REVIEW ARTICLE

The Evaluation of Intraoral Scanners on the Accuracy and Precision of Dental Impressions: Narrative Review

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ABSTRACT

To Intraoral scanners (IOS) have gained widespread use in restorative dentistry due to their ability to produce digital impressions efficiently and comfortably. However, their accuracy and precision vary depending on the scanner type, clinical application, and scanning technique. This narrative review synthesizes current evidence on IOS performance across different clinical conditions. Primescan and TRIOS® 3 showed the highest accuracy in single crown preparations, while Medit i700 and TRIOS® 4 exhibited superior trueness for inlay restorations. IOS has demonstrated high accuracy and clinical reliability in conservative dentistry applications, particularly for single-unit and short-span up to three units fixed restorations. Accuracy was further influenced by scan range, intraoral moisture, and patient movement. Despite recommendations for standardized scanning protocols, the literature lacks clear guidelines regarding specific procedural steps. Inconsistencies in scanner performance and clinical outcomes highlight the need for further research to develop targeted, evidence-based protocols. IOS integration remains promising, but clinical reliability depends on context-specific implementation.

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INTRODUCTION

Intraoral scanners (IOS) have been increasingly adopted in clinical dentistry as a core component of the digital workflow. As an alternative to conventional impression techniques, IOS offers benefits such as improved patient comfort, reduced risk of infection, and enhanced scanning accuracy. The integration of CAD/CAM technology into restorative dentistry relies heavily on the accurate digital capture of dental structures using IOS technologies.(1)

Recent advancements in scanner hardware and software have contributed to the widespread application of IOS, particularly in single-tooth restorations and short-span fixed restorations.(2) Multiple in vivo and in vitro studies have assessed the accuracy of IOS compared to traditional impression materials. Despite the clinical appeal of IOS, their performance is not consistently reliable across different scanners, scanning protocols, and clinical conditions.(3,4) This inconsistency represents a growing concern, especially as IOS becomes more widely used in complex restorations.

A precise and accurate impression is critical for the long-term success of dental restorations. Poor marginal adaptation, often resulting from scanning inaccuracies, can lead to bacterial infiltration, secondary caries, and eventual restoration failure.(5) These clinical consequences underscore the need for reliable digital workflows that ensure the quality of prosthetic outcomes. Accuracy, which encompasses both trueness and precision, is influenced by numerous variables, including scanner design, software algorithms, surface properties, and intraoral conditions such as saliva, access, and lighting.(4)

Although several studies have examined IOS accuracy and technological development, the literature lacks a unified conclusion regarding which scanners perform best under which clinical circumstances. Furthermore, there is a notable absence of standardized scanning protocols, which may contribute to inconsistencies in outcomes.(2-4) Therefore, the aim of this narrative review is to evaluate and compare the accuracy and precision of current intraoral scanners across different clinical applications, identify key influencing factors, and highlight areas requiring further standardization and research.

MATERIALS AND METHODS

Study Selection

This review follows a narrative approach to synthesize current evidence on the accuracy and precision of intraoral scanners (IOS) in dental impressions. A comprehensive literature search was conducted using two widely recognized databases PubMed and Google Scholar selected due to their extensive and complementary coverage of biomedical and dental research. PubMed serves as the standard repository for peer-reviewed medical literature, while Google Scholar includes a broader spectrum of open-access, interdisciplinary, and grey literature. These databases were deemed sufficient to meet the objectives of this narrative review and were chosen based on their accessibility and practical relevance to researchers in dental sciences.

The search included studies published between January 2020 and December 2023, aiming to reflect the most recent developments in IOS technology. The keywords used in the search strategy included combinations of the following terms: "intraoral scanner," "IOS," "accuracy," "precision," and "digital impression", with Boolean operators (AND, OR) applied as appropriate. In PubMed, Medical Subject Headings (MeSH) terms were used where applicable to improve search precision. Additional studies were identified manually through the reference lists of relevant articles and prior reviews.
Inclusion criteria were as follows:

1. Studies evaluating the accuracy and/or precision of intraoral scanners,
2. Articles involving inlay, onlay, endocrown, or single crown preparations,
3. Publications in English, with accessible full-text,
4. Both in vivo and in vitro studies, as well as comparative reviews related to digital dental impressions.

Studies were excluded if they:
1. Focused on unrelated imaging systems,
2. Did not report accuracy or precision outcomes,
3. Lacked evaluative or comparative data relevant to IOS.

