RESEARCH PAPER

Accuracy of Different Intraoral Scanners on the Marginal and Internal Fit of CAD/CAM Ceramic Crowns

Abdelrahman Essam Abdelrahman Elamassy[1*], Amany Mahmoud Nabawy[2], Amjad Saud Alotaibi[3], Norah Ali M Asiri[4] and Saeed Abdulkaliq Almani[5]

[1]*Prosthodontics Specialist- Andalusia Health- Jeddah- Saudi Arabia*
[2]*Prosthodontics Specialist- King Abdul Aziz Hospital- Makkah Al-Mukaraamah Makkah Health Cluster- Saudi Arabia*
[3]*king Abdulaziz medical city-Ministry of National guard health affairs-Jeddah-Saudi Arabia*
[4]*Prince Sultan Military Medical City-Riyadh- Saudi Arabia*
[5]*Administrative supervision of primary health Care- Albaha- Saudi Arabia*
[*]***Corresponding Author:*** *a.alrahman.essam@gmail.com*

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ABSTRACT

The advent of intraoral scanning technology has fundamentally transformed digital prosthodontic workflows, offering a direct chairside alternative to conventional elastomeric impression techniques. However, the accuracy of different intraoral scanners (IOS) in capturing prepared tooth geometry—and its downstream influence on the marginal and internal fit of computer-aided design/computer-aided manufacturing (CAD/CAM) ceramic crowns—remains an area of active investigation. This paper provides a comprehensive review of the current literature examining how scanner type, scanning technology, preparation design, subgingival finish line depth, and post-processing variables interact to determine restoration fit outcomes. Evidence consistently indicates that marginal gap values produced by contemporary IOS systems generally fall within the clinically accepted threshold of 50–120 µm, yet statistically significant differences exist among devices. Systems utilizing active structured-light technologies, such as the CEREC Primescan (Dentsply Sirona), demonstrated superior marginal fit compared to earlier-generation confocal systems. Additionally, the TRIOS 3 (3Shape) and iTero platforms have demonstrated competitive accuracy. Measurement methodologies—including micro-computed tomography (µCT), the silicone replica technique, and scanning electron microscopy (SEM)—influence reported values and complicate direct inter-study comparison. Operator experience, scanning protocol, gingival retraction, and software version are identified as significant confounding variables. Clinical recommendations are drawn from the evidence to optimize the digital workflow for ceramic crown fabrication.

Keywords: intraoral scanner, CAD/CAM, ceramic crown, marginal fit, internal fit.

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INTRODUCTION

The fabrication of fixed ceramic restorations has undergone a paradigm shift over the past three decades, driven by rapid advances in digital dentistry. The integration of intraoral scanning (IOS), computer-aided design (CAD), and computer-aided manufacturing (CAM) technologies has enabled fully digital workflows that circumvent many of the technique-sensitive steps inherent to conventional impression-making (Pereira et al., 2024). Among these steps, the quality of the initial digital impression is foundational; any inaccuracy introduced at the scanning stage propagates through the subsequent design and milling phases, ultimately manifesting as marginal or internal discrepancies in the definitive restoration.

The marginal and internal fit of ceramic crowns are critical determinants of restoration longevity, periodontal health, and the prevention of secondary caries. Excess cement space caused by marginal discrepancies may facilitate bacterial microleakage, increase the risk of caries at the crown margin, compromise cement retention, and promote periodontal disease (Turkyilmaz et al., 2023). The clinical literature has historically established a threshold of less than 120 µm for marginal discrepancy as a benchmark for acceptability, though more recently some authors have proposed a tighter range of 50–120 µm as indicative of optimal clinical performance (Schmalzl et al., 2023; Pereira et al., 2024).

The number of commercially available IOS systems has grown substantially, with leading platforms including the CEREC Primescan and Omnicam (Dentsply Sirona), TRIOS 3 and 4 (3Shape), iTero Element (Align Technology), Medit i500 and i700 (Medit), CS 3600 (Carestream Dental), and Planmeca Emerald, among

**Author for Correspondence: a.alrahman.essam@gmail.com* others. These systems differ in their underlying optical acquisition methods—confocal laser scanning, active wavefront sampling, structured light projection, or video-sequence triangulation—and these differences have been shown to influence scanning accuracy and, by extension, crown fit outcomes (Di Fiore et al., 2024; Accuracy and Clinical Performance, 2025).

