INDONESIAN JOURNAL OF PROSTHODONTICS

REVIEW

Accuracy of intraoral scanning influenced by different scanning distance and ambient light : A systematic literature review

Brandon Thamran,[1] Haslinda Z. Tamin,[2]* Ariyani[2]

Keywords: Accuracy, Ambient light, Intraoral scanners, Precision, Scanning distance

ABSTRACT

Background: Intraoral scanning is now widely used in clinical dental practice. The accuracy of impressions obtained using intraoral scanners is a critical factor in the success of fixed prosthodontic restorations. The accuracy of digital intraoral scanning is influenced by scanning distance and ambient lighting conditions. Objectives: This systematic review aims to evaluate the impact of scanning distance and ambient light on the accuracy of intraoral digital impressions. Methods: Following the PRISMA 2020 guidelines, this study conducted a thorough electronic search across PubMed, ScienceDirect, and ProQuest to identify relevant studies.. The Robins I tool assessed the risk of bias in various study types. Data extraction occurred based on predetermined parameters for studying specimens and assessing outcomes. Results: Multiple studies consistently highlight that maintaining an optimal intraoral scanner (IOS) tip distance, typically around 2,5-10 mm, is critical for achieving high-precision digital models, while both closer and farther distances tend to reduce accuracy. Furthermore, extremes in illumination intensity (0 lux and 1500 lux, especially at 7500 K) leading to diminished scan trueness and prolonged scanning times. Conclusion: Scanning distance and ambient lighting conditions affect the accuracy of digital impressions produced using intraoral scanners. (IJP 2025;6(2):152-156)

Introduction

Intraoral scanning has become an essential part of modern digital dentistry. The accuracy of digital impressions obtained through intraoral scanners (IOS) plays a crucial role in the clinical success of fixed prosthodontic restorations. Compared with conventional impression techniques, digital scanning provides notable advantages, such as improved patient comfort, reduced chair time, and the elimination of distortions caused by impression materials. These devices allow clinicians to quickly create three-dimensional models of the dentition, improving the precision and efficiency of planning and fabricating crowns, bridges, and implant-supported restorations.[1,2]

The performance of intraoral scanners is influenced by a combination of procedural and environmental factors. Procedural factors include the operator's scanning technique, scanning path, device calibration, and particularly the distance between the scanner tip and the tooth surface. Environmental variables, on the other hand, involve illumination, color temperature, humidity, and even patient movement during scanning.[1,2] Among these, scanning distance and ambient lighting are often considered the most critical variables affecting scan accuracy. Scanning distance influences the sensor's ability to capture detailed surface data, while lighting conditions affect how the device interprets reflected light and reconstructs images.[3-6]

Previous studies suggest that optimal scanning distances vary between scanner systems but typically range around 2.5-10 mm. Working too close or too far from the tooth surface can reduce accuracy by oversaturating the sensor or creating missing surface points.[12,14,16] Similarly, changes in lighting conditions can significantly affect scan fidelity. Variations in light intensity (lux) and color temperature can alter both trueness and precision as well as scanning time. Moderate illumination, such as 500 lux at 3900 K, tends to produce more accurate and consistent results than extremely bright or dark conditions.[4-6,10,17] Because lighting environments differ widely between dental offices, controlling this factor remains a challenge in clinical settings.

In addition, intraoral scanners differ in their underlying optical acquisition technology. Systems based on confocal or parallel confocal principles (such as TRIOS or iTero) rely on focused imaging and are generally more tolerant of small variations in distance and lighting. In contrast, triangulation-based scanners (such as CEREC or Medit) depend on projected light geometry and are therefore more sensitive to environmental changes.[10-12,14] Clinical variables, including saliva, patient movement, and soft-tissue interference, may further compromise scanning accuracy.[7-9] It is important to understand how both procedural and environmental parameters—particularly scanning distance and ambient lighting—affect the trueness and precision of intraoral digital impressions. This systematic review aims to summarize current evidence regarding the influence of these parameters on the accuracy and efficiency of intraoral scanning in prosthodontic applications.

