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Comparison of subgingival finish line reproduction in intraoral scanning versus conventional impressions: a randomized crossover clinical study with/without gingival retraction

Prajakta Raghudas Volvaikar[1], Kennedy Mascarenhas[1], Meena Ajay Aras[1], Aradhana Nagarsekar[1]*, Mitalee Mopkar[1], Ridhima Gaunkar[2], Anushka Kunkolienkar[1]
[1]Department of Prosthodontics, Goa Dental College and Hospital, Bambolim- Goa, India
[2]Department of Public Health Dentistry, Goa Dental College and Hospital, Bambolim- Goa, India

ORCID
Prajakta Raghudas Volvaikar
https://orcid.org/0009-0009-8876-1886
Kennedy Mascarenhas
https://orcid.org/0000-0003-4361-0434
Meena Ajay Aras
https://orcid.org/0000-0002-2525-650X
Aradhana Nagarsekar
https://orcid.org/0000-0002-3039-3277
Mitalee Mopkar
https://orcid.org/0009-0007-5602-1483
Ridhima Gaunkar
https://orcid.org/0000-0003-1019-100X
Anushka Kunkolienkar
https://orcid.org/0009-0006-0389-0899

PURPOSE. To evaluate the competence of intraoral scanners in recording subgingival finish lines compared with conventional impressions, with and without gingival retraction. **MATERIALS AND METHODS.** A randomized crossover, clinical trial was conducted on 15 participants. Mandibular first molars were prepared for full-coverage crowns, and four impression techniques were performed: digital without retraction (DWR), digital with retraction (DR), conventional without retraction (CWR), and conventional with retraction (CR). A 1-week washout separated digital and conventional methods. STL files were generated and superimposed using a best-fit algorithm. Measurements were made at three sites (B-buccal, M-mesial, D-distal) for finish line width(1), depth(2), and gingival retraction(3). **RESULTS.** Significant intergroup differences were noted in B3, M1, M3, and D3. In these subgroups, DWR consistently demonstrated lower reproducibility. In B3, DR and CR were significantly better than DWR. In M1 and D3, DR, CWR, and CR showed significantly superior reproduction compared to DWR. In M3, CR showed significantly better results than DWR. Other parameters were comparable across groups. **CONCLUSION.** Digital and conventional impressions demonstrated higher reproducibility for shallow subgingival finish lines when gingival retraction was done. Without gingival retraction, finish line reproduced by conventional impressions was more defined than digital, underscoring the importance of retraction for reliable digital capture of subgingival margins. [J Adv Prosthodont 2026;18:92-102]

KEYWORDS
Intraoral scanner; Gingival retraction; Digital impression; Subgingival finish lines

Corresponding author
Aradhana Nagarsekar
Department of Prosthodontics, Goa Dental College and Hospital, Rajiv Gandhi Medical Complex, Bambolim-Goa, Zip/Pincode-403202, India
Tel +919673991500
E-mail aradhana.nagarsekar@gmail.com

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INTRODUCTION

Digital dentistry has advanced considerably in recent years, with intraoral scanners (IOS) becoming an integral part of routine clinical practice. Digital impressions are increasingly preferred as they reduce chairside time, eliminate the need for plaster models, and enhance communication between clinicians, technicians, and patients.[1-3] A key determinant of their success is the accurate reproduction of preparation finish lines, as this directly influences the marginal and internal fit of fixed prostheses.[4]

Despite these advantages, two major limitations remain with IOS: the reproducibility of full-arch scans and the reliable capture of finish lines, particularly when they are located subgingivally. [5-7] When finish lines are positioned ≥ 0.5 mm below the gingival margin and scanned without gingival retraction, IOS frequently produce trueness errors exceeding 100 µm, surpassing clinically acceptable thresholds for restoration fit.[8] Gingival displacement techniques, such as retraction cords, are therefore recommended to apically reposition the gingival margin and widen the sulcus, thereby improving visibility and enabling more accurate capture of the abutment surface.[9,10]

A growing body of *in vitro* evidence demonstrates that discrepancy in impressions obtained with gingival retraction consistently remain within the 100 µm benchmark, whereas those captured without retraction show significantly reduced reliability.[8,11] However, most of these investigations have been performed under controlled laboratory conditions, and there are limited *in vivo* clinical data to validate these findings.[12] Prospective clinical studies are therefore required to determine whether gingival retraction significantly improves the subgingival finish line capture in digital impressions.

