, USA) and Type IV die stone (Neelkanth, India). Group 2 and Group 3 consisted of monolithic zirconia crowns fabricated using digital impression techniques with Intraoral Scanner-A (UPCERA, China) and Intraoral Scanner-B (Medit i600, South Korea), respectively, followed by fabrication of corresponding 3D-printed resin models (ELEGOO, China).

Tooth preparation was performed on a maxillary first premolar on typodont model (API, India). All samples were fabricated using a single standardized tooth preparation to eliminate variability. Operator calibration was performed prior to the study to ensure consistency in preparation, impression making, and scanning procedures. The preparation included an occlusal reduction of 2 mm and an axial reduction of 1 mm to ensure adequate material thickness and strength. A uniform circumferential shoulder finish line of 1 mm width was prepared to provide adequate marginal support, and the axial walls were prepared with a total occlusal convergence of 6° to achieve optimal retention and resistance form. Four standardized reference points were established on the buccal, palatal, mesial, and distal surfaces of the prepared tooth to facilitate precise and consistent evaluation of marginal adaptation (Figure 1).

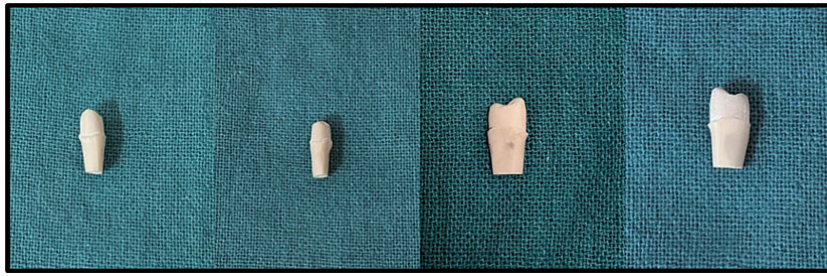


Fig. 1: Four Reference Points: Buccal, Palatal, Mesial and Distal Surfaces

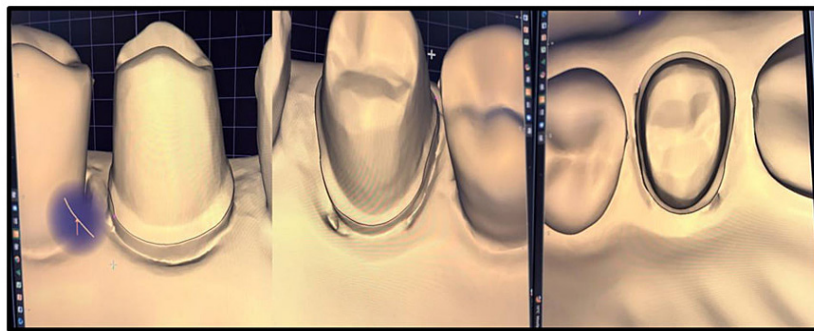


Fig. 2: Monolithic zirconia crowns were designed using CAD software with defined finish lines around the prepared teeth

For the conventional group, impressions were made using polyvinyl siloxane impression material according to the manufacturer's instructions and for the digital groups, impressions were obtained using two different intraoral scanners, and Different model materials, Type IV die stone (Neelkanth, India) for conventional and 3D-printed resin (ELEGOO, China) for digital groups were used as per workflow requirements. The 3D printing process was performed using ELEGOO printer with a layer thickness of 50 μm , followed by post-curing as per manufacturer's instructions to ensure dimensional accuracy. This different model materials may introduce a potential confounding variable, and its possible influence on marginal fit has been considered during interpretation All models were subsequently scanned using a laboratory scanner (Shining 3D, China) after application of scan spray (Alpha Dent, Korea) to enhance scanning accuracy and surface detail capture.

