Accuracy of Intra-Oral Scanners for Full Crown Tooth Preparations with Subgingival Margins: A Systematic Review

Keywords

Accuracy
Digital Impression
Trueness
Tooth Preparation
Subgingival Margin
Intraoral Scanner

Authors

Matías Andrade Villalobos *
(BDS, MDENT(Aesthetics))

Vincent Bennani *
(DDS, PhD)

John M. Aarts *
(MHealSc)

Jithendra Ratnayake *
(Beng (Hons), PhD)

Address for Correspondence

Vincent Bennani *
Email: vincent.bennani@otago.ac.nz

* *Otago University Faculty of Dentistry, Dunedin, New Zealand*

Received: 09.10.2024
Accepted: 19.01.2025
doi: 10.1922/EJPRD_2812Matias09

ABSTRACT

Introduction: The accuracy of intra-oral scanners (IOS) has not been thoroughly evaluated across all clinical scenarios, particularly in crown preparations with subgingival margins. Objectives: This systematic review aims to assess the accuracy of IOS in tooth preparations with subgingival margins and identify factors influencing their performance in these situations. Methods: A comprehensive literature search was conducted in databases including PubMed, Scopus, Embase, Medline, Google Scholar, and Web of Science for studies published in the last five years. Quality Assessment Tool for In-Vitro Studies (QUIN) was used to evaluate study quality. Results: Out of 605 studies, seven met the inclusion and exclusion criteria. The review found that the trueness of IOS is significantly compromised in subgingival margins, often failing to achieve clinically acceptable results. Influencing factors included gingival retraction and saliva contamination. Specifically, cord retraction enhanced IOS accuracy, while saliva contamination reduced it. Conclusions: The accuracy of IOS in crown preparations with subgingival margins is severely affected by saliva contamination and visibility issues. Clinically acceptable results are achieved with proper gingival retraction and a dry field. Clinical Relevance: To ensure accurate scanning for tooth preparations with subgingival margins, achieving proper gingival retraction and dryness is crucial.

INTRODUCTION

During a prosthodontic treatment, a clinician may choose various margin locations such as supra, equi, or subgingival margin on a tooth preparation. Subgingival (SubG) margins may be chosen by a clinician in scenarios with subgingival caries or fractures, to increase the retention and resistance form of the preparation or even for aesthetic reasons.[1-4] However, this scenario poses challenges as the periodontal tissue may be traumatized during the placement of the finish lines, and recording the margin with an impression becomes more difficult.

In the context of restorative dentistry, impressions, whether conventional or digital, comprise the first step in the manufacture of dental restorations. An inaccurate impression will compromise the subsequent steps in the manufacturing process, as the restoration will be created from an impression that does not precisely replicate the surface of the dental tissues.[5] Consequently, this could lead to the fabrication of a poorly fitting dental prosthesis, which could lead to plaque accumulation, gingival inflammation, carious lesions and decreased longevity of the restoration.[6-8]

For these reasons, it is crucial to assess the accuracy of impressions in various clinical scenarios. However, existing literature on intra-oral scanners (IOS) accuracy lacks detailed insights into how the placement of subgingival margins affects their performance.

Multiple factors have been identified that influence the accuracy of IOS.[9-12] These factors are linked to ambient conditions, such as humidity, temperature fluctuations, and lighting, which play a significant role in the resulting accuracy.[13-19] Additionally, factors related to the IOS itself, including the size of the scanner head, software version, type of IOS, operator experience, and scanning strategy are crucial. Tooth-related factors, such as the extent of the scan, tooth type, and type of preparation also contribute to the accuracy.[20-25] The impact of these factors demonstrates the complexity of achieving reliable accuracy with digital impressions.