Despite an expanding body of evidence, direct comparisons across studies remain difficult due to heterogeneity in experimental designs, different evaluation methods, diverse ceramic materials, varying preparation geometries, and inconsistent definitions of marginal and internal fit parameters. This review aims to synthesize the most current and methodologically rigorous evidence on how different intraoral scanners influence the marginal and internal fit of CAD/CAM ceramic crowns. Specific objectives include: (1) reviewing the optical principles underlying major IOS platforms; (2) evaluating comparative accuracy data from in vitro and clinical studies; (3) examining the role of confounding variables including preparation design, subgingival depth, and measurement methodology; and (4) providing evidence-based clinical recommendations for optimizing the digital impression workflow.

BACKGROUND AND THEORETICAL FRAMEWORK

Principles of Intraoral Scanning Technology

Intraoral scanners acquire three-dimensional surface data through fundamentally different optical principles, and understanding these principles is essential for interpreting comparative accuracy data. Active systems project structured or patterned light onto the target surface and capture the resultant distortion to calculate point clouds, while passive systems rely on algorithmic reconstruction of surface geometry from captured video frames (A Comprehensive Review, 2023).

The CEREC Omnicam and Primescan systems utilize structured blue light and active triangulation to capture surface data. The Primescan, introduced as a second-generation active-wavelength-sampling system, features a wider scanning range—up to 20 mm depth—and advanced depth-scanning capabilities compared to its predecessor (Pereira et al., 2024). The TRIOS 3 employs confocal imaging with ultrafast optical sectioning at 3,000 frames per second, enabling continuous scanning without requiring powder application. The iTero Element uses parallel confocal imaging to acquire thousands of optical cross-sections per second, constructing the 3D model in real time (Accuracy and Clinical Performance, 2025).

These optical differences translate into different strengths and limitations in clinical settings. Systems with greater depth-scanning capability may better capture subgingival margins and deep preparations, while those with wider field-of-view cameras may be more efficient for full-arch scans. The error-stitching algorithms—software processes that assemble partial scan frames into a complete 3D model—differ between manufacturers and represent a significant source of variability in the final STL output (A Comprehensive Review, 2023).

Definitions of Marginal and Internal Fit

Standardized definitions of restoration fit parameters are essential for comparing studies. The marginal gap refers to the vertical distance between the internal surface of the restoration at the margin and the preparation finish line. The absolute marginal discrepancy (AMD) encompasses both marginal gap and marginal overhang or underhang components, measured perpendicular to the tooth surface at the margin. Internal fit refers to the space between the intaglio surface of the crown and the axial and occlusal walls of the preparation (Turkyilmaz et al., 2023).

Holmes et al. (1989) established a widely cited taxonomy of marginal discrepancy that continues to be referenced: marginal gap, marginal discrepancy, overextended and underextended marginal areas, and absolute marginal discrepancy. Contemporary studies tend to adopt this taxonomy, though the measurement methods used to quantify these parameters vary substantially. Micro-CT analysis now permits three-dimensional, volumetric quantification of the cement space, providing more comprehensive data than traditional cross-sectional histological methods (Di Fiore et al., 2023).

REVIEW METHODOLOGY

This narrative review was conducted following a structured search of peer-reviewed literature indexed in PubMed/MEDLINE, Scopus, and Web of Science. Search terms included combinations of the following: "intraoral scanner," "digital impression," "marginal fit," "internal fit," "CAD/CAM," "ceramic crown," "accuracy," "trueness," "precision," and specific scanner model names. Inclusion criteria encompassed in vitro studies, clinical trials, systematic reviews, meta-analyses, and umbrella reviews published between 2020 and 2026. Studies were required to report quantitative marginal or internal fit data or scanner accuracy metrics in the context of fixed ceramic prosthodontics. Non-English publications, case reports, and studies with insufficient methodological detail were excluded. Reference lists of included studies were also hand-searched to identify additional relevant publications.