Monolithic zirconia crowns were designed using CAD software (EXOCAD, Germany) with standardized

parameters (Figure 2), including an internal thickness of 0.6 mm and a cement space of 0.05 mm. The crowns were milled from pre-sintered zirconia blanks (Nobilcam, China) using a 5-axis milling machine (Roland DWX-53DC, Japan). Following milling, the crowns were sintered in a zirconia sintering furnace (LNY model 5F, China) according to the manufacturer's instructions. Finishing and polishing procedures were carried out to obtain clinically acceptable crowns with standardized surface characteristics (Figure 3). Marginal Adaptation of all fabricated crowns was evaluated at the four predetermined reference points using a stereomicroscope at 45 $\times$ magnification. Marginal fit was evaluated without cementation to eliminate variability introduced by cement thickness. Standardized digital images were captured and analyzed using image analysis software to measure marginal gap values in micrometers (μm). Consistent imaging conditions were maintained throughout the evaluation process to ensure accuracy and reproducibility of measurements (Figure 4,5,6).

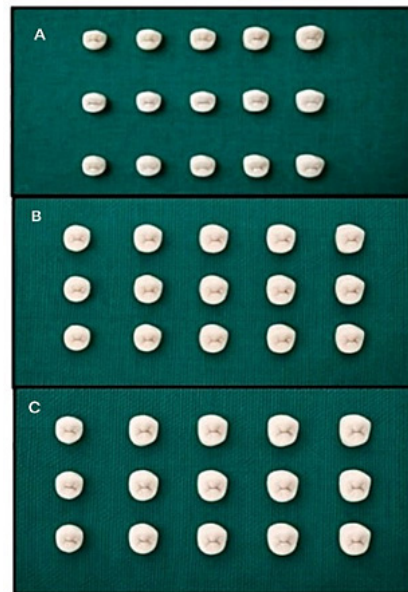


Fig. 3: Sample of Monolithic Zirconia Crowns Fabricated by: A. Conventional Impression Technique, B. Digital Scanning -A, C. Digital Scanning-B

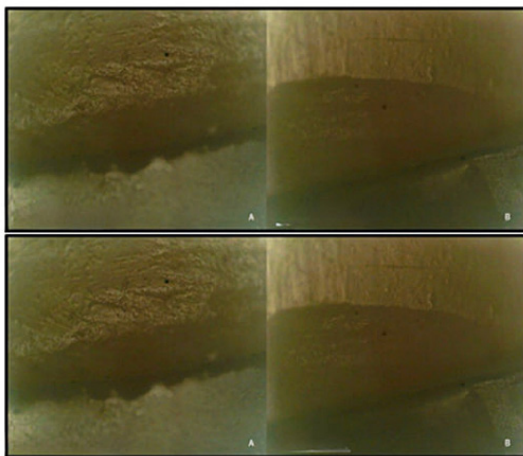


Fig. 4: Stereomicroscopic Photomicrographs Image showing Marginal Discrepancy (Group 1): A. Buccal, B. Palatal, C. Mesial, D. Distal

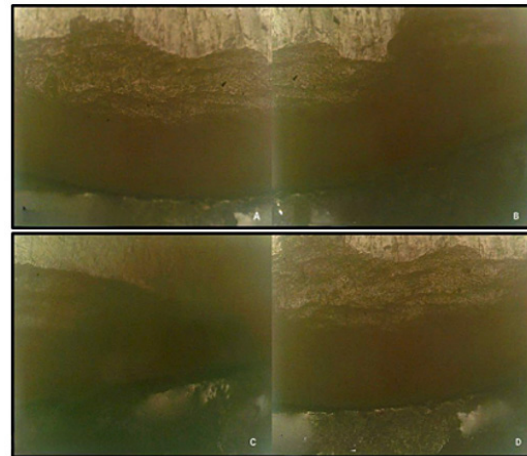


Fig. 5: Stereomicroscopic Photomicrographs Image showing Marginal Discrepancy (Group 2): A. Buccal, B. Palatal, C. Mesial, D. Distal

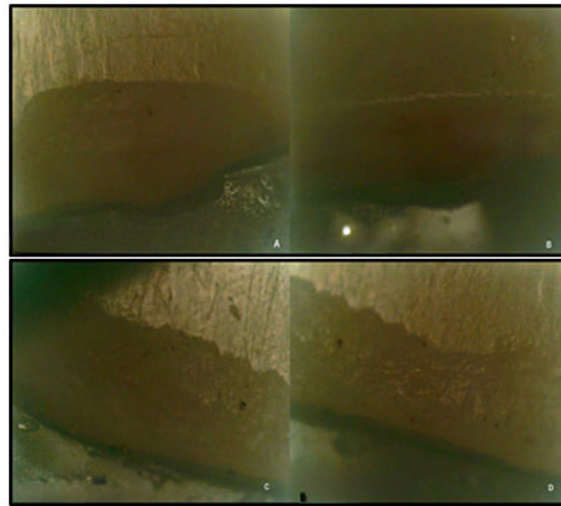


Fig. 6: Stereomicroscopic Photomicrographs Image showing Marginal Discrepancy (Group 3): A. Buccal, B. Palatal, C. Mesial, D. Distal