According to the International Organization for Standardization (ISO), the term "trueness" is defined as the "closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value".[26] Applied to digital impressions, trueness would refer to the scanner's ability to accurately record the true position of a tooth preparation. This concept must be distinguished from "precision", which is defined as "the closeness of agreement between test results obtained under stipulated conditions".[26] Precision, therefore, measures the consistency of results across multiple scans. The ISO specifies that "accuracy" should encompass both trueness and precision.[26]

Currently, there are no reports specifying the required accuracy of an IOS in the literature. Most studies use the clinically acceptable absolute margin discrepancy (AMD) for dental restorations as a reference, typically suggesting a threshold of 100-120 micrometers.[27-30] For this review, a threshold of 100 micrometers will be considered clinically acceptable. Thus, the trueness values for IOS should stay below this threshold. However, it is important to note that other authors have identified a marginal gap of 30 microns as being susceptible to secondary caries lesions.[31] In this study, however, the gap between the tooth and the restoration was left empty, without the presence of cement. Nevertheless, it is widely accepted that dental professionals should strive to minimize this gap as much as possible. According to ISO 5725, precision should be evaluated using standard deviation (SD), which measures data dispersion relative to the mean trueness.[26] However, there are no established clinically acceptable values for IOS precision, posing a challenge for accuracy evaluation in research.

To the best of the authors' knowledge, no systematic reviews have been published specifically examining the performance of IOS in subgingival scenarios. Therefore, this systematic review aimed to assess the accuracy of IOS in tooth preparation for full crowns with subgingival margins and identify the factors that impact the accuracy of IOS in this scenario.

METHODS

A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 Guidelines.[32] The population, intervention, comparison, and outcome (PICO) were defined as follows: P: tooth preparation for crowns with subgingival margins; I: digital impression using intra-oral scanners; C: reference using laboratory scanner, O: accuracy of digital impression.

A comprehensive literature search covering the period from January 2019 to April 2024 was conducted using the following databases: Medline (Ovid), Embase (Ovid), PubMed, Web of Science, Scopus, and Google Scholar. Additionally, a manual search was performed by screening the reference lists of included studies and previous systematic reviews on the accuracy of IOS to identify relevant studies not indexed in the primary databases. The final list of keywords was reviewed and approved by the 4 authors (MA, VB, JA, and JR) and 2 external reviewers. The list of keywords and subject headings with their corresponding Boolean operator where the following: (intraoral scan* OR computer-aided design OR digital impression OR imaging, three-dimensional) AND (subgingival OR "finish line") AND (accuracy OR precision OR trueness OR exactness) AND (Tooth preparation OR crown). The same search strategy was consistently applied across all databases. The inclusion criteria were: studies published in English, full articles available, articles that evaluate the accuracy of intraoral scanners in subgingival margins by comparison with a reference, *in-vivo*, *in-vitro*, clinical trials, prospective, retrospective, comparative and cross-sectional studies. The exclusion criteria were: case reports, systematic reviews, questionaries, unpublished literature, and opinions. Publications evaluating dental implants, studies evaluating types of tooth preparation other than full coverage crowns, studies that did not indicate margin preparation location and studies that considered subsequent steps in the manufacturing process in the calculation of accuracy were also excluded.

The full-text version of relevant articles was retrieved and discussed between the four authors (MA, VB, JA, JR). The data collected from included studies were authors' names, publication year, funding, study design, sample size, IOS used, software version, abutment tooth evaluated, mounting procedure, operator experience, ambient conditions, reference scanner, processing software, finish line design and location, confounding factors evaluated by studies, mean trueness in the form of AMD, precision in the form of SD of mean trueness and main conclusion of studies. The data collection was performed by two authors independently (MA, VB) and recorded in an electronic spreadsheet. The two other reviewers (JA, JR) verified the veracity of the data collected. In the case of missing data, one author (MA) contacted the corresponding author asking to provide complementary information. In the case of non-reply, the missing data was recorded as not available. If the data format varied among studies, raw data was extracted from the studies and recorded in the form of AMD for trueness and SD for precision.

Quality assessment was conducted using the Cochrane Risk of Bias assessment tool for randomized trials[33] and the Quality Assessment Tool for *in vitro* studies (QUIN Tool) for *in vitro* studies.[34] Only studies with a low risk of bias were included in the review.

