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Review Article

A Systematic Review on the Factors Influencing the Precision of Intraoral Scanners

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ABSTRACT

Technological advances in dentistry have led to a significant shift from traditional diagnostic and therapeutic approaches to digital techniques, including digital diagnosis, treatment planning, and prosthesis manufacturing. This transition has heightened the need to evaluate the performance and precision of digital tools and software to achieve more accurate outcomes. Intraoral scanners (IOS) and laboratory model scanners are essential in CAD CAM fabrication, as they are the only means to digitally record the oral environment. The accuracy of IOS is affected by various intra-oral and extra-oral factors. This review aims to investigate the factors that affect the accuracy of intra-oral scanners. A systematic review was conducted using advanced search tools in the PubMed and Cochrane databases, supplemented by a manual search in Google Scholar. A total of 37 studies met the inclusion criteria for the review. Most studies focused on the in vitro evaluation of IOS accuracy under the influence of clinical and extra-oral variables, with fewer in vivo studies. The results showed that multiple factors significantly affected both the trueness and precision of different intra-oral scanning systems, impacting their overall efficiency. While intraoral scanners provide comparable results to conventional methods, they remain susceptible to inaccuracies because of the influence of various intra-oral and extra-oral factors.

Keywords: Optical impressions, Digital impressions, Precision, Accuracy, Trueness, Intraoral scanners

Introduction

Three-dimensional imaging has become increasingly popular in digital dentistry due to its minimally invasive nature and its ability to create an accurate replica of a patient's oral cavity. Currently, 2 methods of digital image acquisition are used: intraoral scanning, performed chairside, and model scanning, which is done in dental laboratories using model scanners. An additional advantage of digital impressions is the ease with which data can be stored and retrieved over time, unlike traditional stone models, which can deteriorate, break, or take up valuable clinical or laboratory space [1-3]. The accuracy of dental impressions is crucial for producing a prosthesis that fits properly and ensures successful treatment outcomes. Like traditional impressions, digital impressions must accurately capture finish lines, surrounding areas, and the occlusal surfaces of adjacent teeth to minimize errors in the final prosthesis. Numerous in vitro and in vivo studies have evaluated the performance of intraoral scanners and have found that intraoral scanners can produce clinically acceptable and relatively precise impressions when compared to conventional methods [4, 5]. Various factors, both intra-oral (such as patient conditions) and extra-

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oral (such as environmental influences, scanner software, and hardware), affect the accuracy of intraoral scanners. Most of the studies assessing accuracy have been conducted in vitro under controlled laboratory settings, leaving a gap in the literature regarding in vivo results. However, a deeper understanding of in vitro findings could guide the design of more robust in vivo studies, contributing to the standardization of ideal conditions for more accurate clinical research. Clinical variables can introduce inaccuracies in intra-oral scanning [4-6]. This review wants to examine the factors that influence the accuracy of intra-oral scanners.

Materials and Methods

The article search was conducted using keywords derived from MeSH terms. These terms were applied in an electronic search across three databases—Cochrane, PubMed, and Google Scholar—focusing on clinical trials published in English. The retrieved articles were then screened based on predefined exclusion and inclusion criteria. The screening process began with an analysis of the title, followed by the abstract, and then the full text. Literature from all periods was considered; however, the search was limited to studies that assessed the reliability of intraoral scanners (IOS) about at least one influencing variable.

Structured question
What factors influence the accuracy of intraoral scanners?

PICO (population, intervention, comparison, outcome)
P - Dentulous model
I - Intraoral scanners
O - Accuracy (Trueness/Precision)

Outcome variables

Accuracy
Refers to how closely a measured value aligns with a known or true value, evaluated by the deviation in distance, typically measured in µm.

Precision
Indicates the closeness of multiple measurements taken independently under the same conditions, reflecting the consistency and repeatability of the results.

Trueness
Describes the extent to which the average of repeated measurements matches the true value, dependent on the reproducibility of results.

Results and Discussion

The database search returned 3100 articles from Google Scholar, 28 from the Cochrane Library, and 73 from PubMed. After screening titles and abstracts, 37 articles were selected for inclusion in the systematic review **(Table 1)**. All articles were examined using a tailored data extraction method **(Figure 1)**.

