

TRUENESS OF INTRAORAL SCANNER AT THE FINISH LINE OF FIXED PROSTHODONTIC ABUTMENTS: INFLUENCE OF FINISH LINE LOCATION, FINISH LINE REGION, AND GINGIVAL RETRACTION TECHNIQUE

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ABSTRACT

This clinical study evaluated the trueness of intraoral scanner at the finish lines of fixed prosthodontic abutments by examining the effects of finish line location, finish line region, and gingival retraction technique. Fifty abutment teeth from 9 patients were scanned intraorally using a TRIOS 5 intraoral scanner, with reference scans generated from conventional polyvinyl siloxane impressions, Type IV stone casts, and an E4 laboratory scanner. Trueness was assessed by comparing test and reference STL files using Geomagic Qualify 12 software. A total of 168 finish line regions were analyzed using a linear mixed model at $\alpha = 0.05$. Finish line region showed a statistically significant main effect on RMS deviation ($F(3, 111.34) = 7.998, p < .001$), while finish line location ($p = .061$) and gingival retraction technique ($p = .328$) showed no significant main effects. A significant three-way interaction was observed ($F(3, 119.79) = 7.891, p < .001$). Pairwise comparisons revealed that the distal region exhibited significantly greater RMS deviations than the mesial and buccal regions. Overall mean RMS deviations were approximately 30 to 40 μm , which were within ranges previously reported as clinically acceptable marginal scan trueness.

Keywords: Intraoral Scanner, Trueness, Finish Line, Fixed Prosthodontics

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INTRODUCTION

The integration of computer-aided design and computer-aided manufacturing (CAD/CAM) technology into contemporary prosthodontic practice has fundamentally transformed clinical workflows. CAD/CAM systems encompass three principal stages: data acquisition, data manipulation, and manufacturing. During data acquisition, intraoral scanners (IOSs) directly capture three-dimensional digital data from the oral cavity, eliminating the need for conventional impression materials and trays. The clinical use of digital impressions has steadily increased because of several advantages, including the elimination of impression material distortion, real-time data visualization, electronic transfer of digital files, and the potential for chairside fabrication of definitive restorations (Chochlidakis et al., 2016).

All optical scanners require an unobstructed line of sight to the target surface, a demand that is particularly challenging when restorative margins are positioned at the equigingival or subgingival level (Revilla-León et al., 2023). In such clinical situations, the optical beam of the IOS may be partially obstructed by sulcular soft tissues, crevicular fluid, or adjacent tooth structure, potentially compromising the fidelity of marginal capture.

Clinically, restorative margins are not always placed supragingivally. In certain clinical situations, margins are intentionally positioned intracrevicularly to improve resistance and retention in short clinical crowns, to extend beyond carious lesions or existing restorations located below the gingival margin, or to optimize the emergence profile for esthetic purposes (Shenoy et al., 2012). In these circumstances, gingival retraction becomes an essential adjunct to expose the finish line and widen the gingival sulcus, thereby improving optical access for the IOS (Donovan & Chee, 2004).

Previous *in vitro* investigations have demonstrated that scanning accuracy decreases as the depth of subgingival finish line increases (Son & Lee, 2021; Son et al., 2022; Nedelcu et al., 2018). However, the extrapolation of *in vitro* findings to clinical practice is inherently limited because the oral environment presents additional variables that are difficult to simulate, including saliva contamination, soft-tissue mobility, restricted intraoral access, and patient movement. Clinical evidence on the combined influence of finish line location, finish line region, and gingival retraction technique on IOS trueness remains limited.

Furthermore, the influence of finish line region, specifically whether trueness differs across buccal, mesial, lingual, and distal aspects of the preparation, has received comparatively less clinical attention. Understanding how these anatomical and geometric constraints affect scan quality under real clinical conditions is essential for guiding clinical protocols and optimizing the reliability of digital impression procedures.

This clinical study therefore aimed to evaluate the influence of finish line location, finish line region, and gingival retraction technique on the trueness of intraoral scans obtained under actual clinical conditions at the postgraduate prosthodontic clinic of Khon Kaen University. The interaction effects among these three variables were also examined.