RESULTS

The electronic search identified 605 articles. After removing duplicates, 132 articles remained for title and abstract screening. From these, 43 articles were deemed potentially relevant, however, 7 of these studies did not have a full version available. For the remaining 36 articles, their full texts were retrieved for further evaluation. After reviewing, 29 studies were excluded for not meeting the inclusion/exclusion criteria. All the studies identified during the manual search were duplicates. The four authors (MA, VB, JA, JR) agreed to include 7 articles in the review.[35-41] Figure 1 details the study selection process.

STUDY CHARACTERISTICS AND QUALITY ASSESSMENT

All seven included articles have an *in-vitro* study design and evaluated the accuracy of IOS in subgingival margins. Among the seven studies, 9 different intra-oral scanners were evaluated and a total of 580 scans were performed among different experimental groups with a mean of 16 samples per group. Table 1 presents a summary of the included studies. As all the studies included are *in-vitro*, only the QUIN assessment tool was used in the present review. A summary of the scores of each study is illustrated in Table 2. The selected studies had scores ranging from 80% to 100%. The categories "Randomization" and "Blinding" were deemed not applicable for the studies, as each sample received both interventions, and these categories were not considered in the overall score.

ACCURACY OF IOS WITHOUT SALIVA OR GINGIVAL RETRACTION

A description of the summary of results from the included studies can be found in Table 3. Three of the five studies that evaluated the trueness of IOS without gingival retraction or saliva contamination concluded that the IOS studied did not demonstrate clinically acceptable results in subgingival scenarios.[36,38,41] One study reported clinically acceptable outcomes solely at 0.25 mm SubG, with discrepancies increasing to levels deemed non-clinically acceptable at greater depths.[39] Another study reported clinically acceptable trueness values at 1 and 2 mm subgingival.[40] Within all five of these studies, the SD varies significantly, with values ranging from 0.13 to 35. From two studies that evaluated the performance of three IOS at 0.5 mm SubG, the trueness values ranged between 101 and 240 µm.[38,39] At 1 mm SubG, three studies evaluated the performance of three different IOS scanners, resulting in trueness values ranging of 37.5 to 548 µm.[39-41] Finally, two studies evaluated the trueness of four different IOS at 2 mm SubG, resulting in values ranging from 32.6 to 170 µm.[36,40]