All titles and abstracts retrieved were independently screened by the primary reviewer. Full texts of potentially relevant studies were assessed in detail. In cases of uncertainty, discussions were held with a second reviewer to reach consensus. While formal risk of bias tools (e.g., QUADAS-2) were not applied, general methodological quality was evaluated based on clarity of outcome measures, scanner type, and relevance to clinical practice.

RESULTS

The Accuracy of The Intraoral Scanner

Based on the search strategy outlined in the methodology, a total of 15 articles published between January 2020 and December 2023 were initially identified through database and manual searches. After removing duplicates and screening titles and abstracts, 3 articles were excluded, one for lacking data on accuracy or precision, one for focusing on non-IOS imaging systems, and one for being clinically irrelevant to dental applications. As a result, 12 studies met the inclusion criteria and were included in the final synthesis. The clinical relevance and application scope of each scanner included are summarized in Table I.

Digital dental impressions serve the primary purpose of capturing an accurate reproduction of one or more prepared teeth, adjacent and opposing dentition, and their occlusal relationships. The quality and reproducibility of impressions are critical for achieving a clinically acceptable restoration fit. Digital impressions using intraoral scanners (IOS) rely on image acquisition and software reconstruction, thus shifting the focus of accuracy to the scanner's performance (1,2).

Accuracy comprises two interrelated components: trueness and precision. Trueness refers to how closely a digital impression matches the actual geometry of the dentition or reference model, while precision refers to the degree of consistency or repeatability among repeated scans under the same conditions. A high degree of trueness with poor precision may result in inconsistent outcomes, while high precision with low trueness could repeatedly produce incorrect measurements. Both parameters are essential for the clinical reliability of digital workflows, particularly when fabricating indirect restorations such as crowns, inlays, or endocrowns (1).
The scanning process itself involves capturing and merging numerous images into a cohesive 3D dataset. However, as the scanned area increases, especially beyond single or short-span regions, cumulative stitching errors may arise. These errors lead to a decrease in overall accuracy, with full-arch scans being particularly prone to deviation due to the propagation of minor alignment errors across the arch (2,4).

Recent comparative studies have highlighted differences

in performance among various IOS systems. For example, Diker & Tak (2020) compared six IOS and found Primescan to have the highest accuracy (trueness: 25 µm; precision: 10 µm), whereas Emerald showed the least accuracy. Similarly, Sacher et al. (2021) reported TRIOS® 3 and CS 3600 as having superior precision (9–10 µm), while Medit i500 and Emerald demonstrated higher deviation.(5)

Ting Zhang et al. (2021) confirmed that Omnicam outperformed TRIOS and iTero in accuracy, especially for anterior and short-span regions, but all scanners showed reduced accuracy with longer arch spans. (6) Meanwhile, Demirel et al. (2023) noted that Medit i700 and Trios 4 had the highest trueness for inlay preparations.(7) In clinical applications, IOS systems have been utilized for fixed restoration, caries detection using near-infrared imaging (NIRI), and shade matching. While some models such as TRIOS 4 showed excellent accuracy in edentulous cases with multiple implants,(8) shade matching continues to exhibit high precision but moderate trueness, requiring supplemental visual confirmation.(9) Furthermore, patient preference plays a role in IOS adoption. Studies consistently report increased comfort, reduced chairside time, and improved patient satisfaction compared to conventional techniques (10,11).

However, discrepancies in the molar region remain a limitation, especially in full-arch or posterior cases, necessitating further refinement of scanning protocols. In summary, while intraoral scanners have shown significant improvements in digital impression accuracy, their performance is still influenced by scanner type, scanning strategy, arch length, and preparation design. These findings suggest that selecting the appropriate IOS model and scanning protocol is essential for ensuring reliable clinical outcomes (6,7).

Table I. Clinical Suitability of Intraoral Scanners for Various Dental Applications

No.	Dental Application	Summary of IOS Performance	References
1	Single Crowns	Primescan and TRIOS® 3 demonstrated the highest accuracy and precision for single crown preparations; ideal for digital impressions.	(12,13,8)
2	Small Bridges	Digital impressions (DI) effective for small spans. Medit i700 and TRIOS 4 showed high trueness for inlay preparations.	(5,2,11)
3	Quadrant Fixed Restorations	Suitable for quadrant scans; however, some IOS show limitations as scanning area expands.	(4,6,7)
4	Complete-Arch Scanning	Digital scanning across full arches can lead to cumulative errors, reducing accuracy for fixed restoration fabrication.	(10,6,9,15)

Evaluation of intraoral scanner accuracy and precision in dental impressions

This review provides a comprehensive synthesis of the accuracy and precision of intraoral scanners (IOS) under various clinical conditions. The included studies presented heterogeneous findings, highlighting that scanner performance is highly dependent on specific use cases, scanner technology, and scanning strategies. While some IOS devices demonstrated high levels of trueness and precision, others showed limitations under certain clinical scenarios (1,6,7,9-11,13,14).