LITERATURE REVIEWS

Accuracy of digital impression

Accuracy is a fundamental requirement of intraoral scanners. It is defined as the closeness of agreement between a measured value and the true value of the measurand. According to ISO 5725-1, accuracy consists of two components as trueness and precision. Trueness refers to the closeness of agreement between the mean value obtained from a large series of test results and an accepted reference value, whereas precision refers to the closeness of agreement between independent test results obtained under specified conditions. In the study by Ender et al. (2020) the evaluation of trueness *in vivo* is challenging because the true geometry of the dental arch cannot be directly determined. Therefore, several studies have assessed the trueness of digital impression systems by comparing direct digital impressions with conventional impressions

used as the reference standard, since conventional impressions are still regarded as the gold standard in fixed prosthodontics. Many previous studies have suggested that 100 µm may be considered a clinically recommended for scan accuracy in the marginal region, because scan errors exceeding this threshold may adversely affect the marginal and internal fit of fixed prostheses (Giachetti et al., 2020; Son & Lee, 2021; Son et al., 2022).

Finish Line Location

The location of the finish line is an important factor influencing scan accuracy. The choice of margin location is influenced by four principal factors: periodontal considerations, esthetics, retention, and the need to place the finish line on sound tooth structure apical to caries or an existing restoration (Gardner, 1982). Supragingival margins are preferred when clinically feasible because they facilitate impression making, plaque control, and cement removal. However, subgingival margins may be required for esthetic demands, caries extension, existing restorations, or improved retention in short clinical crowns. Subgingival finish lines create greater technical challenges for intraoral scanning because soft tissue, sulcular fluid, saliva, and limited visibility can interfere with optical data capture.

Finish Line Region

The circumferential region of the finish line also influences scan accuracy, primarily through differences in optical access and scanner maneuverability. Interproximal regions (mesial and distal) are inherently more challenging to scan due to restricted viewing angles and interference from adjacent teeth (Keeling et al., 2017; Ammoun et al., 2020). Adherence to the manufacturer-recommended scanning distance and angulation is also essential, as any deviation from these parameters has been shown to significantly compromise accuracy (Button et al., 2024). Collectively, these findings suggest that the interproximal region, where scanner access is restricted, represents the greatest challenge for marginal capture.

Gingival retraction technique

Gingival retraction technique Adequate gingival displacement is fundamental for both conventional and digital impressions when finish lines are placed at or below the gingival crest. Single-cord retraction is appropriate for shallow sulci or equigingival margins, whereas the double-cord technique is indicated when greater sulcular displacement and hemostatic control are required (Donovan & Chee, 2004). The importance of cord placement has been demonstrated by a approximately 63% reduction in RMS deviation when a gingival cord was placed at a 0.5-mm subgingival finish line compared with the no-cord condition (Son & Lee, 2021). Proper tissue management has similarly been identified as one of the most critical operator-related factors influencing intraoral scan accuracy (Revilla-León et al., 2023), and no statistically significant difference in marginal reproduction between digital and conventional impressions has been reported when gingival displacement was adequately performed (Chopra et al., 2024). These findings collectively indicate that adequate gingival displacement is essential for accurate finish line capture under subgingival conditions.

RESEARCH METHODOLOGY

This clinical study was conducted at the Postgraduate Prosthodontics Clinic, Faculty of Dentistry, Khon Kaen University. The study protocol was reviewed and approved by the Khon Kaen University Ethics Committee for Human Research (HE672152) and was conducted in accordance with the Declaration of Helsinki and the International Council for Harmonisation Good Clinical Practice (ICH-GCP) guidelines.

A total of 50 abutment teeth prepared for single or multiple fixed prostheses were recruited. Patient inclusion criteria required age of 18 years or older, and patients with limited mouth opening were excluded. Tooth-related inclusion criteria included the presence of a maxillary or mandibular tooth requiring a fixed restoration, clinically healthy gingival conditions (absence or minimal bleeding on probing and probing depths ≤ 3 mm), a vital or satisfactorily

endodontically treated tooth, no pathological radiographic findings, and no clinical signs or symptoms of inflammation. For the mesial and distal finish line regions, only surfaces with an adjacent tooth were included in the analysis.

Each abutment tooth was prepared by postgraduate prosthodontic students at Khon Kaen University according to standardized tooth preparation guidelines. Finish lines were placed and categorized into two levels: supragingival-equiangular (SG-EG) and subgingival (SubG). The depth of subgingival finish lines was measured using a periodontal probe (CP15 UNC; Hu-Friedy, Chicago, IL, USA). Final impressions were made after confirming clinically healthy periodontal conditions. Gingival retraction was performed using either a single-cord or double-cord technique, selected according to the clinical condition of each abutment and operator preference.