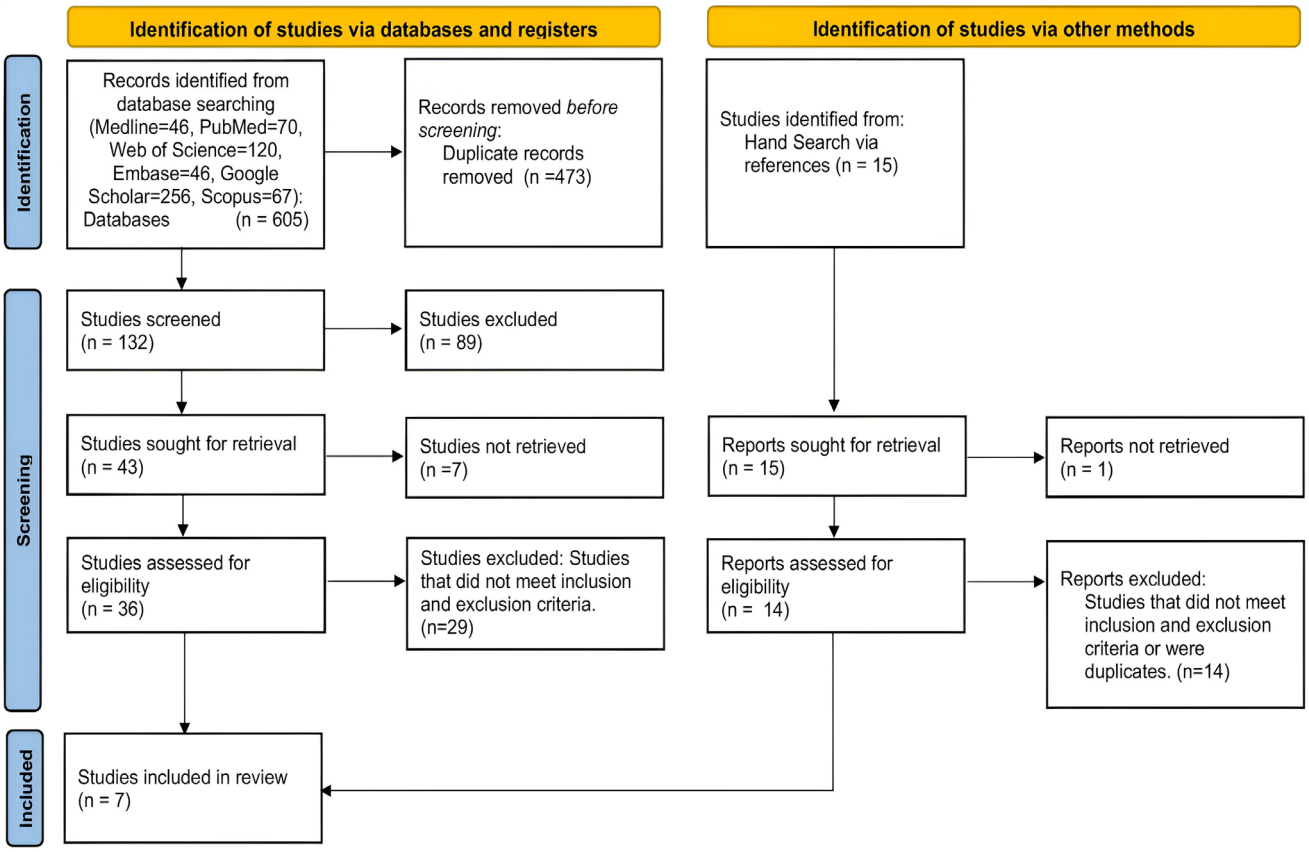

Figure 1: PRISMA Flow diagram of Study Selection Process.

Table 1. Summary of Studies.

Study	Sample Size	IOS Model/ Technology	Type of Teeth	Ambient Conditions	Methods	Processing Software	Outcome Measured	Finish Line Design and Location	Key factors evaluated
An et al, 2024	N=15	• Emerald/ATT • Trios 3/PCI	Ivorine Maxillary: PM	Light: NS T°C: NS H%: NS	Superimposition of STL files with same scanner	3Shape Dental System	Finish line accuracy	Chamfer • Equigingival • Subgingival: 0.5 and 1mm	Saliva
Casucci, et al 2023	N=10	• Trios 3/ PCI • i700/ATT • Vivascan/ATT, • Experimental IOS/ NS	Ivorine Maxillary: M/CI	Light: Constant T°C: NS H%: NS	Superimposition of STL files with Aadva lab scanner	Geomagic Control X; 3D Systems	RMS Marginal accuracy	Feather edge • Subgingival>2mm	NS
Rapone et al, 2020	N=10	• CS 3600/ATT • Trios 3/PCI • Omnicam/ATT	Natural human Maxillary: PM Mandibular: PM/M	Light: NS T°C: 37 H%: 90	Superimposition of STL files with S600 ARTI scanner	Geomagic Studio; 3D Systems	Finish line accuracy	Chamfer • Subgingival: 1mm	Saliva
Son et al, 2021	N=20	• EZIS PO/ATT • i500/ATT	Lithium Disilicate Maxillary: M	Light: NS T°C: 23 H%: 50	Superimposition of STL files with DS10 scanner	Geomagic Design X; 3D systems	RMS Marginal accuracy	Chamfer • Equigingival • Subgingival: 0.5mm	Gingival retraction
Son et al, 2022	N=20	• CS3600/ATT • i500/ATT	Lithium Disilicate Maxillary: M	Light: NS T°C: 23 H%: 50	Superimposition of STL files with DS10 scanner	Geomagic Design X; 3D systems	RMS Marginal accuracy	Chamfer • Equigingival • Subgingival: 0.25, 0.5, 0.75 and 1mm	Gingival retraction
Sorrentino et al, 2024	N=20	• i700/ATT	3D printed UV resin Maxillary: M	Light: Constant T°C: 22 H%: 45	Superimposition of STL files with ATOS Core 80	Geomagic Control X; 3D Systems	RMS Full abutment accuracy	Feather edge • Subgingival: 1 and 2mm	NS
Verniani et al, 2023	N=20	• Trios 3/ PCI • i700/ ATT	Ivorine Maxillary: M/CI	Light: Mildly lit T°C: Constant H%: NS	Superimposition of STL files with Aadva Lab Scanner	Geomagic Control X; 3D Systems	RMS Marginal accuracy	Chamfer /Shoulder • Subgingival: 1mm	NS