A total of 15 studies published between 2020 and 2023 were initially screened, and 12 studies met the inclusion and exclusion criteria and were included in this review. The study selection process and clinical suitability are summarized in Table I, which outlines the performance of various IOS devices for specific dental applications (1,2,4-6,8-11,13-15).

The included studies presented heterogeneous findings, highlighting that scanner performance is highly dependent on specific clinical use cases, scanner technology, scanning strategies, and scanning area. For example, Primescan and TRIOS® 3 demonstrated the highest levels of trueness and precision in single crown preparations,(8,12,13) while scanners such as Emerald and Omnicam showed reduced accuracy in larger or more complex scanning areas, including complete-arch scanning (6,9,15).

These findings are further detailed in Table II, which provides a comparative summary of IOS technologies, scanning areas, and their reported accuracy and precision metrics. The data in Table II corresponds directly to the results described in the narrative, allowing readers to cross-reference device performance under different clinical scenarios. Valuable insights into the performance of intraoral scanners are provided through the evaluation of their accuracy and precision. The studies reviewed demonstrated heterogeneous findings, indicating variations in the performance of different scanners. Some scanners exhibited high levels of accuracy and precision, highlighting their potential for delivering accurate digital impressions.

The results are organized into three main themes to enhance clarity and structure: (1). Comparative Evaluation of IOS Accuracy and Precision: Studies included in this review reported significant differences in scanner performance. Devices such as Primescan and TRIOS® 3 demonstrated the highest trueness and precision in single-tooth and short-span restorations. (8,12,13) However, scanners like Emerald and Omnicam showed greater deviations, particularly in more complex cases such as quadrant and full-arch scanning.

Table II. Comparative Summary of Intraoral Scanners: Technology, Accuracy, and Clinical Application Based on Recent Literature (2020–2023)

Author (Year)	Ios Models Compared	Scanning Area	Technology	Trueness (µm)	Precision (µm)	Key Findings
Diker & Tak (2020)	Primescan, Trios, Omnicam, Virtuo Vivo, iTero, Emerald	Full Arch (Single Crown)	Mixed	Primescan: 25 Emerald: 73.5	Primescan: 10 Emerald: 60	Primescan most accurate; Emerald showed highest deviation
Sacher et al. (2021)	TRIOS 3, CS3600, TrueDef, Medit i500, Emerald	Inlay, Onlay, Crown	Mixed	TRIOS 3: 35 CS3600: 43	TRIOS 3: 9–5 Emerald: 47–9	TRIOS 3 and CS3600 showed best precision; Emerald least accurate
Zhang et al. (2021)	TRIOS, iTero, Omnicam	Multiple Crown Preparations	Confocal/ Triangulation	-	-	Omnicam had best accuracy except second molars; accuracy decreased with scan range
Ryth et al. (2022)	12 IOS incl. Primescan, Trios 4, Medit, CS3700, Emerald S	PMMA Maxillary Arch	Mixed	-	-	Primescan most accurate; GC Aadva had lowest score (5.73/30)
Demirel et al. (2023)	Trios 4, Trios 3, Primescan, Omnicam, Emerald, i700	Inlay, Onlay, Crown	Mixed	i700 & Trios 4 highest	-	i700 and Trios 4 had highest trueness for inlays; Omnicam lower than Planmeca

(6,9,14) (2). Factors Influencing Scanner Performance: Scanner technology (e.g., confocal microscopy vs. active triangulation), software versions, and scanning techniques were identified as major contributors to performance variability. For example, older software iterations or suboptimal scan paths led to reduced accuracy, while improved algorithms and refined scanning strategies enhanced scan quality across newer models. (5,7,10) (3). Clinical Implications of Scanning Variability: The variability in IOS accuracy has direct implications for clinical outcomes. Reduced precision in full-arch scans may affect the fit of fixed restorations, while difficulties in capturing subgingival margins may compromise the adaptation of restorations in complex preparations.(9,10,14) Understanding these limitations is crucial for clinicians to select the most appropriate scanning approach based on the clinical situation.

DISCUSSION

Factors Affecting the Accuracy of Intraoral Scanners

The accuracy of intraoral scanners (IOS) is influenced by a multifactorial interplay of technical specifications, scanning conditions, and clinical scenarios. While some IOS devices have demonstrated high performance in specific conditions, others show limitations depending on the application, software used, or scanning technique.