Table 1. Inclusion and exclusion criteria of the research

Inclusion criteria	Exclusion criteria
Invitro studies and invivo studies	Review studies
Research on factors influencing the accuracy of IOS devices	Research on factors impacting the mesh quality of intra-oral scanners
Studies examining the effectiveness of IOS devices	Studies focused solely on the efficiency of IOS
Studies involving both manually and digitally produced models	Studies using models with orthodontic brackets or appliances
Studies that included lab scanners in the experimental group	Research solely on extraoral or laboratory scanners

Availability of full-text articles	Studies involving models related to implant abutments or scan bodies
Literature published in English	Literature available in languages other than English

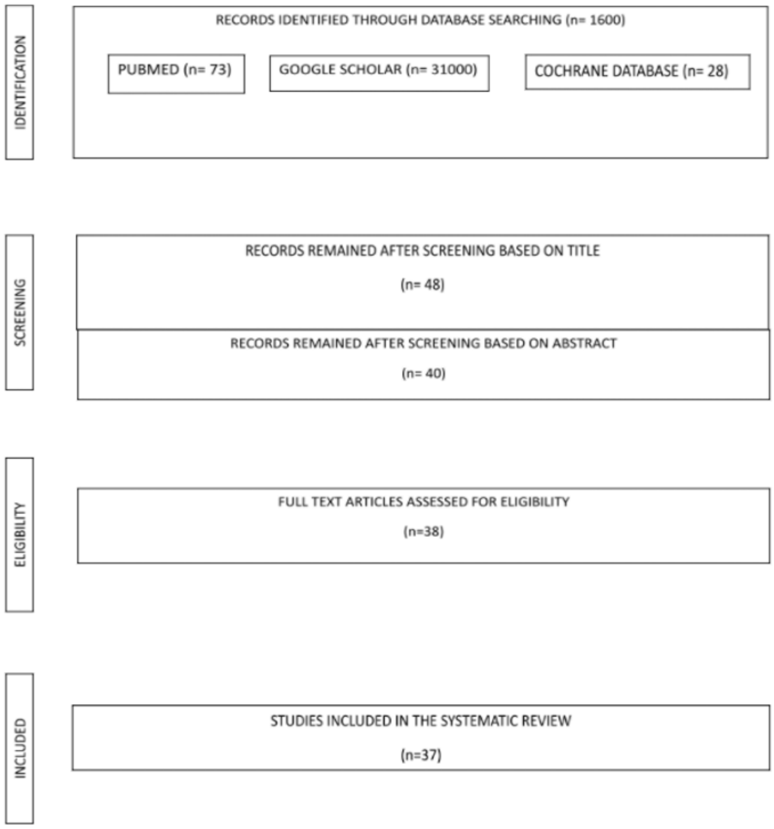

Figure 1. Diagram showing the total number of articles searched, evaluated, and selected for inclusion in the study.

The concept of using CAD-CAM technology for prosthesis fabrication may have seemed like science fiction in the past, but today, the integration of intra-oral scanners, design software, and computer-aided manufacturing tools such as 3D printers and milling units is becoming standard practice in creating dental prostheses [5]. To ensure that the fabricated prosthesis exhibits minimal clinical errors, it is essential to evaluate the accuracy of intra-oral scanners. The performance of IOS is influenced by various factors.