ATT: Active Triangulation Technology; CI: Central Incisor; IOS: Intra-oral scanner; M: Molar; NS: Not specified; PCI; Parallel Confocal Imaging; PM: Premolar

Table 2. Results of the QUIN assessment tool.

		Studies						
Item	Criteria	An et al 2024	Casucci et al 2023	Rapone et al 2020	Son et al 2021	Son et al 2022	Sorrentino et al 2024	Verniani et al 2023
1	Aims/Objective	2	2	2	2	2	2	2
2	Sample Size	2	0	0	2	2	0	0
3	Sampling Technique	2	2	2	2	2	2	2
4	Comparison group	2	2	2	2	2	2	2
5	Methodology	2	2	1	2	2	1	2
6	Operator	2	2	2	2	2	2	2
7	Randomization	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	Outcome Measurement	1	2	1	2	2	1	2
9	Outcome Assessor	2	2	2	2	2	2	2
10	Blinding	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	Statistical Analysis	2	2	2	2	2	2	2
12	Results	2	2	2	2	2	2	2
	Overall Score	95%	90%	80%	100%	100%	80%	90%

N/A: Not Applicable; 2: Adequately specified; 1: Inadequately specified; 0: Not specified.

EFFECT OF GINGIVAL RETRACTION

Four studies evaluated the trueness of IOS in SubG margins with gingival retraction and without saliva contamination.[35,37-39] All of them obtained clinically acceptable mean trueness values. Three studies evaluated five different IOS at 0.5 mm SubG with gingival retraction in a dry field. The mean trueness reported ranged between 16.4 and 147.2 µm.[35,38,39] Three studies evaluated the trueness of five IOS in a preparation with a 1 mm SubG margin. The mean trueness values ranged between 16.8 and 98.8 µm.[35,37,39]

Regarding precision measurements, two studies directly compared the accuracy of IOS between samples with and without gingival retraction.[38,39] The results showed that using gingival retraction significantly improved precision, as indicated by lower standard deviations in all groups. Specifically, the standard deviation range for the control group (without gingival retraction) was 5.7 to 28.7, while the range for the group with gingival retraction was much narrower, from 1.1 to 8.1.

EFFECT OF SALIVA CONTAMINATION

Two studies evaluated the performance of IOS in subgingival margins contaminated with saliva. Both reported that non-clinically acceptable results were obtained, with a significant increase in discrepancies compared to their control which was without saliva.[35,37] In margins placed 1 mm SubG, there was a mean increase of 343% in discrepancies compared to their reference. Additionally, among the 16 saliva-contaminated groups evaluated across the two studies, 15 exhibited decreased precision, as indicated by higher standard deviations than their control groups. Only one study evaluated the trueness of two IOS at 0.5 mm subgingival with saliva contamination and gingival retraction. The mean trueness values reported ranged was between 145.8 and 312.9 µm.[35] Furthermore, at 1 mm SubG the studies reported a mean trueness ranging between 167.6 - 504 µm.[35,37]

None of the studies conducted a statistical analysis to systematically evaluate the impact of additional variables, such as ambient conditions, intra-oral scanner factors, and tooth-related factors, on the accuracy of IOS.

Table 3. Summary of Results.