Test scans were obtained using a TRIOS 5 intraoral scanner (3Shape, Copenhagen, Denmark) following the manufacturer's recommended scanning strategy. Scan data were saved in standard tessellation language (STL) format. Reference scans were generated from the conventional impression workflow: polyvinyl siloxane impressions (Silagum Putty and Honigum Light; DMG, Hamburg, Germany) were made, poured with Type IV dental stone (Vel-Mix Stone; Kerr, Brea, CA, USA), and the resulting casts were scanned using an E4 laboratory scanner (3Shape A/S, Copenhagen, Denmark). Before inclusion in the analysis, all datasets were inspected by the researcher to confirm complete reproduction of the finish line area, adequate visibility of the scanned data, and the absence of obvious voids, tears, or distortions in the conventional impressions.

Trueness analysis was performed by a single researcher using three-dimensional inspection software (Geomagic Qualify 12; 3D Systems, Rock Hill, SC, USA). The finish line area was defined as the area between the internal and external finish lines of the abutment and was divided into four regions: buccal, mesial, lingual, and distal. The test and reference STL files were first subjected to initial alignment followed by best-fit alignment through iterative minimization of overall surface deviations. Quantitative discrepancies within the finish line area were expressed as root mean square (RMS) deviation. A lower RMS value indicates greater agreement between the two datasets.

All statistical analyses were performed using IBM SPSS Statistics version 29.0, with the significance level set at $\alpha = 0.05$. Descriptive statistics were calculated for RMS values in each subgroup. A linear mixed-effects model was fitted using restricted maximum likelihood estimation to evaluate the effects of finish line location, finish line region, gingival retraction technique, and their interactions on RMS deviation. A random intercept for abutment tooth within participant was included to account for clustered repeated observations. The covariance structure was specified as variance components, and denominator degrees of freedom were estimated using the Satterthwaite approximation. When significant main effects were identified, pairwise comparisons were performed using the Bonferroni adjustment for multiple comparisons.

RESEARCH RESULTS

A total of 50 abutment teeth from 9 patients were evaluated, comprising 26 maxillary and 24 mandibular teeth. The sample included 15 incisors, 7 canines, 15 premolars, and 13 molars. A total of 168 finish line regions were analyzed. Of these, 83 regions were classified as SG-EG and 85 as SubG. The finish line regions comprised buccal ($n = 50$), mesial ($n = 38$), lingual ($n = 50$), and distal ($n = 30$). Regarding tissue management, 65 regions were managed using the single-cord technique and 103 using the double-cord technique.

Descriptive analysis of RMS deviations revealed that the distal region exhibited the highest mean values ($36.41 \pm 9.09 \mu\text{m}$), followed by the lingual ($34.87 \pm 7.94 \mu\text{m}$), mesial ($33.22 \pm 7.88 \mu\text{m}$), and buccal regions ($31.91 \pm 8.55 \mu\text{m}$). Regarding finish line location, subgingival

finish lines demonstrated higher mean RMS values ($35.91 \pm 8.35 \mu\text{m}$) compared with SG-EG finish lines ($31.82 \pm 8.00 \mu\text{m}$). For gingival retraction technique, slightly higher mean RMS values were observed with the single-cord technique ($35.19 \pm 5.93 \mu\text{m}$) compared with the double-cord technique ($33.07 \pm 9.60 \mu\text{m}$) (Table 1).

Mixed-model analysis revealed a statistically significant main effect of finish line region on RMS deviation ($F(3, 111.34) = 7.998$, $p < .001$). In contrast, finish line location showed no statistically significant main effect ($F(1, 146.96) = 3.556$, $p = .061$), and gingival retraction technique also demonstrated no statistically significant main effect ($F(1, 48.48) = 0.976$, $p = .328$). No statistically significant two-way interactions were detected among the factors (all $p > .05$). However, a statistically significant three-way interaction among finish line location, gingival retraction technique, and finish line region was identified ($F(3, 119.79) = 7.891$, $p < .001$), indicating that the combined influence of these factors on scan trueness was complex and could not be explained by any single factor in isolation.

Pairwise comparisons with Bonferroni adjustment confirmed that the distal region exhibited significantly greater RMS deviations than the mesial region (mean difference = $6 \mu\text{m}$, $p < .001$, 95% CI [2.0, 10.0]) and the buccal region (mean difference = $6.0 \mu\text{m}$, $p < .001$, 95% CI [3.0, 10.0]). No statistically significant differences were observed between the distal and lingual regions ($p = .073$), or among the mesial, lingual, and buccal regions (all $p > .05$).