Data were tabulated using Microsoft Excel 2010 and analyzed using SPSS version 27.0. Descriptive statistics included mean and standard deviation. Normality was assessed using the Kolmogorov-Smirnov test. For normally distributed data, t-test and one-way ANOVA were applied, followed by Tukey's post hoc test; for non-normal data, Wilcoxon signed-rank and Kruskal–Wallis tests were used. Statistical significance was set at $p < 0.05$.

Results

This study evaluated the marginal adaptation of monolithic zirconia crowns fabricated using three different impression techniques: conventional impression technique, digital scanner-A (UPCERA, China), and digital scanner-B (Medit i600, South Korea). Table 1 shows intragroup comparison of Marginal discrepancy within each technique and was measured at the buccal, palatal, mesial, and distal surfaces. For the conventional impression group, the mean marginal discrepancy was $77.33 \pm 4.386 \mu\text{m}$, $80.80 \pm 4.074 \mu\text{m}$, $84.00 \pm 4.174 \mu\text{m}$, and $79.53 \pm 4.340 \mu\text{m}$ on buccal, palatal, mesial and distal surface respectively, with the mesial surface showing the highest marginal discrepancy. For the digital scanner-A (UPCERA, China), the mean marginal discrepancy values were markedly lower, with $41.60 \pm 2.873 \mu\text{m}$, $44.60 \pm 2.873 \mu\text{m}$, $46.60 \pm 2.873 \mu\text{m}$, and $43.60 \pm 2.873 \mu\text{m}$ at the buccal,

palatal, mesial and distal surface respectively. Similarly, for the digital scanner-B (Medit i600, South Korea), the mean marginal discrepancy was $42.60 \pm 2.873 \mu\text{m}$, $45.60 \pm 2.873 \mu\text{m}$, $47.60 \pm 2.873 \mu\text{m}$, and $44.60 \pm 2.873 \mu\text{m}$ at buccal, palatal, mesial and distal surface respectively. Table 2 shows Intragroup analysis demonstrated that, within each technique, the mesial surface consistently exhibited the highest marginal discrepancy, while the buccal surface showed the lowest marginal discrepancy, indicating surface-wise variation in marginal adaptation. The post hoc comparison of marginal discrepancies at all four surfaces (buccal, palatal, mesial, and distal) demonstrates a consistent pattern. The conventional impression technique showed higher marginal discrepancy across all surface compared to both digital scanning methods Scanner A (UPCERA, China) and Scanner B (Medit i600, South Korea). All these differences were highly significant ($p < 0.001$). In contrast, the comparison between Scanner A (UPCERA, China) and Scanner B (Medit i600, South Korea) revealed minimal mean differences of approximately $-1.00 \mu\text{m}$ across all surfaces, which were statistically non-significant ($p > 0.05$). This indicates that both digital scanning systems performed similarly and provided superior marginal fit compared to the conventional technique across all evaluated surfaces.

Table 1: Intragroup Comparison of Marginal Discrepancy of Monolithic Zirconia Crowns Fabricated by Conventional Impression and Digital Scanning Techniques

Parameters	Groups	Mean(μm)	Std. Deviation(μm)	F-value(μm)	p-value, S/NS
BUCCAL	Conventional	77.33	4.386	521.142	<0.001, HS
	Scanner A	41.60	2.873		
	Scanner B	42.60	2.873		
PALATAL	Conventional	80.80	4.074	577.654	<0.001, HS
	Scanner A	44.60	2.873		
	Scanner B	45.60	2.873		
MESIAL	Conventional	84.00	4.174	602.053	<0.001, HS
	Scanner A	46.60	2.873		
	Scanner B	47.60	2.873		
DISTAL	Conventional	79.53	4.340	533.035	<0.001, HS
	Scanner A	43.60	2.873		
	Scanner B	44.60	2.873		