Scanner Technology

IOS accuracy begins with the acquisition of a point cloud, representing the scanned dental structure in three dimensions. This accuracy is largely dependent on both the quality of the hardware (e.g., optical sensors) and the software algorithms responsible for constructing the mesh. One important algorithm is the decimation mesh, which modifies the triangle density of a 3D model based on surface curvature. Although it reduces file size, triangle reduction can lead to variable detail preservation depending on the surface curvature, the complexity of anatomical features, and the specific decimation algorithm used by each intraoral scanner.
In a comparative study, Diker and Tak (2020) evaluated six different intraoral scanners and reported significant variation in trueness and precision. Notably, hardware differences combined with algorithmic processing were the main contributing factors to these disparities.(1) The choice of scanning technology also plays a pivotal role. For instance, confocal-based scanners such as Trios 3 demonstrated higher trueness and precision compared to triangulation-based scanners like Medit i700, which showed the lowest precision values, particularly in scanning extended areas such as full arches or edentulous maxillae, where image stitching and surface registration errors were more prominent (12).

The role of intraoral scan bodies (ISBs) is also critical in determining implant scan accuracy. Rutkūnas et al. (2023) found that the diameter, height, and placement of ISBs significantly influence trueness.(3) Subgingival ISBs, especially those with reduced height, are more prone to scanning errors, while incorporating artificial landmarks was shown to improve accuracy in partially edentulous models.

Scanning speed, pattern, and tip size further affect data acquisition. Hardan et al. (2023) revealed that fast scan speeds and complex patterns such as S-shaped motions negatively impact precision.(4) Conversely, occlusal-first scanning patterns yield better reproducibility. Similarly, Button et al. (2023) reported that optimal distance and angulation between the scanner tip and the tooth surface significantly enhance scan fidelity (5).

Preparation design also contributes to scan variability. Sindhu et al. (2023) demonstrated that simpler, non-retentive preparations show better trueness compared to complex preparations with grooves or isthmus reduction. (6) Additionally, Donmez et al. (2023) found that scan accuracy is reduced in posterior 3-unit cases, although scanners like CEREC Primescan maintained higher performance in those models.(7) Recent advancements in diagnostic scanning, such as the integration of near-infrared imaging (NIRI), further improve clinical utility. Several newer IOS models integrate near-infrared imaging (NIRI) to aid in interproximal caries detection, providing diagnostic benefits that support overall scan precision. validated the use of NIRI for detecting interproximal caries, providing complementary data that indirectly supports IOS accuracy during digital impression acquisition.(8) Lastly, Sacher et al. (2021) emphasized that variations in local accuracy may result from differing acquisition protocols and algorithmic processing, even when overall system performance remains high.(9) These findings highlight the necessity of standardized scanning approaches and software transparency in evaluating IOS technologies.

Local Factors

Numerous local clinical and environmental variables significantly affect the accuracy and precision of intraoral scanners (IOS). These include intraoral fluids, tooth morphology, environmental lighting, surface reflectivity, and patient or operator movement during scanning. Intraoral conditions, particularly the presence of saliva and oral fluids, have been extensively documented as potential disruptors of scanning precision. Chen et al. (2022) evaluated the performance of TRIOS 3 and CEREC Primescan under varying oral conditions—wet, dry, and blow-dried—and found that moisture presence on tooth surfaces leads to increased image distortion and decreased trueness. Air-drying the surface with a three-way syringe significantly improved accuracy (11).

This was corroborated by Rapone et al. (2020), who reported that TRIOS 3 and CS 3600 maintained higher precision compared to CEREC Omnicam in moist environments, although overall accuracy declined for all systems in the presence of biological fluids. (13) These findings emphasize the importance of moisture control protocols, such as suction, drying, or isolation, to enhance scan outcomes. Tooth inclination, positioning, and interproximal space also influence IOS performance. The scanner's optical pathway may be obstructed or misaligned in difficult-to-access areas such as deep interproximal regions or subgingival margins. Preparation geometry and margin positioning further affect how comprehensively the scanner captures fine anatomical detail (8,9,10).

Extraoral factors like lighting conditions are equally critical. Revilla-Leyn et al. (2020) demonstrated that different IOS systems perform optimally under different lighting environments. For example, the iTero Element achieved the highest consistency under chair light (15000 lux) and room light (1003 lux), whereas CEREC Omnicam performed better in complete darkness. TRIOS 3 produced its most accurate scans under standard room lighting (12,13).