Light conditions

A total of ten researchers have examined how light conditions influence intra-oral scanners **(Table 2)**, with 3 of these studies addressing multiple factors, including one in vivo study. Martínez-Rodríguez *et al*. [7] found significant differences in accuracy when scans were recorded under 4 different lighting conditions: chair light (15000 lux, 4100k), zero light, room light (1003 lux), and natural light (500 lux). Comparisons were made both between and within these light conditions using 3 intra-oral scanners: Trios 3, iTero Element, and CEREC Omnicam [8]. Her study on the Trios 3 intraoral scanner concluded that 1000 lux lighting conditions yield the best scan accuracy and recommended avoiding chairside lighting for this device [9]. In another study comparing the impact of lighting on right quadrant scans and complete arch scans, Marta Revilla-León found an important difference in trueness and precision, with room light at 1003 lux showing the least deviation in complete arch scans, while right quadrant scans showed no statistically significant differences, though chair light at 10000 lux had the least discrepancies [10]. Christian Wesemann, in his research with six intraoral scanners, observed that ambient light affects both scan time and accuracy, with the impact varying depending on the intraoral scanning system. Although lighting conditions did not have a clinically significant effect on 4-unit scans, proper illumination improved both scan time and scanning accuracy for full-arch scans [11]. Toshio Arakida understood that 500 lux, 3900 K lighting was ideal for digital impressions using the True Definition intra-oral scanner, and that high illuminance ambient light increased scanning time [12]. Anca Jivanescu, in research using the Planmeca PlanScan intra-oral scanner, found minimal differences in trueness under six different light conditions, with the best trueness values at 10000 lux and the worst at 400 lux. Precision showed a significant difference ($P = 0.016$), with the best results at 3300 lux and the worst at 1100 lux [13]. Merve Koseoglu *et al*. [14], in their research with the Medit i500 intra-oral scanner, found a significant difference in trueness ($P < 0.0001$) under the influence of 2 ambient light conditions and 2 scanning light modes, with the best accuracy recorded in the room light condition (1003 lux, blue light mode). In her in vivo study, Marta Revilla-León found that the accuracy of the Trios 3 intraoral scanner decreased as the range of the digital scan increased, with larger scans showing lower accuracy values.

Table 2. Summary of studies examining the impact of light conditions on the accuracy of intra-oral scanners.

Journal name/ Year	Type of study	Comparison group	Model	Parameters assessed	Intraoral Scanners used	Outcome values	Drawbacks
J Prosthet Dent, 2019	In vitro	natural light, room light, chair light, and no light	A mandibular typodont (NISSIM type 2; Nissim) was scanned using the L2 Scanner system	Accuracy	CEREC Omnicam, iTero Element, and Trios 3 scanners	The iTero element exhibited improved accuracy under chair light (10000 lux) and room light (1003 lux) conditions, while the CEREC Omnicam performed best in zero light, and the TRIOS 3 showed superior accuracy under room light (1003 lux) conditions.	This in vitro study, conducted on dentate models, suggests that intra-oral edentulous environments may have a higher concentration of unattached tissues, potentially causing inaccuracies.
J Prosthodontic Research, 2018	In vitro	0, 500, 2500 lux color	Mandibular dentulous model (500H-1; Nissin dental products)	precision and true scanning time	True definition	The true definition 3M IOS demonstrated improved trueness values under 500 lux and 3900K lighting conditions. Additionally, the digital impression process took more time at 2500 lux compared to 0 lux or 500 lux when using the true definition IOS.	In a clinical environment, the effect of ambient light cannot be fully evaluated on the model. Other factors such as saliva and patient movement can also influence the accuracy of the impressions in real-world settings.