Review

The systematic review was reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analy-

1Specialist Program in Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, Medan, Indonesia
2Department of Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, Medan, Indonesia

*Corresponding author: lid_zt@usu.ac.id

DOI 10.46934/ijp.v6i2.317

Table 1. Summary of reviewed studies of factors affecting the accuracy of intraoral scans

Author/Year	Study Type	Independent Variables	Scanners Used	Evaluation Parameters	Key Findings
Arakida et al/2018 (17)	In vitro	Ambient light (0, 500, 2500 lux); Temp (3900K–19000K)	3M True Definition (active wavefront sampling)	Trueness, Precision, Scan time	Accuracy : Best accuracy at 500 lux & 3900K; high lux scan time
Kim et al/2019 (12)	In vitro	Scanning distance (0, 2.5, 5.0, 7.5 mm)	TRIOS (confocal), CS 3500 (confocal) PlanScan (triangulation)	2D linear (Rapidform), 3D RMS (Geomagic)	Accuracy : 2.5 - 5.0 mm had best accuracy; 0 mm was worst
Revilla-Leon et al/2020 (15)	In vitro	Light condition (chair, room, natural, no light)	iTero Element (confocal), CEREC Omnicam (triangulation), TRIOS 3 (confocal)	MeshLab RMS (Trueness & Precision)	Accuracy : iTero chair and room light, CEREC Omnicam zero light, Trios 3 room light
Koseoglu et al/2021 (13)	In vivo	Ambient light (0 vs. 1003 lux); Scanning light (Blue vs. White)	Medit i500 (triangulation)	3D deviation	Trueness : The 3900 K and 500 lux condition is the most appropriate lighting condition for taking a digital impression.
Rotar et al/2022 (14)	In vitro	Scanning distance (5, 10, 15, 20, 23 mm)	Medit i700 (triangulation)	Trueness, Precision	Accuracy : 10 mm had highest accuracy
Piedra-Cascon et al/2023 (11)	In vitro	Ambient light (0–10,000 lux, 12 groups)	PrimeScan (confocal)	RMS deviation	Accuracy : 1000 lux group had best accuracy; 0 lux worst
Karakuzu et al/2024 (10)	In vitro	Ambient light (0, 500, 1000, 1500 lux); Color temp (white, blue, yellow)	YOUJOY 3DS 2.0 (triangulation)	RMS, Scan time	Accuracy : Best at 500 lux + yellow; worst at 0 lux
Button et al/2024 (16)	In vitro	Scanning distance (0,2,4mm) and angulation (0°, 15°, 30°, 45°)	i700(triangulation), TRIOS4(confocal), CS 3800(triangulation), iTero(confocal)	RMS, Scan area	Accuracy : i700: Highest accuracy at 0 mm, 15°;TRIOS 4: Best at 2 mm, 15°; CS 3800: Best at 0–2 mm, 0°–15°; iTero: Best at 0–4 mm, 15°.