The current study aims to evaluate the reproducibility of intraoral scanners in recording subgingival finish lines by evaluating the three critical parameters, i.e. the depth and width of the finish line and the extent of gingival retraction of the prepared tooth, with and without gingival retraction for fabrication of fixed prostheses in comparison with the conventional impression techniques.

The null hypothesis states that the subgingival finish line capture is not influenced by the impression technique or by the use of gingival retraction. The research hypothesis states that differences exist in the finish line capture of intraoral scanners depending on the impression technique used and the application of gingival retraction.

MATERIALS AND METHODS

This study was done in accordance with CONSORT guidelines for crossover trials (2025).

1. Study design

The trial was a randomized double blind, crossover design of 1.5 months' duration. Each subject served as its own control. Within-subject control improves statistical power and reduces variability. Each participant contributed one prepared tooth, which was evaluated under four experimental conditions (intraoral scan with and without gingival retraction; conventional impression with and without gingival retraction). A washout period of one week was maintained between intraoral scanning and conventional impression phases to minimize potential carryover effects between the crossover. Finish line visibility was assessed digitally using Exocad software (Exocad Dental CAD 3.0 Galway, Exocad GmbH, Darmstadt, Germany) and by blinded evaluators to ensure objectivity. The allocation sequence was generated using a Latin square design and allocation concealment was maintained by assigning the intervention sequence using sealed, opaque envelopes prepared by an independent investigator not involved in participant recruitment, intervention delivery, outcome assessment, or data analysis. Double blinding was implemented at the level of outcome assessment and data analysis; both the outcome assessor and the statistical analyst were blinded to group allocation and intervention sequence throughout data collection and analysis to minimize assessment and analytical bias. The overall study workflow is illustrated in Figure 1.

2. Patient selection

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki

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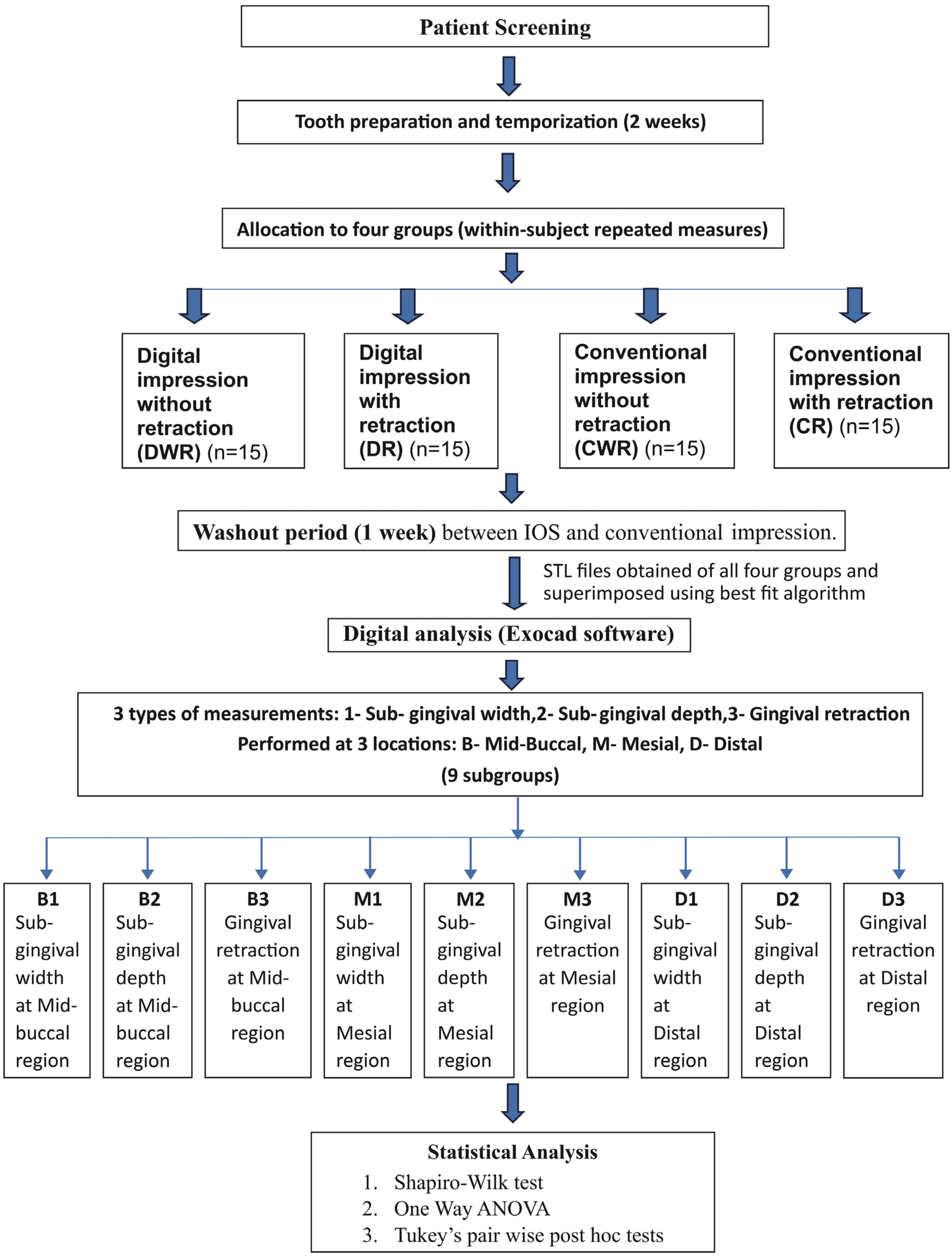