Post hoc analyses of the three-way interaction revealed that, at the distal region specifically, significant differences between SubG and SG-EG finish lines were observed under both single-cord and double-cord retraction conditions, suggesting that finish line location exerts a region-specific influence on scan trueness at the distal aspect.

Table 1 Comparison of RMS values (mean $\pm$ SD, μm) according to finish line location, finish line region, and gingival retraction technique

Factor	Group	n	RMS (Mean $\pm$ SD, μm)	F(df)	p-value
Finish line location	SG-EG	83	31.82 ± 8.00^a	$F(1, 146.96)$ $= 3.556$	.061
	SubG	85	35.91 ± 8.35^a		
Finish line region	Buccal	50	31.91 ± 8.55^a	$F(3, 111.34)$ $= 7.998$	< .001
	Mesial	38	33.22 ± 7.88^a		
	Lingual	50	34.87 ± 7.94^{ab}		
	Distal	30	36.41 ± 9.09^b		
Gingival retraction technique	Single	65	35.19 ± 5.93^A	$F(1, 48.48)$ $= 0.976$	.328
	Double	103	33.07 ± 9.60^A		

Note: Descriptive values are presented as mean $\pm$ standard deviation. F statistics and p-values were derived from the linear mixed-effects model, accounting for participants and abutment tooth as random effects. Within each factor, groups with different superscript letters (a, b) indicate statistically significant pairwise differences based on Bonferroni adjustment ($p < .05$).

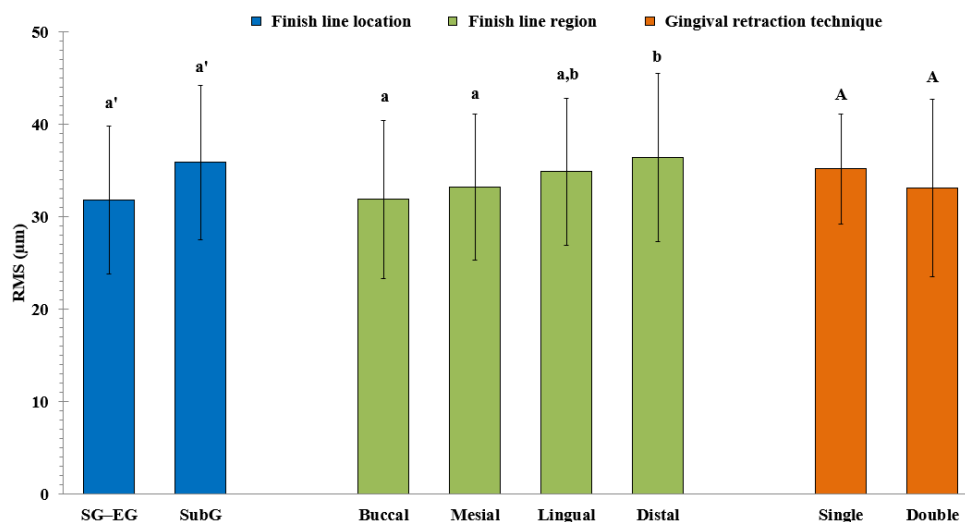


Figure 1 Mean RMS values (μm) by finish line location, finish line region, and gingival retraction technique. Different superscript letters (a, b) indicate statistically significant pairwise differences within the same factor based on Bonferroni-adjusted comparisons ($p < .05$). Statistical inference was based on a linear mixed-effects model with participants and abutment tooth as random effects.

CONCLUSION AND DISCUSSION

This clinical study evaluated the influence of finish line location, finish line region, and gingival retraction technique on the trueness of intraoral scans at the finish line of prepared abutments. Overall, the findings indicated that finish line region was the only main factor that significantly influenced scan trueness, whereas no significant differences were observed according to finish line location or gingival retraction technique. However, a significant three-way interaction among finish line location, finish line region, and gingival retraction technique was also identified, indicating that scan trueness was influenced by the combined effect of these factors rather than by each factor independently. The greater RMS deviation observed at the distal region is consistent with previous reports identifying the distal margin as particularly challenging for intraoral scanning. Keeling et al. (2017) demonstrated that the distal margin was significantly influenced by the presence of adjacent teeth and by limitations in IOS wand positioning, which restrict direct optical access to the margin. Kim et al. (2024) similarly reported higher deviations in the proximal regions (mesial and distal) than in buccal or lingual regions, supporting the concept that interproximal regions are more susceptible to scanning inaccuracies. The geometrical constraints of the interproximal space force the clinician to tilt or angulate the IOS wand, which may deviate from the manufacturer-recommended scanning distance and angle, thereby degrading scan quality. Button et al. demonstrated that scanning angulation and distance significantly influence accuracy, and that deviations increase when recommended scanning parameters are altered. Ammoun et al. (2020) further confirmed that the presence of adjacent teeth reduced scan accuracy compared with isolated preparations, consistent with reduced achievable viewing angles in the proximal region. Collectively, these findings underscore that restricted interproximal clearance and compromised optical access are the primary determinants of the inferior trueness observed at the distal finish line region in this study.