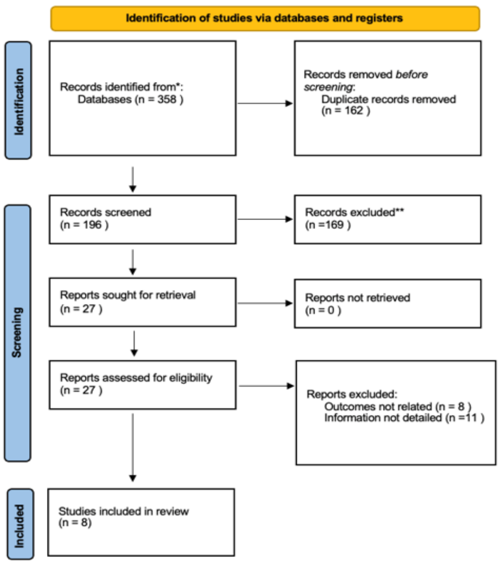

Figure 1. Flow chart of literature screening process

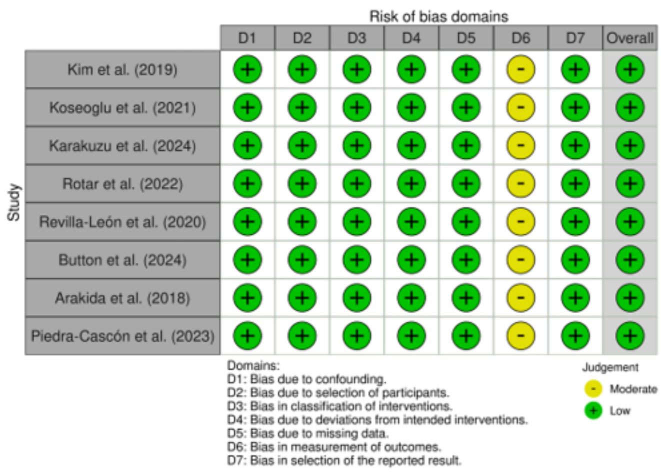

Figure 2. Example of 'Risk of bias' table for a single study

ses) statement.

Objectives

This systematic review aims to evaluate the impact of scanning distance and environmental factors like scanning distance and color temperatures on the accuracy of intraoral digital impressions

PICO question

Population (P): Dental models (typodonts) and patients requiring intraoral scanning — both in vitro (lab-based typodonts) and in vivo (human subjects). Intervention (I): Intraoral scanning performed under different scanning distances and ambient light. Comparison (C): Intraoral scanning performed under other scanning distances or different ambient lighting conditions. Outcome (O): Accuracy, which is further defined by: Trueness: The closeness of the digital model to a "true" or reference model. Precision: The repeatability of the scan, or how close multiple scans of the same object are to each other.

Sources of information and search strategy

An electronic search of three databases was conducted to identify eligible studies: PubMed, Science Direct, and Proquest. The publication time was the period from January 2015 to January 2025. The language or publication type was limited to English. The literature search was conducted in August 2025, using a combination of controlled vocabulary and free keywords: intraoral scanner, scanning distance, ambient light and accuracy. Additional reports were identified through a manual search of the bibliographies of all included studies and relevant systematic reviews. The search strategy for each database was established as follows: ("intraoral scanner" AND "scanning distance") AND ("ac-curacy"), ("intraoral scanner" OR "scanning distance") AND ("accuracy"), ("intraoral scanner" AND "ambient light") AND ("accuracy"), and ("intraoral scanner" OR "ambient light") AND ("accuracy"). These terms were selected after careful consideration of Medical Subject Headings (MeSH) and relevant prosthodontic terminology.

Eligibility criteria

Inclusion criteria; Studies that compared intraoral scans of teeth or typodonts under different ambient light conditions; Studies that compared intraoral scans of teeth or typodonts with different scanning distance; Studies that evaluated at least one of the following outcomes: trueness or precision; In vitro or in vivo studies; Studies published in English language.

DOI 10.46934/ijp.v6i2.317

Exclusion criteria; Case reports, reviews, expert opinions, or clinical guidelines; Studies lacking detailed values of color temperature of ambient light conditions; Studies lacking detailed values of scanning distance; Studies for which the full text could not be retrieved.

Study selection

Titles and abstracts identified in the search were screened independently by two reviewers using Zotero software. If a title or abstract did not provide sufficient information on eligibility criteria, the full text was obtained. The full text was independently assessed by the same reviewers in order to select studies that met the eligibility criteria as described. Articles that did not meet the eligibility criteria were excluded. Reasons for exclusion were recorded.

Data extraction

The selection process was conducted in two hierarchical stages. The first stage involved screening by title and abstract, while the second stage entailed comprehensive evaluation of the full text of the articles. Assessment was performed independently, and upon confirmation of the selected studies, data were systematically extracted, including general information such as publication title, author names, journal source, and year of publication.

Quality assessment and risk of bias

The included studies were independently assessed by two reviewers for their methodological quality at the study level, and differences of opinion were resolved by discussion. A risk of bias quality assessment was performed using the ROBINS-I (Risk Of Bias In Non-randomized Studies - of Interventions) to assess the quality and potential bias of the included studies. The ROBINS-I tool was used for non-randomized studies.