COMPARATIVE ACCURACY OF INTRAORAL SCANNERS

Key Findings from Recent Studies

A landmark 2024 study by Pereira et al. directly evaluated the marginal fit of CAD/CAM lithium disilicate crowns fabricated using three Dentsply Sirona IOS platforms: CEREC Omnicam 1.0 (O1), Omnicam 2.0 (O2), and Primescan (PS). Using a standardized 3D-printed composite resin die scanned ten times per system, and subsequently evaluating crown fit via micro-CT with 52 measurements per crown, the authors found mean vertical fit values of 46.7 ± 16.4 µm (O1), 33.8 ± 21.4 µm (O2; $p = 0.041$), and 12.3 ± 6.6 µm (PS; $p < 0.001$). The Primescan demonstrated significantly superior marginal fit compared to both Omnicam versions, underscoring the role of scanner generation and underlying optical technology in determining restoration fit outcomes (Pereira et al., 2024).

A comprehensive umbrella review published in 2025 synthesized evidence from ten systematic reviews published between 2020 and 2024, encompassing more than 30 IOS models across a wide spectrum of clinical and laboratory settings. The review found that trueness and precision were the most frequently evaluated outcomes, with TRIOS 3 and Primescan consistently ranking highest in complete-arch accuracy. Compared to traditional elastomeric impressions, IOS systems generally reduced procedural time and enhanced patient comfort, though accuracy in partially edentulous and edentulous arches remained a limiting factor (Accuracy and Clinical Performance, 2025).

A parallel finding was reported in a study examining the marginal fit of ceramic crowns fabricated from data obtained via different scanner types. Comparing intraoral scanner data, model scanner data, and cone-beam computed tomography (CBCT)-derived data for ceramic inlay restorations, researchers documented significantly lower marginal and internal gap values for restorations produced from IOS-derived STL files compared to CBCT-converted models (intraoral scanner group: 124.55 ± 26.51 µm internal gap; CBCT group: 224.64 ± 49.98 µm; model scanner group: 153.73 ± 19.02 µm), with the IOS demonstrating the most clinically favorable results ($p < 0.05$; Comparison of Marginal and Internal Fit, 2025).

A large multi-scanner accuracy study evaluated six IOS platforms—TRIOS 3, iTero Element 2, Planmeca Emerald, CEREC Omnicam, CEREC Primescan, and Virtuo Vivo (Dental Wings)—in Kennedy Class I and Class IV partially edentulous scenarios using a high-precision industrial scanner as the reference standard. Accuracy was evaluated via deviation analysis using Geomagic Studio 12. The Primescan and TRIOS 3 demonstrated the lowest deviation values, while significant inter-scanner differences were found across scanning sequences (Accuracy of Digital Impressions, 2021). These findings are consistent with the broader umbrella review evidence favoring these two platforms.

A study evaluating IOS marginal accuracy for single-crown fabrication using eight different scanners found an overall mean marginal gap of 53.45 ± 30.52 µm across all groups, all within the clinically acceptable threshold. PlanScan, 3D Progress Plus, and True Definition Scanner demonstrated the lowest mean values (approximately 40 µm), while TRIOS 3 recorded the highest among those tested (67.95 ± 30.41 µm). Despite statistically significant inter-group differences, all scanners produced marginal gaps within clinically acceptable limits, supporting the viability of IOS-based workflows for single-tooth restorations (Influence of IOS on Marginal Accuracy, 2019).

Systematic Reviews and Meta-Analyses

A systematic review and meta-analysis by Ma et al. (2023) investigated the accuracy of IOS impressions for implant-supported restorations in in vivo settings. Although focused on implants rather than crown preparations, the meta-analysis provided robust insight into the in vivo accuracy limitations of IOS systems compared to idealized in vitro conditions. The included ten in vivo studies reported variability in trueness conclusions, reflecting the complexity of clinical environments with moisture, patient movement, and limited inter-occlusal access (Ma et al., 2023).