Although finish line location did not reach statistical significance as a main effect ($p = .061$), SubG finish lines consistently demonstrated higher mean RMS deviations than SG-EG finish lines. This trend is in agreement with the general principle that subgingival margin placement challenges optical scanners due to the line-of-sight dependency of confocal-based systems. Son and Lee (2021) reported significantly higher deviations at equigingival and 0.5-mm

subgingival finish lines compared with supragingival finish lines, with the poorest trueness observed in the absence of gingival displacement. Son et al. (2022) demonstrated that trueness decreased as the finish line extended 0.5 to 1.0 mm into the sulcus and that gingival retraction improved trueness across all subgingival depths. An et al. (2024) further reported that saliva contamination exacerbated marginal errors at subgingival finish lines. The near-significant trend in the present study ($p = .061$) may reflect the mitigating role of gingival retraction performed across all specimens; when adequate sulcular access was achieved, the negative influence of subgingival margin placement was attenuated. This interpretation aligns with Koulivand et al., who found no significant difference in prosthetic outcomes between supragingival and subgingival finish lines when appropriate impression procedures were employed.

Similarly, gingival retraction technique did not demonstrate a statistically significant main effect, descriptive findings indicated slightly greater RMS deviations in the single-cord group than in the double-cord group. This observation should be interpreted with caution, as the retraction method was selected according to site-specific clinical factors, including margin depth, visibility, and soft-tissue condition, rather than through predetermined allocation. As Abadzhiev noted, retraction techniques should be selected individually according to the clinical requirements of each case. The present findings do not suggest that one technique is inherently superior to the other under all conditions; rather, adequate gingival displacement of any form appears sufficient to maintain scan accuracy within clinically acceptable limits when properly executed.

A statistically significant three-way interaction was identified among finish line location, gingival retraction technique, and finish line region, indicating that the influence of finish line location on scan trueness differed according to both finish line region and tissue management. At the distal region, significant differences between SubG and SG-EG finish were observed under both single- and double-cord conditions. This finding demonstrates that finish line location significantly affects scan trueness at the distal region, irrespective of the retraction technique applied. Clinically, these results suggest that finish line placement at the distal region requires careful consideration, as this area appears particularly sensitive to variations in finish line depth during digital impression procedures.

This study has several limitations. First, the reference scan was derived from a conventional workflow involving polyvinyl siloxane impression making, Type IV dental stone pouring, and laboratory scanning. Thus, the RMS deviations represent relative differences between intraoral scans and cast-derived reference scans, rather than absolute deviations from the true intraoral geometry. Dimensional changes from impression materials, gypsum expansion, and laboratory digitization may have influenced the calculated trueness values (Chochlidakis et al., 2016). Second, only one IOS system (TRIOS 5) and software version were evaluated, limiting generalizability to other scanner systems. Third, finish line location and gingival retraction technique were determined by clinical necessity rather than randomization. These limitations should be considered when interpreting the findings.

Within the limitations of this study, finish line region was the primary factor influencing intraoral scan trueness, with the distal region exhibiting significantly greater RMS deviations than the mesial and buccal regions. Overall mean RMS deviations of approximately 30 to 40 μm remained within ranges previously reported as clinically acceptable marginal scan trueness. Finish line location and gingival retraction technique did not show significant independent effects; however, their combined three-way interaction with finish line region was significant. The distal region appeared particularly susceptible to the effect of finish line location across both retraction techniques, suggesting a clinically vulnerable area for intraoral scan trueness.

From a clinical standpoint, Clinicians should pay particular attention to the completeness of the digital impression at the distal finish line region. Intraoperative verification of marginal clarity in this area is recommended.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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