Study	IOS	Tooth	Finish line	SG Margin Position (mm)	Baseline Mean Accuracy (mm)	Mean Accuracy with Modifying Factor (mm)	Conclusions
An et al, 2024					Retraction Cord	Saliva Contamination	• Clinically acceptable results for SG margin without saliva only in TRIOS 3 group. • No clinically acceptable results were obtained for SG margins with saliva contamination.
	Emerald	Mx. Premolar	C	0	7.28 ±23	25.30 ±32	
				0.5	147.24 ±59	312.95 ±42	
				1	93.59 ±34	262.38 ±44	
	Trios 3	Mx. Premolar	C	0	19.21 ±19	65.53 ±121	
				0.5	52.79 ±16	145.81 ±52	
				1	53.59 ±26	180.91 ±155	
Casucci, et al 2023	Trios 3	Mx. Molar	FE	2	166 ±0.34	NS	• No clinically acceptable mean trueness values were observed, except for i700 in one sample.
		Mx. Incisor	FE		147 ±2.18		
	i700	Mx. Molar	FE	2	96.3 ±0.13		
		Mx. Incisor	FE		154.2 ±1.89		
	Vivascan	Mx. Molar	FE	2	141.2 ±2.20		
		Mx. Incisor	FE		170 ±1.33		
	Prototype	Mx. Molar	FE	2	145.2 ±1.87		
		Mx. Incisor	FE		135.7 ±0.83		
Rapone et al, 2020					Retraction Cord	Saliva Contamination	• Clinically acceptable trueness values were obtained in samples with gingival retraction and without saliva contamination. • Saliva contamination significantly affected the trueness, resulting in no clinically acceptable values.
	Trios 3	Md. Molar	C	1	66.9 ±21.6	287.6 ±115.6	
		Md. Molar	C		72.9 ±14.2	279.2 ±112.9	
		Md. Premolar	C		75.6 ±16.6	256.5 ±50.8	
		Mx. Premolar	C		55.9 ±16.7	371.2 ±65.7	
	CS3600	Md. Molar	C		52.5 ±13.9	231.0 ±71.9	
		Md. Molar	C	1	61.9 ±17.4	179.2 ±33.5	
		Md. Premolar	C		46.6 ±12.7	167.6 ±28.6	
		Mx. Premolar	C		53.6 ±14.1	329.2 ±29.1	
		Md. Molar	C		98.8 ±18.1	421.9 ±29.4	
	Omnicam	Md. Molar	C	1	97.8 ±20.4	378.2 ±27.5	
		Md. Premolar	C		63.1 ±15.7	431.9 ±23.9	
		Mx. Premolar	C		89.3 ±16.7	505.0 ±33.7	
Son et al, 2021						Retraction Cord	• Non-clinically acceptable trueness in subgingival margins without retraction. • Clinically acceptable trueness with retraction cord.
	i500	Mx. Molar	C	0	127.6 ±14.7	68.5 ±7.3	
				0.5	208.6 ±25.6		
	EZIS PO	Mx. Molar	C	0	159.5 ±15.6	98.7 ±8.1	
				0.5	240.5 ±28.7		
Son et al, 2022						Retraction Cord	• The trueness of IOS decreased with an increase in the depth of the subgingival finish line. • At a 0.25-mm subgingival margin without cord retraction, both IOS showed clinically acceptable trueness. With gingival displacement cord, they maintained clinical trueness up to 1 mm depth.
	CS3600	Mx. Molar	C	0	20.2 ±2.1	21.1 ±2.1	
				0.25	46.9 ±6.8	15.2 ±1.6	
				0.5	101.3 ±6.1	16.4 ±2.8	
				0.75	93.0 ±5.7	17.8 ±2.0	
				1	228.2 ±6.7	16.8 ±1.7	
	i500	Mx. Molar	C	0	30.7 ±2.4	27.3 ±2.2	
				0.25	73.0 ±14.9	24.9 ±1.6	
				0.5	132.4 ±11.5	25.7 ±1.1	
				0.75	141.4 ±17.8	26.3 ±1.9	
				1	255.6 ±8.0	25.8 ±1.6	
Sorrentino et al, 2024	i700	Mx. Molar	FE	1	37.5 ±2.6	NS	• Trueness values were within clinically acceptable range in both depths. • No significant differences in trueness were observed between the two groups.
				2	32.6 ±0.9		
Verniani et al, 2023	Trios 3	Mx. Molar	C	1	542.6 ±10	NS	• No IOS demonstrated a clinically acceptable trueness on the marginal area.
		Mx. Incisor	C		360.1 ±16		
		Mx. Molar	S		530 ±5.4		
		Mx. Incisor	S		267 ±7.3		
	i700	Mx. Molar	C	1	548.8 ±7.3		
		Mx. Incisor	C		375.6 ±7		
		Mx. Molar	S		505 ±5.4		
		Mx. Incisor	S		178 ±35		