Turkyilmaz et al. (2023) conducted a systematic review specifically addressing the marginal and internal fit of lithium disilicate and zirconia CAD/CAM crowns fabricated using digital impressions. The review concluded that all-ceramic crowns produced via digital workflows consistently achieved marginal discrepancy values within clinically acceptable ranges, though the magnitude of fit accuracy varied by scanner platform, ceramic material, and **CONFOUNDING VARIABLES AFFECTING CROWN FIT**

Preparation Design and Finish Line Configuration

The design of the tooth preparation exerts a profound influence on IOS scanning accuracy and subsequent crown fit. Finish line morphology—chamfer, rounded shoulder, feather-edge, or rounded shoulder with bevel finish line (RSBFL)—affects the margin volume, seating precision, and cement distribution of the final restoration. A study evaluating ceramic crowns fabricated from Medit i700 and TRIOS 3 scan data across three finish line configurations (chamfer, rounded shoulder, and RSBFL) found that RSBFL produced the smallest marginal gap and internal fit values regardless of the IOS used or additive manufacturing technique applied (Lopez et al., 2024).

An in vitro study on lithium disilicate crowns fabricated using a TRIOS scanner with three different finish lines (rounded shoulder, chamfer, and feather-edge) evaluated with micro-CT found that the feather-edge preparation exhibited the largest marginal gap, likely due to the thin marginal structure offering insufficient surface area for optical detection by the scanner (Evaluation of Marginal and Internal Fit, 2021). These findings suggest that preparation design should be selected not only for its biomechanical merits but also with consideration of its compatibility with IOS optical principles.

The axial wall convergence angle is another critical preparation variable. Although a total convergence angle of 6° is theoretically ideal, clinical preparations consistently exhibit higher angles. A study comparing intraoral scanning to indirect digitization of plaster casts found that convergence angles were significantly higher in the intraoral scanning group ($p < 0.001$), though marginal design and finish line homogeneity were superior, potentially due to real-time visual feedback provided by the IOS software (Influence of Intraoral Scanning, 2020).

Subgingival Finish Line Depth

Scanning subgingival finish lines poses a specific challenge for intraoral scanners, as the IOS must capture margin geometry obscured by gingival tissue. A recent in vitro study assessed the impact of varying subgingival finish line depths (0 to 1.00 mm) on IOS accuracy using the Medit i500, with and without gingival retraction. Without retraction, internal trueness and marginal fit deteriorated significantly as finish line depth increased; at 1.00 mm subgingival depth without retraction, marginal fit reached 189.1 ± 42.2 µm, exceeding the clinical threshold. With gingival retraction, trueness and fit remained stable and within acceptable limits across all depths, with marginal fit of 95.2 ± 22.9 µm at 1.00 mm depth (Does Intraoral Scanning at the Subgingival Finish Line, 2025).

These findings carry important clinical implications: gingival retraction is not merely advisable but is demonstrably necessary for maintaining acceptable scan quality and crown fit when finish lines are placed at or below the gingival crest. Retraction cord placement prior to IOS use should therefore be considered a mandatory procedural step in the digital impression workflow for subgingivally placed preparations.

Measurement Methodology

The method used to quantify marginal and internal fit has a substantial effect on reported values and directly influences inter-study comparability. The most widely used methods include micro-computed tomography (µCT), the silicone replica (or triple-scan) technique, scanning electron microscopy (SEM), and optical cross-sectional analysis. Each method has distinct advantages and limitations.

Micro-CT is widely regarded as the gold standard for non-destructive, three-dimensional quantification of cement space. It enables simultaneous assessment of multiple parameters across the entire crown circumference without requiring sectioning. However, the technique is expensive, requires specialized equipment, and the spatial resolution of clinical-grade micro-CT units may be insufficient to detect very fine marginal discrepancies (Di Fiore et al., 2023; Pereira et al., 2024).

The silicone replica technique involves seating the crown with a low-viscosity silicone material, retrieving the cured silicone, sectioning it, and measuring the cement space width under a calibrated microscope or digital imaging system. While widely accessible and reproducible, this technique is destructive, labor-intensive, and provides only two-dimensional data from the measured cross-sections. SEM provides high-resolution two-dimensional images of the marginal interface but similarly requires sectioning and can only evaluate discrete measurement points (A Comprehensive Review, 2023).