JOPR, 2020	Hindawi, 2021	JPD, 2020	JOPR, 2021
In vitro	In vitro	In vitro	In vitro
Lighting conditions included chair light (10000 lux), room light (1003 lux), natural light (500 lux), and no light (0 lux).	400 lux; 1000 lux; 3300 lux; 3800 lux; 10 000 lux; 11 000 lux	100,500, 1000 l 5000 lux	Ten groups between 1000lux to 10000 lux.
The maxillary arch model was scanned with the E4 dental scanner; 3Shape laboratory scanner.	A dental mannequin (Phantom head PK-2 TSE; Frasaco) was scanned using an extraoral scanner (D700 3D scanner, 3Shape).	A maxillary model printed using model resin (Form 2 - Formlabs) was scanned with an optical coordinate measuring system (ZEISS)	A mandibular typodont (Nissin type 2; Nissin) was scanned using the L2 laboratory scanner by Imetric.
Precision and Trueness	Accuracy	Accuracy scanning time of intra-oral scanners	Precision and trueness
Trios 3	Planmeca PlanScan	Trios 3, CEREC Omnicam, iTero Element, CS 3600, Planmeca Emerald, and GC Aadva.	Trios 3
In complete arch scans, the room light condition at 1003 lux resulted in the smallest deviation values for trueness and precision. However, in right quadrant scans, the chair light condition with 10000 lux yielded the lowest deviation values.	The highest trueness was observed in the 10,000 lux group, while the 400 lux group showed the lowest level of trueness. A statistically significant difference was found between the groups in terms of precision, with the 3300 lux group yielding the best results.	A notable variation in accuracy was observed with all intra-oral scanners during 4-unit scans. However, for full arch scans, a significant difference was noted across all other IOS systems tested, except for the Trios 3 and GC Aadva. Among all lighting conditions, the Trios 3 IOS produced the quickest scans.	For the Trios 3 intraoral scanner, the group with 1000 lux showed the smallest discrepancy values, while the group with 5000 lux exhibited the largest discrepancy values.
A single intra-oral scanner was utilized in the study. Additional clinical factors, such as moisture presence and the inclusion of metallic or ceramic surfaces, were not addressed. The reference scan served as the model scan.	As an in vitro study, it does not take into account other influencing factors such as saliva, blood, or patient movement.	The accuracy of intra-oral scanning may be impacted by clinical factors and the type of scanning substrates present, such as metal, ceramic, or polyether ketone scan bodies.	In an in vitro study, only a single intraoral scanner was used. Clinical settings, however, may introduce inaccuracies.

JOPR, 2020	J. Pers. Med, 2020	ACP Journal of Prosthodontics, 2021
Invivo study	In vitro	In vitro
Scanning distance: Full arch scan, right quadrant Lighting conditions: chair light (10000 lux), room light (1003 lux), natural light (500 lux), no light (0 lux).	Crowding of the lower incisors, mesial tipping of the lower molars, type of surface material, and surrounding light conditions.	Scanning light modes included blue [B] and white [W], with light conditions of room light at 1003 lux and no light at 0 lux.
The model was scanned using a laboratory scanner (E4 Dental Scanner; 3Shape).	The perfect lower model was generated using ortho analyzer software (3Shape).	The maxillary arch model was scanned using the E4 Scanner (3Shape), a dental LS system.
Trueness and precision of complete and partial arch scans	Efficacy and efficiency	Trueness
Trios 3	Trios 3	Medit i500
Notable variations in the trueness and precision values were observed under different lighting conditions, with the room light condition yielding the smallest absolute error in comparison to the other lighting setups.	The accuracy of digital acquisition is affected by the extent of crowding and the inclination of the molars ($p < 0.05$). The scanning surface material impacts both efficiency and effectiveness, with calcium sulfate hemihydrate—a modified compound scanning surface—showing lower performance ($p < 0.05$). Increased ambient light intensity in the scanning area was linked to a decrease in scanning efficacy ($p < 0.05$). The scanner detected greater volumes of undetected areas as crowding and mesial tipping of the lower second molar exceeded 25°.	A notable difference in the trueness values of the Medit i500 intra-oral scanner was observed ($p < 0.0001$), with the room light condition at 1003 lux and blue mode showing the smallest deviations.
The study utilized a single intra-oral scanner, and factors such as moisture presence and the use of metallic or ceramic surfaces were not addressed. The reference scan served as the model scan for comparison.	In an in vitro study, intra-oral scanning performed in patients' mouths may encounter varying light and dark areas due to the oral environment, which cannot be replicated under controlled in vitro conditions. These factors could contribute to additional errors and inaccuracies during the scanning process.	Two light conditions were tested, excluding chair light and no light settings. The precision of the intra-oral scanner was not assessed.