Fig. 1. Flowchart of study design.
Schematic representation of patient recruitment, tooth preparation, impression procedures (with and without gingival retraction), and digital analysis workflow.

(2008 revision) and received approval from the Institutional Ethics Committee, (Ref. No.:GDCH/IEC/VII-2025(03)). Trial was registered (Registration number-CTRI/2025/10/095921).

Patients who reported to the Department of Prosthodontics, in the month of October 2025, for fixed prosthetic rehabilitation on natural teeth were screened for eligibility.

Inclusion criteria

- Age – between 18 – 50 years
- Requirement for a single full-coverage crown on a mandibular first molar
- Periodontally healthy (Whole mouth bleeding sites < 10%, full mouth plaque score (FMPS) < 20%, no loss of attachment)
- General good systemic health

Exclusion criteria

- Presence of active infection or severe periodontal inflammation
- Restorations in cervical 1/3rd of teeth
- History of chronic systemic disease
- Current or past smoking habit
- Presence of parafunctional habits

Eligible participants were rehabilitated with either a single monolithic zirconia crown or a porcelain-fused-to-metal crown, according to the planned treatment. Informed consent was obtained from all participants prior to enrollment.

3. Tooth preparation and temporization

Pretreatment radiographs and intraoral photographs were obtained for all participants. A polyvinyl siloxane putty index (Zhermack Elite HD+, Italy) was fabricated for the construction of temporary crowns. Tooth preparation was performed according to the planned definitive restoration, i.e. either an All-ceramic crown or a porcelain-fused-to-metal crown with occlusal reduction of 1.5 – 2.0 mm, 4° to 8° taper, 1.5 mm axial reduction and 1.0 mm shoulder finish line. All finish lines were located 0.5 – 1.0 mm subgingivally.

The prepared abutments were temporized with a bis-acrylic resin (Cool Temp Natural, Coltene, Germany) using non-eugenol temporary cement (NETC, Meta Biomed, Cheongju, Korea) for a duration of 2 weeks. To avoid tissue fatigue, a minimum interval of 7 days was maintained between post-displacement impressions within the same participant, following a Latin block design for cross over.[8,13] The Latin block design is a randomization method used in gingival displacement studies to eliminate sequence bias from tissue fatigue. Each technique is rotated systematically so that it appears equally across patients. A wash-out period (7 days) is given between procedures to allow gingival recovery, ensuring that results reflect the true effect of the technique rather than order of application. Periodontal health was re-evaluated and confirmed before impression making.

4. Impression procedures

Conventional impressions

Conventional impressions were made according to the manufacturer's instructions using polyvinyl siloxane material (Zhermack Elite HD+, Italy; putty and light body, normal set) with a two-phase, two-step technique using a sulcus tip. A polyethylene sheet (DPI, Mumbai, India) was used as a spacer. Casts were fabricated using type IV dental stone under controlled laboratory conditions.