Results

Included studies

A total of 358 articles were initially identified from three different databases. After the removal of duplicates, 196 articles underwent a title and abstract screening. Subsequently, 27 articles were subjected to a full-text review. Nineteen articles were excluded for not meeting the eligibility criteria. Lastly, 8 articles were deemed eligible. Figure 1 shows the flow chart of the screening process in the current study, generated using the PRISMA Flow Diagram tool. A manual search was performed, but no additional articles meeting the inclusion criteria were found.

Quality assessment of studies

Two independent reviewers assessed the risk of bias in each study across several domains, including randomization, deviations from intended interventions, missing data, outcome measurement, and reporting. Discrepancies were resolved through discussion and consensus. All studies demonstrated low risk across most domains, with only minor methodological limitations in one domain (D6) rated as moderate. Overall, the studies were judged to have acceptable methodological quality and provide reliable evidence table 2.

Scanning distance and light conditions influencing the accuracy outcome of intraoral scans

In an in vitro study, Kim et al. examined the effect of scanning distance on the accuracy of three intraoral scanners—TRIOS 3, CS 3500, and PlanScan—using a standardized dental model.[12] Resin frames with heights of 0, 2.5, 5.0, and 7.5 mm were fabricated to maintain consistent distances. Accuracy was analyzed using both two-dimensional linear measurements and three-dimensional root mean square (RMS) deviations. The most accurate results were obtained at 2.5–5.0 mm, while 0 mm (tip contact) produced the least accuracy due to sensor oversaturation. TRIOS 3 and CS 3500 (confocal) outperformed PlanScan (triangulation), and all scanners demonstrated clinically acceptable RMS values below 100 μm.

Rotar et al. evaluated scanning distances of 5, 10, 15, 20, and 23 mm in an in vitro study.[14] The highest accuracy was recorded at 10 mm (trueness 23.05 μm; precision 4.2 μm), while accuracy decreased at both shorter and longer distances. The authors attributed this to light oversaturation at close range and loss of reflected light at greater distances.In a comparative in vitro study, Button et al. analyzed four intraoral scanners—i700, Trios 4, CS 3800 and iTero—to assess scanning accuracy and area discrepancies at varying distances and angulations.[16]

In an in vivo study, Koseoglu et al. investigated the effect of four lighting conditions—room light with white (RLW), room light with blue (RLB), zero light with white (ZLW), and zero light with blue (ZLB) scanning modes—on scanning accuracy.[13] The RLB condition yielded the highest trueness, whereas ZLW resulted in the lowest accuracy. The authors recommended maintaining moderate room illumination with blue scanning light. Karakuzu et al. analyzed four illuminance levels (0, 500, 1000, and 1500 lux) and three color temperatures (white, blue, yellow) in an in vitro study.[10] Both lighting intensity and color temperature significantly influenced accuracy. The best results occurred at 500 lux with yellow light, while 0 lux and 1500 lux conditions reduced trueness.

Revilla-León et al. compared iTero Element, CEREC Omnicam, and TRIOS 3 under four lighting environments—zero (0 lux), natural (500 lux), room (1003 lux), and chair (10,000 lux)—in an in vitro setup.[15] Lighting significantly affected all scanners, but the optimal condition varied: iTero performed best under chair and room light, CEREC Omnicam under zero light, and TRIOS 3 under room light.

Arakida et al. tested several lighting combinations, varying illuminance (0, 500, and 2500 lux) and color temperature (3900 K–19,000 K).[17] The best accuracy was obtained at 500 lux and 3900 K, while higher

DOI 10.46934/ijp.v6i2.317

brightness prolonged scanning time and reduced trueness.

Similarly, Piedra-Cascón et al. examined a confocal-based PrimeScan under twelve ambient lighting conditions (0–10,000 lux).[11] The most accurate results were achieved at 1000 lux, whereas 0 lux yielded the poorest performance.