Saliva/oral liquids

A total of three studies examined the role of saliva and oral liquids in affecting the accuracy of intra-oral scanners, with one being an in vivo study **(Table 3)**. In a study by Yuming Chen, DDS, Ph.D., the impact of liquids on tooth surface scanning was evaluated using the Trios 3 and CEREC Prime Scan under 3 conditions: wet, dry, and blow-dried. The liquids tested were artificial saliva and ultra-pure water. Results showed that the wet conditions yielded significantly higher mean RMS values compared to the dry and blow-dried conditions, suggesting that the presence of liquid on the tooth surface can introduce inaccuracies in digital impressions with both Trios 3 and Prime Scan. Additionally, using a three-way syringe for blow drying helped reduce scanning errors [15]. In another study by Biagio Rapone, the CS 3600, Trios 3, and CEREC Omnicam intra-oral scanners were assessed in the presence and absence of saliva. The study found notable differences in accuracy across the scanners, with the CS 3600 and Trios 3 showing the highest accuracy, while the CEREC Omnicam showed the lowest. The research concluded that biological fluids significantly affect the accuracy of digital impressions, and the results were clinically unacceptable under wet conditions [16]. Lastly, Camcı and Salmanpour conducted an in vivo study to test the accuracy of the Trios 3 scanner under varying light and salivary conditions. Although no significant differences were observed between the test groups, the group with saliva and lower light intensity exhibited higher deviations [17].

Table 3. The studies exploring the impact of oral moisture on the accuracy of intra-oral scanners

Journal name/ Year	**Type of study**	**Comparison group**	**Model**	**Parameters assessed**	**Intraoral scanners used**	**Inference/Clinical implication**	**Draw Backs**
ACP, Journal of Prosthodontics, 2021	In vitro	Ultra-pure water, artificial saliva	The mandibular model (NISSIN) was scanned using the Zeiss Metrotom 800, an industrial computed tomography device.	Accuracy	Trios 3, Prime scan	The average RMS values in wet conditions were significantly higher compared to dry conditions (p=0.001), suggesting lower accuracy for the Trios 3 and Prime Scan in wet environments.	In this in vitro study, a frame-by-frame analysis was not performed during the superimposition process.
Appl. Sci, 2020	In vitro	Without saliva, with artificial saliva	An optical scanner, the S600 ART scanner by Zirkonzahn, was used to scan two molars and two premolars.	Accuracy	CS 3600, Trios 3, CEREC	There was a statistically significant difference in accuracy among the three intraoral scanners, with the CS 3600 and Trios 3 exhibiting superior accuracy compared to the CEREC Omnicam, both with and without the presence of saliva.	In vitro, study limitations include a limited sample size, lack of a biological environment, and the use of an opaque film, which may have affected the accuracy of the reference scans under both salivary conditions.

Am J Orthod Dentofacial Orthop, 2020	Invivo study	daylight and saliva, daylight with saliva isolation, reflector light and saliva, and relatively dark oral environment and saliva.	daylight and intraoral scanner trios models with saliva isolation	Accuracy	TRIOS 3	Saliva contributed to 13 percent of the deviations, and lower light levels further amplified these deviations.	The research focused solely on maxillary arches, noting that soft tissue movement in the lower arch could influence scanning accuracy.

Studies that discussed more than one factor

César Martínez-Rodríguez's research examined how intraoral factors like molar tilt and anterior crowding, along with extraoral elements such as surface materials and ambient lighting, influence the performance of the Trios 3 intraoral scanner. The findings indicated a significant variation in scanner efficiency and effectiveness—measured by scan chair time, scan error, and undetected volume—with $P < 0.05$. The study highlighted that digital acquisition with an intraoral scanner is particularly sensitive to clinical conditions, including the curvature and mesial inclination of the mandibular second molars, as well as external aspects like the material of the scanning surface and lighting conditions. These factors were shown to impact the scanning outcome [7]. In another study evaluating intraoral scanner accuracy with different crowns and scanning techniques, Ji-won Anha found no statistically important difference in scanner performance across varying levels of tooth irregularity. However, differences emerged in terms of accuracy depending on the scanning strategy used, with iTero being less precise than Trios **(Table 4)** [18].