Environmental stability also contributes to scan quality. Patient motion, operator tremor, or unstable scanning posture may introduce alignment errors during image stitching. Additionally, surface reflectivity, particularly from ceramic restorations or metallic components, can impair data acquisition by deflecting light away from sensor pathways. Subsurface scattering, enamel translucency, and media transmission properties within the scanned model can further influence the scanner's ability to reconstruct 3D geometry. These effects are more pronounced when scanning highly reflective or irregularly contoured surfaces. Revilla-Leyn et al. and others recommend adjusting lighting and scanning angles depending on the material and region being scanned. In summary, local and environmental conditions significantly impact the precision of digital impressions. Effective saliva management, patient positioning, operator technique, and lighting control are key contributors to improved scan fidelity. Clinicians must adapt their scanning protocols based on individual patient anatomy, scanner type, and the surrounding environment to ensure optimal digital outcomes.

Different scanning techniques

Standardization of scanning techniques is critical for ensuring accuracy and reproducibility in digital impressions captured with intraoral scanners (IOS). Variability in operator methods, scanning sequences, and device handling has been shown to significantly influence trueness and precision. Establishing evidence-based protocols and adhering to manufacturer-recommended strategies can help minimize inconsistency across clinical settings. Numerous studies have examined the influence of scanning patterns on scan quality. Hardan et al. (2023) concluded that S-shaped scanning patterns generate greater discrepancies in scan data compared to linear or occlusal-first methods.(1) These irregular patterns can disrupt the alignment of sequential images, thereby reducing precision and trueness. Similarly, starting the scan at specific points such as from the posterior to anterior or vice versa affects the final model's consistency.

Movement dynamics during scanning are equally important. Rotational and vertical shifts in the scanner head can interfere with real-time image-stitching algorithms, leading to dimensional inaccuracies. Clinicians are advised to maintain smooth, steady motion and avoid abrupt directional changes. Vertical rotation, in particular, has been shown to compromise

the internal consistency of the scan mesh (1).

Zimmermann et al. (2020) emphasized that cumulative and systematic errors become more pronounced when scanning larger intraoral regions, especially full arches. (2) This phenomenon is particularly evident in posterior areas where visual access is limited and the number of captured frames is high. As the quantity of image superimpositions increases, so does the risk of distortion and shape deformation.

To address this, manufacturers often recommend scanning protocols designed to reduce the number of required overlaps. For example, the Medit i500 scanning sequence begins with the occlusal surfaces from one posterior segment to the other, followed by buccal and palatal surfaces.(3) Adhering to these sequences helps reduce software burden and improves stitching accuracy, especially in complex geometries.

It is also important to note the integral role of software in merging image data into cohesive 3D models. If the scan path is inconsistent or the scanner is operated erratically, the software may struggle to merge images effectively, producing a flawed digital impression. Therefore, operator training and adherence to recommended practices are critical (15,16).

A further challenge arises from patient cooperation. In cases involving paediatric, geriatric, or anxious patients, maintaining stillness during the scanning process can be difficult. Movements, gag reflexes, and psychological discomfort may degrade scan quality.(17) Although this review focuses on technical aspects of IOS efficacy, it is important to recognize that patient-related variables can also influence the accuracy and reliability of intraoral digital impressions. In summary, precise scanning technique, including scanning pattern, movement control, starting point, and scan sequence is essential to the success of IOS-based impressions. Operator training and patient management strategies should be integrated into clinical protocols to ensure high quality and consistency (15-17).

CONCLUSION

This review highlights that the accuracy and precision of intraoral scanners (IOS) are influenced by a wide range of interrelated factors, including scanning technology, software algorithms, clinical conditions, lighting environments, and operator technique. Evidence from the reviewed studies indicates that IOS performance varies not only between brands but also depending on the specific clinical application, such as single-unit restorations, inlays, onlays, and implant-supported prostheses.

Certain scanners consistently demonstrated higher levels of trueness and precision for particular tasks for instance, TRIOS 3 and CEREC Primescan yielded superior results in scanning single crowns and posterior implants, while other systems showed reduced accuracy in moist environments or complex geometries. The studies reviewed suggest that no single IOS universally outperforms others across all scenarios, reinforcing the importance of case-specific scanner selection and adherence to standardized scanning strategies. The findings of this review emphasize the critical role of operator training, patient management, and environmental control in optimizing IOS performance. Clinicians should carefully consider scanner capabilities and limitations relative to clinical goals, particularly when performing full-arch scans or working in challenging intraoral conditions. Future research should focus on standardizing scanning protocols, improving transparency in software version reporting, and evaluating scanner performance in diverse patient populations. With the continued advancement of IOS technologies, such studies are essential to establish reliable clinical guidelines and ensure predictable outcomes in digital dentistry.

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