5. Interventions

(a) Intraoral scans

Digital impressions were obtained using an intraoral scanner (Allied Star AS 100, Shanghai, China) following the manufacturer's recommended protocol. The scanning sequence included the maxillary arch, the mandibular arch, and bite registration. All scans were saved in standard tessellation language (STL) format.

(b) Gingival retraction procedure

For groups requiring gingival retraction, a knitted gingival displacement cord (Sure-Cord®, SureDent Corporation, Seongnam, Korea) was placed in the gingival sulcus below the preparation finish line. The cord was pre-soaked in a hemostatic agent (Hemostaz® Gel; Maarc Dental, Vasai, Mumbai, India) and inserted using a gingival cord packer (GDC® GCP113N,GDC Fine Crafted Dental, Punjab, India). A single-cord technique was employed.

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6. Digital analysis

Casts of conventional impressions were scanned with a laboratory scanner (AutoScan-DS-EX Pro(C), Shining 3D Tech, Hangzhou, China) and STL files were generated. All STL files were processed by a single dental master technician using Exocad software (Exocad DentalCAD 3.0 Galway, Exocad GmbH, Darmstadt, Germany).

All four STL files were superimposed using best fit algorithm.

Superimposition of the four STL datasets was performed using an iterative closest point (ICP)-based best-fit registration algorithm. Alignment was conducted pairwise to a predefined reference STL file (i.e. CR), with convergence achieved when the change in mean square error between iterations fell below the software-defined threshold. Outlier points were automatically excluded by the software to minimize the influence of noise.

The region of interest for registration was limited to stable hard-tissue tooth surfaces and marginal gingiva. Following registration, the aligned STL files were sectioned in the mesiodistal and buccolingual planes (Fig. 2). Measurements were performed at three standardized locations—mid-buccal (B), mesial (M), and distal (D)—by a blinded outcome assessor. To facilitate clear and consistent identification of the finish line depth, a virtual coping was designed in the CAD software following margin delineation. The coronal edge of the coping was used as a standardized coronal reference point for measuring finish line depth.

Three linear distances were recorded:

1. Width: between the most external point of the shoulder margin (cavosurface margin), and the internal line angle of the shoulder where the axial wall meets the horizontal shoulder floor.
2. Depth: between the finish line demarcated by the virtual coping marginand the most subgingival part of the tooth
3. Amount of Retraction: between the most distal point of the finish line and the gingiva

The measurement locations are illustrated in Figure 3.

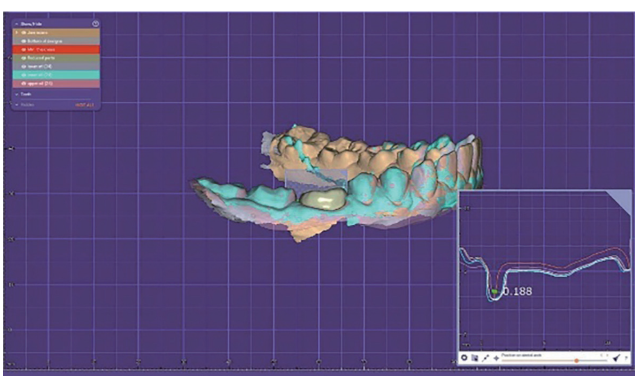

Fig. 2. All four impressions superimposed and sectioned mesiodistally.

7. Sample size

The required sample size was calculated as 15 participants per condition, yielding a total of 60 observations across the four experimental groups. The estimation was based on effect sizes reported in previous clinical studies evaluating finish line reproduction in intraoral versus conventional impressions, with a target power of 80% and an alpha level of 0.05. This ensured adequate power to detect clinically relevant differences between groups.