Table 4. An overview of studies examining how tooth preparation, tooth type, and preparation geometry influence the accuracy of intraoral scanners

Journal name/ Year	**Type of study**	**Comparison group**	**Model**	**Parameters assessed**	**Intraoral scanners used**	**Inference/ Clinical implication**	**Draw Backs**
J Prosthet Dent, 2016	In vitro	−8, −6, −4, 0, 4, 8-, 12-, 16-, and 22-degree occlusal convergence angles	Reference models were fabricated using the ProJet 3500HD Max from 3D Systems and digitized with the Rexcan DS reference scanner from Solutions	Accuracy (Trueness and precision)	Trios 3	When the total occlusal coverage angle was below 8 degrees ($p<0.05$), the TRIO 3 intra-oral scanner showed significantly higher accuracy compared to manual impressions and desktop model scanner impressions.	The preparation geometries used were ideal. However, 3D-printed resin models may differ from real human teeth in properties such as hardness, surface roughness, light reflection, and wettability. The study does not address factors like the lack of oral fluids, patient movements, or potential distortions caused by temperature variations.

JOPR	MDPI Materials, 2020	JOPR, 2020
In vitro	In vitro	In vitro
There are three groups, with two subgroups based on intra-coronal and extra-coronal preparations. Each subgroup is further divided into two categories, with divergent and convergent angles of 6 and 12 degrees.	2 model scanners and 5 intra-oral scanner groups	PC preparation with neighboring teeth, CC preparation with neighboring teeth, PC preparation without neighboring teeth, and CC preparation without neighboring teeth.
A typodont model (Nissin Dental Product, Kyoto, Japan) was digitized using the Ineos X5 extraoral desktop scanner (Dentsply Sirona).	scanner use: industrial 3D scanner Solutionix C500, MEDIT. Typodont model (ANKA-4 V CER,Frasaco)	A maxillary typodont (Columbia Dentoform) was digitized with a desktop laboratory scanner (D900L, 3Shape)
Accuracy	Accuracy	Accuracy
Cerec AC Omnicam Trios Medit i500	CS 3500, CS 3600, Trios 2, Trios 3, Medit i500	Trios 3, True Definition
Intra-coronal preparations exhibited lower accuracy values compared to extra-coronal preparations. The Trios and Medit i500 scanners demonstrated higher accuracy than the Omnicam. A greater tapering of the axial wall directly affects the trueness of the intra-oral scanner (IOS).	A statistically significant difference in accuracy was observed with the intraoral scanner based on tooth type, with $p<0.001$. The accuracy trend for the intraoral scanner generally decreased from the front teeth to the back.	A significant difference was observed between the average absolute discrepancy and the maximum absolute discrepancy of the Trios 3 and True Definition intra-oral scanners, with $P<0.001$
The outcomes could vary in real intra-oral conditions due to the presence of living tissues, such as enamel, dentin, and soft tissue movements. Tooth preparation geometries in clinical settings may result in higher inaccuracies. While a dental model scanner was used for the reference scan, using an industrial scanner might have yielded more accurate results.	Tooth characteristics such as steep cusp inclinations, the depth of pits and fissures, and the presence of minimal occlusal morphologies in real intra-oral conditions can significantly affect intra-oral scans. These factors were not accounted for in the study, as it was conducted on a standardized model.	The study was conducted outside of the oral cavity. The oral environment may pose challenges that restrict access to scanning with the intra-oral scanner. Oral fluids could impact the accuracy of the IOS. While the preparation design and adjacent teeth were standardized, real oral conditions may differ, with variations in adjacent tooth positioning and preparation design, potentially leading to inaccuracies.

IJP, 2020	In vitro	FDI 15- full crown with chamfer margin and layer thickness approx 1.5mm FDI 11- veneer with chamfer margin thickness 0.5mm FDI 24- MOD shoulder prep FDI 26- onlay with occlusal chamfer layer thickness 1.5mm	A typodont model (ANA-4 Frasaco, Tettnang, Germany) was digitized using the Lava ST laboratory scanner from 3M ESPE.	Accuracy (Trueness and Precision)	Trios 2, Omnicam, True definition, Primescan	There were significant differences in the precision and trueness values between the IOS and preparation geometries (p<0.05).	In an in vitro study, clinical variables could potentially have a considerable impact on the results.