Table 2: Intergroup Comparison of Marginal Discrepancy of Monolithic Zirconia Crowns Fabricated by Conventional Impression and Digital Scanning Techniques

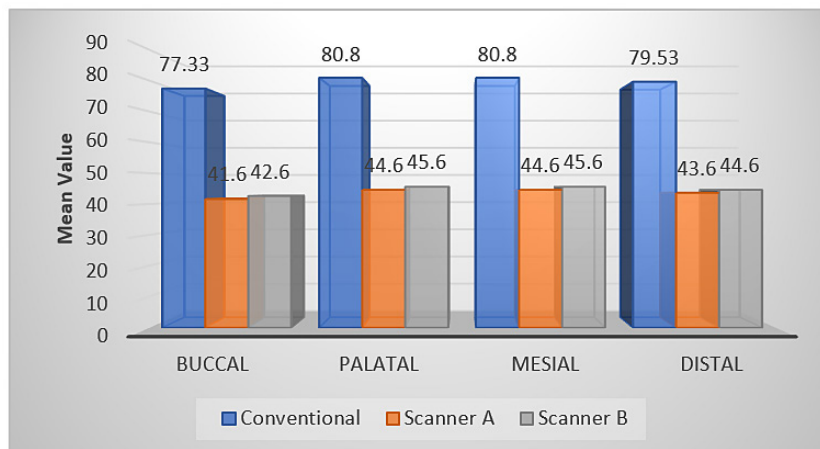
Dependent Variable	(I) GROUP(μm)	(J) GROUP(μm)	Mean Difference (I-J) (μm)	p-value, S/NS
BUCCAL	Conventional	Scanner A	35.73333*	<0.001, HS
		Scanner B	34.73333*	<0.001, HS
	Scanner A	Scanner B	-1.00000	0.709, NS
PALATAL	Conventional	Scanner A	36.20000*	<0.001, HS
		Scanner B	35.20000*	<0.001, HS
	Scanner A	Scanner B	-1.00000	0.690, NS
MESIAL	Conventional	Scanner A	37.40000*	<0.001, HS
		Scanner B	36.40000*	<0.001, HS
	Scanner A	Scanner B	-1.00000	0.696, NS
DISTAL	Conventional	Scanner A	35.93333*	<0.001, HS
		Scanner B	34.93333*	<0.001, HS
	Scanner A	Scanner B	-1.00000	0.706, NS

Graph 1 illustrates the comparative mean marginal discrepancy values (μm) of monolithic zirconia crowns fabricated using the conventional impression technique, digital scanner-A (UPCERA, China), and digital scanner-B (Medit i600, South Korea) at the buccal, palatal, mesial, and distal surfaces. The graph clearly demonstrates that the conventional impression technique recorded the highest marginal discrepancy values across all evaluated surfaces, ranging approximately from 77 μm to 84 μm , indicating comparatively poorer marginal adaptation. In contrast, both digital scanning techniques showed

substantially lower marginal discrepancy values. Digital scanner-A (UPCERA, China) exhibited values ranging from approximately 41 μm to 47 μm , while digital scanner-B (Medit i600, South Korea) showed values between 42 μm and 48 μm , indicating improved marginal accuracy. Among the two digital systems, scanner-A (UPCERA, China) showed slightly lower marginal discrepancy values compared to scanner-B (Medit i600, South Korea). Post hoc pairwise test showed that the conventional impression technique had significantly higher marginal discrepancy than both digital scanner-A and scanner-B ($p < 0.001$).

However, no statistically significant difference was observed between the two digital scanners ($p > 0.05$), indicating comparable performance. Across all three techniques, the mesial surface consistently demonstrated the highest marginal

discrepancy, whereas the buccal surface showed the lowest values, indicating better marginal adaptation at the buccal region. Overall, the graph highlights the superior marginal fit obtained with digital impression techniques compared to the conventional method.