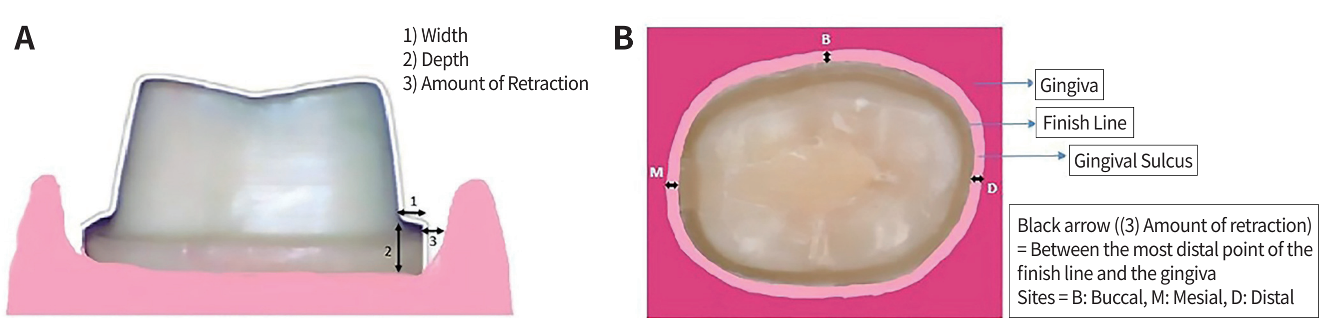

Fig. 3. Schematic diagram of measurements (A) and sites (B).
Diagrammatic representation of the three reference points (mid-buccal, mesial, distal) and the corresponding linear measurements used for finish line analysis.

8. Statistical analysis

Data were coded and organized in Microsoft Excel 2019 (Microsoft Corp., Redmond, WA, USA) prior to analysis. Descriptive statistics were reported as mean, standard deviation, median, and proportions. The Shapiro-Wilk test was used to assess normality. Since the data followed a normal distribution ($P > .05$), parametric tests were applied.

A generalized linear mixed-effects model was used to account for the crossover repeated-measures design. Participant was included as a random effect to model within-subject correlation, while technique (digital vs conventional), retraction (yes vs no), site, period, and sequence were included as fixed effects.

Comparisons between groups were performed using repeated measures ANOVA from which P values were derived and Tukey's post hoc test was conducted for pairwise comparisons. The Chi-square test was used for categorical variables. Statistical analyses were conducted using SPSS software (IBM, version 23). A P-value < .05 was considered statistically significant.

RESULTS

The generalized linear mixed-effects model demonstrated that neither period nor sequence had a significant effect on the outcome ($P > .05$), supporting the absence of carryover or ordering effects in the crossover design. However, technique and retraction showed statistically significant effects on the outcome ($P < .05$).

CONSORT Flowchart of crossover study is presented in Figure 4.

Examiner reliability was assessed using the intraclass correlation coefficient (ICC). The intra-examiner ICC reported was 0.84. Sensitivity analysis was performed to assess whether the observed