Tooth preparation geometry

Four studies have explored the impact of tooth geometry on the accuracy of intra-oral scanners. Jeison B. Carbajal's research, using the Trios 3 intra-oral scanner, examined the effect of 9 occlusal clearance angles (−8, −6, −4, 0, 4, 8, 12, 16, and 22 degrees). The findings indicated that the Trios 3 scanner could accurately capture abutment tooth preparations, regardless of their geometry [19]. Additionally, an increase in axial wall tapering was found to directly affect the trueness of intra-oral scans, and the type of intra-oral scanning system was shown to influence scan accuracy, even for simple single-tooth restorations. In another study, Kamal Ebeid tested three intra-oral scanners—Trios 3, Medit i500, and Omnicam—under varying conditions with extra-coronal and intra-coronal preparations featuring convergent and divergent angles of six and twelve degrees. The results revealed that extra-coronal preparations provided higher accuracy than intra-coronal ones, with Trios 3 and Medit i500 outperforming Omnicam, yielding statistically significant results [20]. Alexander Schmidt's research, involving 4 intra-oral scanners (True Definition, Prime Scan, Trios 2, Omnicam) and four different preparation geometries across various teeth, found that simpler geometries resulted in more accurate scans compared to more complex ones. A notable difference was observed between scanners based on preparation geometry, with clinically acceptable negative and positive deviations [21].

Location of gingival margins

The placement of tooth preparation margins can negatively impact the accuracy of intra-oral scanners. In a study conducted by Keunbada Son, two intra-oral scanners, Medit i500 and EZIS PO, were tested under 3 margin placement conditions: supra, subgingival, and equi-gingival. The results revealed an important difference in the accuracy of the scanners ($P < 0.001$), with equi-gingival and subgingival margins demonstrating lower accuracy levels. The use of a retraction cord improved gingival accuracy ($P < 0.05$). Additionally, Medit i500 showed better accuracy compared to EZIS PO, with $P < 0.001$ [22].

The design of the preparation and limitations in scan angulation caused by adjacent teeth

In his study, Rami Ammoun used the Trios 3 and True Definition intra-oral scanners to create four distinct conditions involving partial and complete coverage crowns, both without and with adjacent teeth. The results showed an important difference between the 2 scanning devices under various preparation designs and conditions involving adjacent teeth. Trios 3 demonstrated higher accuracy than True Definition for partial coverage crowns, with $P < 0.001$. Additionally, a statistically important difference was found within the groups regarding the presence or absence of adjacent teeth and preparation design, with $P < 0.001$ [23].

Tooth types

Tooth types are believed to negatively impact the accuracy of intra-oral scanners. In his study, Keunbada Son utilized five intra-oral scanners (Medit i500, CS3500, Trios2, CS3600, and Trios3,) to assess the effect of various tooth types on scanner accuracy. The findings indicated that scanners performed more accurately on anterior teeth and less so on second molars. The reduced accuracy in full arch scans in the posterior region might be attributed to the natural buccal widening of the arches compared to the midline, while the Medit i500 scanner typically narrows toward the lingual side. A statistically important difference in accuracy was found between the groups, with $P < 0.001$. The trend of inaccuracy decreased from the front to the back of the arch [24].

Scanning distance

Kim's study highlighted the significant impact of scanning distance **(Table 5)** on the accuracy of intra-oral scanners. In a comparison of three scanners—Trios, CS3600, and Plan Scan—the results showed that in two-dimensional comparisons, the accuracy was highest at 5 mm and lowest at 0 mm. However, in three-dimensional analysis, there were no notable differences in trueness, though precision varied significantly. The best results for precision were observed at 5 mm for Trios, 3 mm for CS3600, and 2.5 mm for Plan Scan [25].

Table 5. Overview of studies on how scanning distance and scanning strategies influence the accuracy of intra-oral scanners

Journal name/ Year	**Type of study**	**Comparison group**	**Control group**	**Parameters assessed**	**Intraoral scanners used**	**Inference/ Clinical implication**	**Draw Backs**
Wiley Periodicals, 2019	In vitro	Four different scanning distances 0, 2.5, 5.0, and 7.5 mm in	model scanned with laboratory scanner Identica Hybrid; Medit	Accuracy	TRIOS; CS 3500; and PlanScan	In three-dimensional comparisons of trueness, there were no statistically significant results observed but the most accurate values were observed at 5 mm in Trios 3mm in CS 3600, and 2.5 mm for plans can and the lowest values of trueness observed with 0mm distance; When 2D comparison showed the effective difference. In a 3-dimensional comparison of precision there was a significant difference with the most accurate results observed that 7.5mm with trios at 5 mm in cs 3600 and 2.5mm in plans can with lowest values observed in 0mm.	In vitro studies suggest that real-life oral conditions may influence accuracy. Scanning all teeth at a consistent distance is challenging, and reproducing this intra-orally, particularly for full arch scans, can be difficult.