Discussion

Several studies have demonstrated that scanning distance exerts a significant and nonlinear influence on the accuracy of intraoral scanning. An intermediate distance between the scanner tip and the tooth surface generally provides the highest accuracy, while distances that are either too close or too far reduce trueness and precision. Kim et al., reported that scanning at 2.5–5.0 mm produced optimal results, whereas direct contact at 0 mm led to oversaturation and reflection artifacts.[12] Similarly, Rotar et al., using Medit i500 identified an optimal working distance of approximately 10 mm, with accuracy deteriorating at both shorter and longer distances.[14]

Button et al. examined four intraoral scanners—TRIOS 4 (confocal), iTero Element 5D (parallel confocal), Medit i700 (triangulation), and CS 3800 (active triangulation)—and found that both scanning distance and angulation significantly affected trueness and surface coverage.[16] Moderate distances (2–4 mm) and 15 degree scanning angles produced the most accurate results, while deviations increased when the scanner tip was positioned too close or angled obliquely. Triangulation-based systems showed greater sensitivity to distance and angulation changes, whereas confocal systems maintained more stable performance. These findings support manufacturer recommendations emphasizing a stable working distance within the optical depth of field of the scanner.

The difference in behavior between confocal and triangulation scanners can be explained by their optical design principles. Confocal and parallel confocal systems (e.g., TRIOS, iTero) capture reflected light from specific focal planes, reconstructing a 3D surface from multiple focused images using optical sectioning. This depth-based imaging method reduces sensitivity to small distance fluctuations and ambient light changes [11,12,15]. In contrast, triangulation-based scanners (e.g., CEREC, Medit, PlanScan) operate by projecting structured light patterns or laser beams onto the surface and calculating depth from reflection angles. This geometric triangulation requires precise alignment between the projector and sensor; deviations in distance or angle reduce measurement accuracy.[3,14,16] Triangulation systems are thus more sensitive to light interference, surface gloss, and translucency.[10,15] Clinically, maintaining a scanning distance of approximately 2.5-10 mm while avoiding tip contact or excessive withdrawal is essential for reproducible results.

Ambient light intensity and color temperature also influence the accuracy and efficiency of intraoral scanning. Changes in illumination can disrupt the scanner's exposure calibration and alter the reflected optical signal quality, affecting surface reconstruction.[11,15,17] Arakida et al., using the 3M True Definition, found that 3900 K and 500 lux condition is the most appropriate lighting condition for taking a digital impression.[17]

Revilla-León et al. compared CEREC Omnicam, TRIOS 3, and iTero Element under different light intensities and found that the Omnicam performed best in complete darkness, while iTero and TRIOS achieved better accuracy under room or chair lighting conditions.[15] These results highlight that the optical design of the scanner dictates how lighting influences performance. Confocal systems tolerate a broader range of lighting environments because they rely on focused light collection from specific depths, which reduces the impact of stray or ambient light.[11,17] In contrast, triangulation systems depend on light projection geometry; thus, external illumination can distort structured light patterns, reducing scanning precision.[4,10,15] Clinically, maintaining consistent, moderate illumination (approximately 500–1000 lux at 3900–4100 K) is recommended. Environmental stability, combined with operator awareness and adherence to manufacturer guidelines, remains crucial for accurate digital impressions.

Conclusion

The accuracy of intraoral digital impressions are highly dependent on scanning distance and ambient light. Because current manufacturer guidelines do not fully account for these variables, clinicians must carefully manage scanning parameters, particularly the working distance between the scanner tip and the tooth surface, while maintaining consistent and moderate ambient lighting during the procedure. An optimal scanning distance of approximately 2.5 - 10 mm and controlled illumination, typically within 500–1000 lux, are recommended for achieving accurate digital impressions. Existing evidence remains largely limited to in vitro conditions and single-scanner evaluations, underscoring the need for comprehensive in vivo research that simultaneously examines scanning distance, lighting, and other environmental factors.