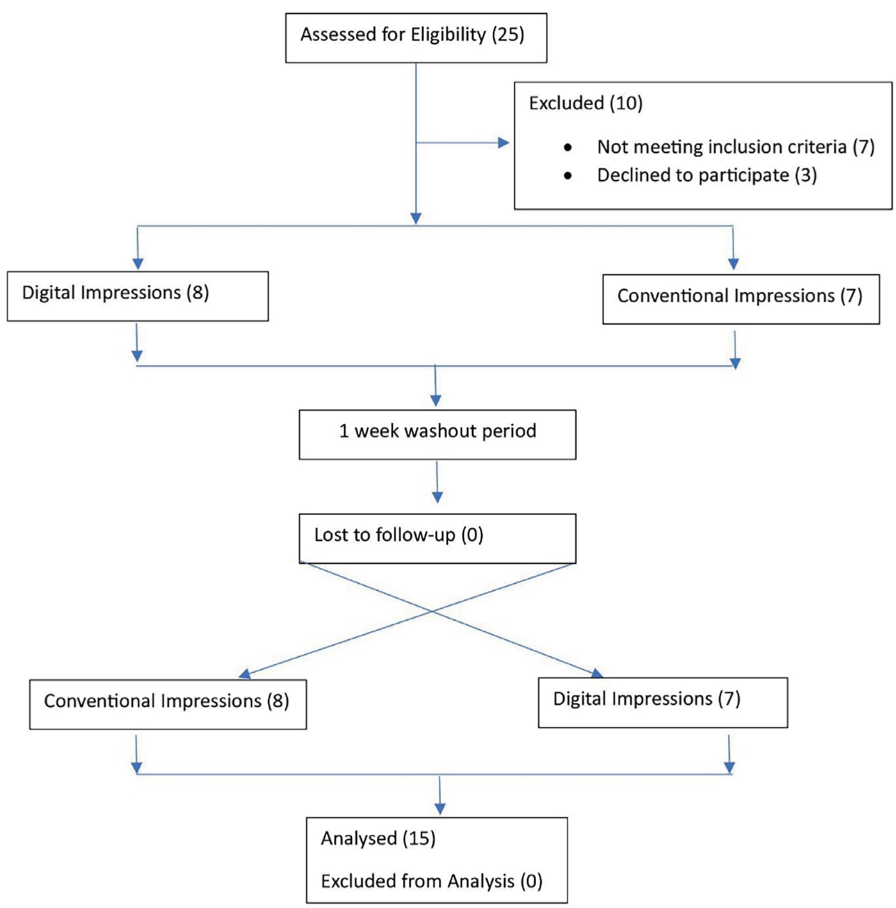

Fig. 4. CONSORT Diagram for Crossover Trial.

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differences between impression techniques with and without retraction were dependent on the alignment method used for best fit analysis. The direction and magnitude of the results remained consistent suggesting that the findings were not sensitive to the alignment method.

The intergroup comparisons of width, depth, and retraction using repeated-measures ANOVA are presented in Tables 1 – 3.

In the B subgroup, width (B1) ranged between 0.596 ± 0.207 (DWR) and 0.652 ± 0.199 (DR), depth (B2) from −0.001 ± 0.218 (CR) to 0.073 ± 0.148 (DR), and retraction (B3) from 0.229 ± 0.066 (DWR) to 0.327 ± 0.139 (DR). In B3, both DR and CR were significantly better than DWR ($P < .05$) (Table 1).

In the M subgroup, width (M1) ranged between 0.407 ± 0.132 (DWR) and 0.493 ± 0.129 (CR), depth (M2) from −0.036 ± 0.284 (CWR) to 0.017 ± 0.004 (DWR), and retraction (M3) from 0.186 ± 0.061 (DWR) to 0.239 ± 0.079 (CR). In M1, DR, CWR, and CR each showed significantly superior outcomes compared to DWR. In M3, CR showed better results than DWR with a statistically significant difference ($P < .05$) (Table 2).

In the D subgroup, width (D1) varied from 0.429 ± 0.141 (DWR) to 0.500 ± 0.093 (CR), with no significant difference among groups ($P > .05$). Depth (D2) ranged from −0.146 ± 0.238 (CWR) to 0.020 ± 0.004 (DWR), and retraction (D3) from 0.157 ± 0.047 (DWR) to 0.228 ± 0.098 (CR). In D3, DR, CWR, and CR all exhibited significantly better results than DWR ($P < .05$) (Table 3). According to the predefined sign convention, negative depth values denote that the recorded finish line depth was positioned coronally to the coping

Table 1. Intergroup comparison of subgroup B (width, depth, and retraction) among four impression techniques using repeated-measures ANOVA

Subgroup	Group	Mean ± SD	ANOVA *P*-value
B1 (Width)	DWR	0.596 ± 0.207	.205
	DR	0.652 ± 0.199	
	CWR	0.626 ± 0.184	
	CR	0.643 ± 0.215	
B2 (Depth)	DWR	0.019 ± 0.003	.546
	DR	0.073 ± 0.148	
	CWR	0.047 ± 0.268	
	CR	-0.001 ± 0.218	
B3 (Retraction)	DWR	0.229 ± 0.066	.017*
	DR	0.327 ± 0.139	
	CWR	0.270 ±0.125	
	CR	0.326 ± 0.184	

Table 2. Intergroup comparison of subgroup M (width, depth, and retraction) among four impression techniques using repeated-measures ANOVA

Subgroup	Group	Mean ± SD	ANOVA *P*-value
M1 (Width)	DWR	0.407 ± 0.132	.019*
	DR	0.466 ± 0.145	
	CWR	0.476 ± 0.119	
	CR	0.493 ± 0.129	
M2 (Depth)	DWR	0.017 ± 0.004	.88
	DR	0.012 ± 0.200	
	CWR	-0.036 ± 0.284	
	CR	-0.007 ± 0.318	
M3 (Retraction)	DWR	0.186 ± 0.061	.023*
	DR	0.212 ± 0.064	
	CWR	0.224 ± 0.081	
	CR	0.239 ± 0.079	