Graph 1: Comparison of mean marginal discrepancy values at buccal, palatal, mesial, and distal surfaces among Conventional, Scanner A, and Scanner B techniques

Discussion

This study evaluated the marginal fit of monolith zirconia crowns fabricated using a conventional impression technique compared with those fabricated using two different digital scanning techniques. The results demonstrated clear differences in marginal discrepancy values among the three groups, highlighting the significant influence of the impression technique on marginal accuracy.

Crowns fabricated using the conventional impression technique exhibited the highest marginal discrepancy values at all evaluated reference points. Mean values ranged from approximately 77 µm to 84 µm, with the mesial surface consistently showing the greatest discrepancy. These findings can be attributed to the inherent limitations of conventional impression procedures, including impression material shrinkage, tray distortion, incomplete seating, and dimensional changes during impression removal, stone pouring, and die trimming. Each of these steps introduces potential sources of error, which may accumulate and adversely affect the final marginal fit of the restoration.

In contrast, crowns fabricated using digital scanner-A (UPCERA, China) and digital scanner-B (Medit i600, South Korea) demonstrated significantly lower marginal discrepancy values across all surfaces, with mean values ranging from approximately 41 µm to 47 µm. The superior marginal adaptation observed in the digital groups may be explained by the elimination of multiple intermediate steps associated with conventional impressions. The improved marginal fit observed in digital workflows may be attributed to elimination of intermediate steps, reduced material distortion, and enhanced precision of CAD/CAM systems, leading to improved dimensional stability. Furthermore, the ability to visualize scan data immediately allows for the detection and correction of errors during the scanning process itself, improving overall accuracy.^{11,12}

These findings are consistent with recent studies. Dogan *et al.*, (2025) reported that CAD-CAM fabricated monolithic zirconia crowns demonstrate superior marginal and internal fit due to improved material processing and digital accuracy. Similarly, Seshan *et*

al., (2024) showed that crowns fabricated using digital impressions exhibited better marginal adaptation compared to indirect workflows, emphasizing the role of direct data capture in minimizing distortion. Furthermore, a systematic evaluation by Rojas-Rueda *et al.*, (2025) concluded that digital impressions provide higher accuracy and consistency, supporting their increasing adoption in prosthodontics.¹³⁻¹⁵

Statistical analysis revealed a highly significant difference between the conventional impression technique and both digital scanning techniques at all reference points, confirming the superior marginal accuracy of digitally fabricated monolithic zirconia crowns. These findings are consistent with previous studies reporting improved marginal adaptation with digital impression workflows. When comparing the two digital scanning systems, digital scanner-A (UPCERA, China) showed slightly lower marginal discrepancy values than digital scanner-B (Medit i600, South Korea) however, this difference was not statistically significant.

Surface-wise analysis revealed that the mesial surface exhibited higher marginal discrepancy values across all groups, likely due to its complex anatomy and limited accessibility, which can compromise both impression making and scanning accuracy. Conversely, the buccal surface consistently showed the lowest marginal discrepancy values, possibly due to better visibility and ease of access. This study has limitations, including its in-vitro design, absence of cementation, use of different model materials, and possible operator-related variability. However, future scope relies on modifications and standardization for the same.

Conclusion

This study shows that impression technique plays a crucial role in the marginal fit of monolithic zirconia crowns. Conventional methods resulted in greater and uneven discrepancies, while digital scanners produced more accurate and uniform results within clinically acceptable limits. A highly significant difference was found between conventional and digital techniques, with no significant difference between the two digital systems. Overall, digital impressions offer better accuracy and reliability for fixed prosthodontic applications.

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Conflict of Interest

The author(s) declares no conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to reproduce material from other sources

Not Applicable

Authors Contribution

- **Komal Shah:** Study Design, Data Collection, Analysis, Manuscript Drafting.
- **Mukesh Kumar Goyal:** Supervision, Study Design, Data Interpretation, Revision.
- **Geeta Paul:** Data Analysis, Manuscript Revision.
- **Isha Saxena:** Data Collection, Sample Preparation, literature Review.
- **Madhav:** Methodology, Data Validation, Editing
- **Shreysha:** Statistical Analysis, Proofreading, Final Preparation.

- **Nidhi Shree:** Data Collection, Literature Review, Editing.
- **Bajaj Amitkumar Shamlal:** Supervision, data Interpretation, Critical Review.

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