References

1. Lim JH, Park JM, Kim M, Heo SJ, Myung JY. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. J Prosthet Dent. 2017;119(2):225–233.
2. Kernen F, et al. Accuracy of intraoral scans: An in vivo study of different scanning devices. J Prosthet Dent. 2022;128(6):1303–1309.
3. Abduo J, Elseyoufi M. Accuracy of intraoral scanners: a systematic review of influencing factors. Eur J Prosthodont Restor Dent. 2018;26(3):101–21.
4. Revilla-León M, Subramanian SG, Att W, Krishnamurthy VR. Analysis of different illuminance of the room

DOI 10.46934/ijp.v6i2.317

lighting condition on the accuracy (trueness and precision) of an intraoral scanner. J Prosthodont. 2021;30(2):157–162. doi:10.1111/jopr.13276.
5. Jivanescu A, Faur AB, Rotar RN. Can dental office lighting intensity conditions influence the accuracy of intraoral scanning? Scanning. 2021;2021:9980590.
6. Viana SWA, Ribeiro MA, de Oliveira AEM, Sotto-Maior BS. Influence of luminosity on the precision and accuracy of intraoral scanning: A comparative in vitro study. Eur J Prosthodont Restor Dent. 2024;32(3):326–334.
7. Van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of intraoral dental scanners in the digital workflow of implantology. PLoS One. 2012;7(8):e43312. doi:10.1371/journal.pone.0043312.
8. Kernen F, et al. Accuracy of intraoral scans: An in vivo study of different scanning devices. J Prosthet Dent. 2022;128(6):1303–1309.
9. Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent. 2016;115(3):313–320.
10. Karakuzu M, Öztürk C, Karakuzu ZB, Zortuk M. The effects of different lighting conditions on the accuracy of intraoral scanning. J Adv Prosthodont. 2024;16(5):311–318.
11. Piedra-Cascón W, Adhikari RR, Özcan M, Krishnamurthy VR, Revilla-León M, Gallas-Torreira M. Accuracy assessment (trueness and precision) of a confocal-based intraoral scanner under twelve different ambient lighting conditions. J Dent. 2023;134:104530.
12. Kim MK, Kim JM, Lee YM, Lim YJ, Lee SP. The effect of scanning distance on the accuracy of intraoral scanners used in dentistry. Clin Anat. 2019;32(3):430–438.
13. Koseoglu M, Kahramanoglu E, Akin H. Evaluating the effect of ambient and scanning lights on the trueness of the intraoral scanner. J Prosthodont. 2021;30(9):811–816.
14. Rotar RN, Faur AB, Pop D, Jivanescu A. Scanning distance influence on the intraoral scanning accuracy—An in vitro study. Materials (Basel). 2022;15(9):3061.
15. Revilla-León M, et al. Intraoral digital scans. Part 1: Influence of ambient scanning light conditions on the accuracy (trueness and precision) of different intraoral scanners. J Prosthet Dent. 2021;126(4):473–481.
16. Button H, Kois JC, Barmak AB, Zeitler JM, Rutkunas V, Revilla-León M. Scanning accuracy and scanning area discrepancies of intraoral digital scans acquired at varying scanning distances and angulations among four different intraoral scanners. J Prosthet Dent. 2024;132(1).
17. Arakida T, Kanazawa M, Iwaki M, Suzuki T, Minakuchi S. Evaluating the influence of ambient light on scanning trueness, precision, and time of an intraoral scanner. J Prosthodont Res. 2018;62(3):324–329.
18. Sezer T, Sezer AB. Effects of operator experience and scanning distance on intraoral scanner accuracy. Necmettin Erbakan Univ Dis Hekim Derg. 2024;4(2):113–120. doi:10.51122/neudentj.2024.113.
19. Lee J. Digital workflow for establishing the posterior palatal seal on a digital complete denture. J Prosthodont. 2021;30(9):817–821.
20. Ma Y, Guo YQ, Saleh MQ, Yu H. Influence of ambient light conditions on intraoral scanning: A systematic review. J Prosthodont Res. 2024;68(3):212–219.

DOI 10.46934/ijp.v6i2.317