Table 3. Intergroup comparison of subgroup D (width, depth, and retraction) among four impression techniques using repeated-measures ANOVA

Subgroup	Group	Mean ± SD	ANOVA *P*-value
D1 (Width)	DWR	0.429 ± 0.141	.08
	DR	0.471 ± 0.125	
	CWR	0.489 ± 0.118	
	CR	0.500 ± 0.093	
D2 (Depth)	DWR	0.020 ± 0.004	.185
	DR	-0.057 ± 0.208	
	CWR	-0.146 ± 0.238	
	CR	-0.065 ± 0.264	
D3 (Retraction)	DWR	0.157 ± 0.047	.012*
	DR	0.194 ± 0.055	
	CWR	0.201 ± 0.063	
	CR	0.228 ± 0.098	

margin, which served as the coronal reference point. The occurrence of negative values therefore reflects the anatomical relationship rather than an error in measurement.

DISCUSSION

This crossover study evaluated the ability of digital and conventional impressions, with and without gingival retraction, to record shallow subgingival finish lines. Because all four techniques were applied to the same participants, the findings represent within subject differences rather than comparisons between independent groups. The results showed that both conventional PVS impressions and digital intraoral scans produced comparable measurements of finish line depth and width when adequate gingival retraction was used. However, digital impressions without retraction consistently demonstrated reduced capture of the margin, indicating that soft tissue management remains essential for precise digital recording.

Accordingly, the null hypothesis was partially accepted. The comparable outcomes may be explained by the compensatory nature of limitations inherent to each method: while conventional impressions are susceptible to material distortion and inaccuracies during cast fabrication, intraoral scanners (IOS) are influenced by operator technique, saliva or blood contamination, and optical artifacts.

A consistent pattern in this study was the poorer performance of the digital without retraction (DWR) technique across all measurement sites. This is a biologically plausible finding. Without sulcular displacement, the scanner is unable to visualise the subgingival contour, and blood or gingival shadowing may obscure the true margin. This agrees with studies reporting that digital impression reliability decreases as margin depth increases, with a notable decline beyond 0.5 mm subgingival (Cagidiaco *et al*.).[11] Son *et al*.[8] reported that IOS reproducibility decreased with finish lines > 0.5 mm subgingival, although cords preserved trueness within clinically acceptable limits. Nedelcu *et al*.[5] emphasized difficulties in differentiating gingiva from finish lines when they were placed subgingivally. Son *et al*.[12] demonstrated that displacement cords did not negatively affect the marginal or internal fit of interim crowns. These results substantiate the rationale for limiting finish line placement in the present study to 0.5 – 1 mm subgingival.

An *et al*.[14] emphasized that accurate scanning of finish lines is not possible without adequate gingival retraction. Ensuring sufficient soft-tissue displacement is essential for achieving precise intraoral scans, particularly when the finish line is positioned subgingivally. In conventional impression techniques, gingival retraction cords or other retraction materials are typically employed to temporarily displace the marginal gingiva, allowing proper capture of subgingival anatomical details and preventing distortion or tearing of the light-bodied impression material. The digital impression workflow requires the same foundational principles. As noted by Cagidiaco *et al*.,[11] both conventional and digital approaches depend on maintaining a clean and healthy gingival sulcus, achieving effective soft-tissue retraction, and ensuring clear visibility of the prepared tooth structure for accurate finish-line detection. Previous studies have highlighted that limited interproximal space, unfavorable emergence profiles, and the relative height of adjacent teeth can compromise digital finish line capture.[13,15]

In this investigation, knitted cords impregnated with a hemostatic agent were employed for gingival displacement. This chemico-mechanical approach is widely endorsed for safety and efficacy, as it provides both hemostasis and sulcular widening.[16-20] Nevertheless, sulcular trauma and bleeding during removal may occasionally occur. The recommended placement time of 7 – 10 minutes was strictly followed in this study.[16-20]

Polyvinyl siloxane (PVS) was selected for conventional impressions due to its superior dimensional stability and reproducibility.[21] The two-step technique ensured light-body material penetration into the sulcus, thereby enhancing finish line recording. The intraoral gingival sulcus tips of 0.5 mm diameter were used, which help push the wash material (light body) inside the sulcus.[9] This explains superiority of CWR over DWR. However, both digital and conventional approaches demonstrated reduced reproducibility as finish line depth increased, corroborating earlier reports.[8,11,12] Adequate tissue displacement enhances light penetration and margin visibility, enabling the IOS to detect the termination line clearly.