A systematic review by Di Fiore et al. (2023) specifically addressed methods for assessing marginal and internal fit of partial crown restorations, evaluating studies published from 2017 to 2023. The review found significant heterogeneity in measurement approaches and recommended standardization of reporting to facilitate future meta-analyses. The authors noted that micro-CT-based methods and the silicone replica technique were most frequently cited, and that combined use of multiple methods improved the reliability of fit assessments.

Operator Experience and Scanning Protocol

The human factor in IOS operation is a significant but often underreported source of variability. A comprehensive review of factors influencing IOS accuracy noted that operator experience, including the learning curve associated with each scanner's ergonomics and software interface, significantly affects scanning time and scan data quality (A Comprehensive Review, 2023). Beginners demonstrate larger trueness deviations and more stitching artifacts compared to experienced operators, particularly in posterior regions and for full-arch scans.

Scanning sequence—the order in which arch segments are captured—has also been shown to influence full-arch accuracy. However, for single-tooth preparations, the effect of scanning sequence is less critical, as the isolated preparation scan is typically overlaid onto a full-arch contextual scan. Software updates represent another underexamined variable: a study examining the impact of software updates on CEREC scanner accuracy found that newer software versions can significantly alter scan accuracy outcomes even when the hardware remains unchanged (The Impact of Software Updates, 2023).

CAD/CAM Milling System and Material

The IOS represents only the first stage of the digital workflow; the accuracy of the CAM milling system and the physical properties of the ceramic material also contribute to final crown fit. Bur wear during milling, block composition, and crystallization protocols all introduce additional variables. A study examining the effect of Primescan-based IOS scanning on zirconia-reinforced lithium silicate (ZLS, CELTRA DUO) crowns evaluated marginal gap before and after crystallization. Pre-crystallization mean marginal gap was 24.25 ± 5.49 µm, which increased significantly to 79.82 ± 7.86 µm after crystallization—though both values remained within the clinically acceptable threshold (< 120 µm; SEM Evaluation, 2024).

The virtual-fit method developed and described in recent literature offers a promising approach to decouple IOS accuracy from milling accuracy, enabling clinicians and researchers to assess whether new IOS or CAM systems meet clinical accuracy thresholds without physically testing all device combinations. Cement spacing between 70–100 µm is identified as a range providing reasonable accuracy for chairside CAD/CAM crown fabrication (Unifying Intraoral Scanner, 2025).

CLINICAL IMPLICATIONS AND RECOMMENDATIONS

The aggregate of the reviewed evidence supports several clinical recommendations for practitioners integrating IOS technology into ceramic crown fabrication workflows.

First, scanner selection should prioritize systems with demonstrated superior accuracy in the single-tooth restoration context. Current evidence favors the CEREC

Primescan and TRIOS 3 platforms for this application, though all major contemporary IOS systems generally produce clinically acceptable marginal fit values for single-unit ceramic crowns when used correctly (Pereira et al., 2024; Accuracy and Clinical Performance, 2025).

Second, preparation design should be standardized to facilitate accurate optical capture. Rounded shoulder and chamfer finish lines are preferable to feather-edge designs for IOS-based workflows, and RSBFL configurations appear to produce the most favorable fit outcomes (Lopez et al., 2024). Adequate preparation taper, sufficient occlusal reduction, and avoidance of undercuts are fundamental prerequisites for both scanning accuracy and milling feasibility.

Third, gingival management is non-negotiable for subgingival preparations. The evidence clearly demonstrates that the absence of gingival retraction prior to scanning leads to unacceptable marginal fit when finish lines are placed more than 0.5 mm below the gingival crest (Does Intraoral Scanning at the Subgingival Finish Line, 2025). Adequate retraction cord placement—or the use of electrosurgery or laser tissue management where appropriate—should be performed before IOS scanning.