C: Chamfer; FE: Feather Edge; IOS: Intra-oral Scanner; Md: Mandibular; Mx: Maxillary; S: Shoulder; SG: Subgingival

DISCUSSION

This review aimed to analyze the accuracy of IOS in tooth preparations with subgingival margins. These studies varied in design, including differences in IOS used, finish line designs, tooth abutment types and materials, and finish line locations. Accuracy assessment also differed: some studies evaluated the finish line, others the complete abutment, and some focused on the marginal region. This variability precluded the possibility of conducting a meta-analysis.

The studies included in the present review showed that the trueness of an IOS is significantly affected in tooth preparations with subgingival margins. In the absence of gingival retraction and without saliva contamination, most of the studies showed that IOS did not reach clinically acceptable trueness values regardless of how deep the finish line was positioned and the IOS evaluated.[36,38,39,41] Regarding precision, standard deviations ranged from 0.13 to 28.7. However, it was not possible to determine the clinical acceptability of these values, as there are no established clinically acceptable standards for precision described in the literature.

Only one study reported clinically acceptable values for vertical preparations with finish lines 1 and 2 mm subgingivally, but it had significant limitations.[40] It measured the accuracy of the entire abutment which resulted in most cloud points being recorded from easier-to-register supragingival areas, masking lower trueness in marginal areas.

Decreased trueness in subgingival scenarios may be explained by several factors. Firstly, subgingival margins limit IOS access, increasing the distance between the scanner tip and the margin, which reduces trueness.[41-44] Additionally, the proximity to the gingiva affects margin curvature detection, making it difficult for IOS to detect sharp angles.[45] Moreover, the stitching effect during image processing can reduce accuracy, as point clouds are merged incorrectly in complex topographies.[39,46] Although some IOS increase cloud points to enhance resolution, this has not been shown to increase trueness.[46,47]

The data extracted strongly supports the positive effect of gingival retraction, with most subgingival margin samples showing trueness within clinically acceptable ranges. Moreover, all groups with gingival retraction showed increased precision indicated by a lower SD compared to their control groups without gingival retraction. Among four studies evaluating six different IOS, only one group obtained trueness values exceeding the acceptable threshold.[35] Specifically, the IOS Emerald showed a mean trueness of 147 µm at 0.5 mm SubG, which improved to 94 µm at 1 mm, indicating this result may be an outlier.[35] Overall, the evidence suggests that gingival retraction can mitigate IOS limitations in subgingival scenarios, with one study noting a 90% increase in trueness with cord retraction compared to no retraction.[39]

These results warrant cautious interpretation due to study limitations. First, it is important to acknowledge that no gold standard method exists for measuring the accuracy of IOS, as each technique possesses its own inherent limitations. Two studies assessed accuracy at specific points along the finish line, with one examining only four points[35] and the other twenty points[37], potentially missing discrepancies outside these areas. To enhance accuracy measurement, it is recommended to evaluate at least 50 points.[48] Other studies used root mean square (RMS) values, which can obscure significant marginal errors.[36,38,39,41] Some authors advocate for different methods of evaluating trueness such as reporting the largest error measurement, as this will likely be the point of failure of the restoration[45,49], comparing linear distances between key points or using percentage of surface lying beyond 0.1mm rather than using mean values.[50] Given these methodological variations, the results of these studies, as well as the present review, should be interpreted with caution, as the choice of measurement method can significantly influence the outcomes and their clinical interpretation.