Previous studies have reported that gingival tissue health returns to an optimal state when evaluated 7 – 8 days after gingival displacement. Although 7 days has been advocated as the minimum time required for gingival tissues to recover following trauma, a Latin block design was employed to ensure that each segment had an equal chance of being assigned to a different treatment order, thereby minimising sequence effects.[9] Thus, to minimize bias and ensure methodological rigor, a Latin block randomization protocol was implemented, periodontal health was assessed prior to displacement, and all measurements were recorded by a single blinded operator. These measures improved internal validity and reduced variability related to operator technique or sequence.

A structured comparison of the limitations of conventional and digital impression techniques is presented in Table 4, providing a concise evidence-based summary that contextualizes the present findings within the broader literature.

An evidence-based overview of the limitations of conventional and digital impression techniques is provided in Table 4, facilitating comparison and interpretation of the present findings in relation to earlier studies.

1. Clinical implications

Both IOS and conventional techniques remain viable options for recording finish lines in clinical practice. While IOS offer efficiency and patient comfort, their limitations in subgingival regions necessitate caution. Gingival retraction enhances visibility for both methods but may not eliminate the challenges posed by deeply placed finish lines. Clinicians should select impression techniques based on clinical requirements, patient factors, and operator expertise.

2. Limitations

The present study was limited to finish lines placed at 0.5 – 1 mm subgingival and evaluated a single IOS

Table 4. Comparison of limitations associated with conventional and digital impression techniques

Parameter	Conventional Impressions	Digital Impressions (IOS)
Material	Susceptible to deformation, tearing, voids, or bubbles in elastomeric material (PVS).[22]	No material distortion; scanning errors may occur due to improper angulation or incomplete coverage.[13,15,23]
Cast/model	Stone casts may undergo dimensional changes, fracture, or abrasion during laboratory handling.[24]	Virtual models remain dimensionally stable and are easily archived without physical wear.[25]
Subgingival finish line reproducibility	Elastomers exhibit favourable flow, permitting sulcus penetration when gingival retraction is adequate.[10]	Limited by light penetration and difficulty distinguishing gingiva from the finish line in subgingival regions.[5]
Oral fluids	Minor contamination by blood or saliva has minimal effect on PVS reproducibility.[26]	Reproducibility compromised by saliva, sulcular fluid, or bleeding due to obstruction of the optical pathway.[27]
Operator dependence	Technique-sensitive during impression making but less reliant on operator movement once material sets.[10,28]	Requires substantial operator skill; scanning strategy errors are common.[29,30]
Access	Narrow or distal areas accessible with adequate retraction and tray design.[9,10]	Scanner tip bulk restricts capture in posterior regions and interproximal sites.[13,15]
Patient comfort	Tray insertion may cause gagging or discomfort; procedure is time-intensive.[3]	More comfortable, faster, and less invasive, improving patient acceptance.[7]
Repeatability	Errors necessitate complete remake of the impression.	Partial rescanning of localized regions possible without repeating the entire procedure.[25]
Cost	Material and laboratory dependent	High initial cost for scanner hardware/software; lower long-term material expenditure.[3]

system and one retraction technique. Therefore, the findings may not be generalizable to deeper finish line placements, other displacement methods, or newer scanner models. Long-term clinical trials assessing the biological response and marginal adaptation of restorations fabricated from both digital and conventional impressions would further strengthen the clinical relevance of these findings. The conventional workflow involves impression making, cast fabrication, and laboratory scanning, each of which can introduce dimensional inaccuracies. The cumulative effect of these steps may influence the resulting STL geometry and can therefore be acknowledged as a limitation when interpreting comparative outcomes.

CONCLUSION

Digital and conventional impressions demonstrated higher reproducibility for shallow subgingival finish lines when gingival retraction was done. Without gingival retraction, finish line reproduced by conventional impressions was more defined than digital, underscoring the importance of retraction for reliable digital capture of subgingival margins.

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