Fourth, practitioners should remain current with software updates for their IOS platform, as algorithm improvements have been shown to meaningfully improve scan accuracy and crown fit outcomes. Regular system calibration according to manufacturer guidelines is also advisable (The Impact of Software Updates, 2023).

Fifth, the choice of measurement method for research and quality assurance purposes should favor micro-CT where resources permit, given its ability to provide three-dimensional, quantitative data across the entire marginal circumference without the destructive sectioning required by silicone replica or SEM methods. Standardization of measurement protocols and reporting conventions across studies is urgently needed to facilitate valid comparisons in the future literature.

DISCUSSION

The body of evidence reviewed in this paper consistently supports the clinical viability of IOS-based digital workflows for single-unit ceramic crown fabrication. Contemporary intraoral scanners, particularly second- and third-generation devices, reliably produce marginal discrepancy values within the accepted clinical threshold of 120 µm, and in many cases achieve values approaching the optimal range of 50 µm or below. The Primescan in particular has demonstrated markedly superior marginal fit compared to earlier-generation confocal systems in controlled in vitro conditions (Pereira et al., 2024), a finding supported by the broader umbrella review literature (Accuracy and Clinical Performance, 2025).

However, several areas of uncertainty and controversy persist. The heterogeneity of experimental designs, measurement methodologies, ceramic materials, preparation geometries, and statistical analyses across studies makes it challenging to draw definitive comparative conclusions. The clinically accepted threshold of 120 µm, while widely cited, is itself based on relatively old empirical data and may not reflect the capabilities or requirements of modern ceramic materials and adhesive cementation protocols. Some contemporary authors argue that with the increasing use of resin cement systems, which are more forgiving of cement space than zinc phosphate cements, the clinically meaningful threshold may be higher—though consensus on this point has not been reached.

The distinction between in vitro and in vivo accuracy is also critical. Controlled laboratory studies eliminate the confounding effects of patient movement, saliva, blood, and limited access that characterize the clinical environment. In vivo IOS accuracy is systematically lower than in vitro measurements, and the magnitude of this difference varies by scanner type, arch region, and clinical scenario (Ma et al., 2023). Future research should prioritize well-designed clinical trials with standardized outcome measurement to bridge this gap.

The role of artificial intelligence and machine learning in IOS software development represents a frontier that will likely reshape this field in coming years. AI-powered algorithms for real-time scan optimization, automatic margin detection, and error correction are already being integrated into commercial IOS platforms. As noted in recent reviews, these advances are expected to substantially expand the clinical utility and accuracy of digital impressions (A Comprehensive Review, 2023; Accuracy and Clinical Performance, 2025).

The finding that gingival retraction is critical for achieving acceptable marginal fit with subgingival finish lines (Does Intraoral Scanning at the Subgingival Finish Line, 2025) has immediate practical implications and should be integrated into clinical education curricula and prosthodontic protocols. Similarly, the influence of finish line design on scan accuracy and crown fit supports a re-evaluation of preparation guidelines in light of the specific optical requirements of IOS technology.

CONCLUSION

Intraoral scanners have matured into reliable instruments for digital impression-making in the context of single-unit CAD/CAM ceramic crown fabrication. The evidence reviewed demonstrates that most contemporary IOS platforms produce marginal and internal fit values for ceramic crowns that are clinically acceptable, with some systems—particularly the CEREC Primescan and TRIOS 3—demonstrating superior accuracy metrics. However, the final restoration fit is not solely determined by scanner accuracy; preparation design, finish line configuration, subgingival depth management, measurement methodology, software version, and CAM system calibration all contribute meaningfully to the clinical outcome.

Clinicians adopting or refining digital workflows should select scanner platforms with evidence-based performance data for their intended application, adhere to preparation design principles compatible with IOS optical requirements, implement rigorous gingival retraction protocols, and maintain updated scanner software. Researchers in this domain should prioritize standardized experimental designs and reporting conventions to advance the comparability and clinical relevance of the evidence base. As IOS technology continues to evolve with improvements in optical hardware and software intelligence, further improvements in digital crown accuracy can be anticipated, reinforcing the trajectory toward fully digital prosthodontic workflows as the standard of clinical care.

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