The beneficial effects of gingival retraction are thought to come from both horizontal and vertical displacement of the gingiva. Horizontal displacement creates a gap between the gingiva and the tooth, allowing more light access and reducing stitching at the margin. Vertical displacement enables an IOS to capture the surface beyond the finish line, theoretically improving the recorded margin curvature.[51] However, this hypothesis lacks support from the included studies, as they did not evaluate tooth surface reproduction beyond the finish line. Furthermore, cord retraction is theoretically more critical in non-contact IOS compared to conventional impressions, as the latter physically displaces the gingiva upon injection of the impression material into the sulcus, providing additional horizontal displacement of the gingiva. In contrast, during digital impressions, gingival displacement relies exclusively on the use of cord retraction.

Saliva contamination severely compromises the trueness of digital impressions in subgingival scenarios. Trueness values increased by 343% with saliva present compared to uncontaminated samples, and no group achieved clinically acceptable trueness regardless of IOS type or margin depth.[35,37] Interestingly, even if a retraction cord is used and the site is contaminated with saliva, its effectiveness appears limited in improving trueness under these conditions. Additionally, nearly all groups with saliva contamination exhibited decreased precision, indicated by increased SD values compared to their dry control groups.

The reduction in accuracy due to saliva contamination may be explained by fluids on the scanned surface refracting, reflecting, and deviating light, which leads to significant errors in height measurements.[35,52] Additionally, moisture alters the tooth surface texture and appearance, smoothing or obscuring critical features such as margins, surface roughness, grooves, and undercuts, posing challenges for accurate detail capture by the IOS.[35]

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Moisture control is theoretically more critical during digital impressions compared to conventional techniques, as certain modern conventional impression materials exhibit hydrophilic properties, allowing for greater tolerance to suboptimal moisture enviroment. In contrast, digital impressions require more stringent moisture control for optimal accuracy.

Previous research suggests that different types of IOS may influence scan accuracy.[23,25,47,53] However, in this review, while some variations were noted among IOS systems, these differences did not demonstrate clinical relevance, as all systems yielded comparable results. Similarly, although the literature indicates lower trueness in posterior teeth compared to anterior teeth, the studies included, consistently reported similar trueness values across all tooth types, suggesting clinical insignificance.

The present review has several limitations. Other factors including ambient conditions, scanner head size, scan strategy, occlusal convergence, and abutment material were intended to be evaluated for their impact on accuracy. However, insufficient data reported prevented the evaluation of these factors. In addition, all included studies were conducted *in vitro*, which restricts the applicability of findings to clinical settings.

Furthermore, to mitigate the impact of older IOS generations in the results, only articles published in the last five years were included. However, not all IOS currently available were evaluated, and newer generations have since been introduced. Therefore, the findings may not apply to these newer IOS models, necessitating further research to assess their performance accurately. In addition, this review was unable to determine the accuracy of the root surface beyond the finish line, as most studies recorded trueness values only up to the finish line. This information is also crucial for achieving biological success of the restoration, as it guides the emergence profile of the prosthesis.[54] For this reason, the results and conclusions of the present review should be interpreted within those limits.

CONCLUSIONS

Within the limitations of the review, the following conclusions were drawn:

- The performance of IOS in subgingival tooth preparations without gingival retraction is compromised, resulting in insufficient trueness values for clinical acceptability.
- Saliva contamination negatively impacts IOS performance in SubG scenarios, leading to increased deviations even with gingival retraction, and failing to achieve clinically acceptable accuracy values.
- Gingival retraction on a dry SubG preparation improves IOS accuracy yielding potential clinically acceptable results.

ROLE OF FUNDING SOURCE

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

DECLARATION OF INTEREST

None.

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