International Journal of Computerized Dentistry, 2013	In vitro	Four scanning strategies were used: COS Straight: A straight movement across the occlusal, lingual, and buccal surfaces. Coc Cross: A zigzag motion covering the entire arch. Bc Top: The impression focused solely on the occlusal surface. Bc Diag: The scanner was tilted at 30 degrees, covering only the buccal and lingual areas. Bc Rot: The impression was captured from all angles. CiT: As per the manufacturer's recommendations.	A maxillary steel model was scanned using the Alicona Infinite Focus imaging system, based in Graz.	Precision and trueness	Lava cos, CEREC Bluecam, Cadent itero	A notable difference in trueness was observed across the groups, with BC rot exhibiting the highest trueness and coc cross-presenting the lowest. However, no statistically significant variation was found in precision.	The in vitro study did not account for factors such as patient movements, saliva, and space constraints. Additionally, the potential impact of scanning technology and substrates on accuracy was not addressed in the study.
Int. J. Environ. Res. Public Health, 2021	In vitro	Three groups were formed, each with two types of tips and two scanning strategies. Group 1 used a new tip, Group 2 used an old tip, and Group 3 applied the second strategy. Strategy 1 involved scanning starting from the left posterior side on the occlusal surface, moving in a zigzag pattern toward the anterior, and then proceeding from the right posterior to the left posterior on the lingual side. Strategy 2 began at the left canine, progressing to the right canine on the occlusal surface, then covering the lingual surface from right posterior to left canine and the buccal surface from left canine to right posterior. The same procedure was repeated starting from the right canine to the left posterior.	Models scanned with lab scans Medit T 710	Trueness and precision	Medit i 500	No significant differences were observed in trueness and precision; however, the use of new tips in the first strategy resulted in better accuracy values compared to the other two groups.	In the in vitro study, the intra-oral scan was performed by a single operator. Future research should focus on comparing results from two different inspection software programs.

The Korean Association of Orthodontists, 2016	In vitro	Model C1 represents an ideal dental arch (ALD, 0 mm). Model C2 exhibits mild crowding (ALD, 3 mm). Model C3 illustrates moderate crowding (ALD, 7 mm), while Model C4 shows severe crowding (ALD, 10 mm). The scanning protocol suggested by the manufacturer for the Itero system involves two subgroups: in the first subgroup, the right molar is scanned before the left molar, while in the second subgroup, the left molar is scanned first. For the Trios group, scanning begins at the right molar, progresses to the left occlusal surface, and ends on the left lingual surface. In the reverse subgroup, the scanning starts from the left side.	-	Precision	iTero, Trios	No statistically significant differences were found between the scanners for varying tooth irregularities. However, a significant difference was observed in the accuracy of the scanners depending on the scanning strategies used, with the Itero scanner showing lower accuracy compared to the Trios.	Scanning posed challenges on the incisal surfaces of the anterior teeth and the distal surfaces of the last molars due to limited light reflection and light scattering. These areas were difficult to capture, resulting in errors during the scanning process. Consequently, when performing intraoral scans, careful consideration should be given to the tooth geometry and the materials used in the prosthetics.
Quintessence International, 2016	In vitro	Three scanning strategies were employed: A - Starting from the distobuccal area of the maxillary second right molar, moving to the occlusal-palatal side and returning. B - Scanning the occlusal-palatal surface of the maxillary right second molar and returning from the buccal side of the arch. C - An S-shaped motion covering all surfaces of the tooth at once.	Maxillary model industrial scanner infinite focus standard Alicona imaging	Accuracy in terms of trueness and precision.	Trios pod scanner	No statistically significant differences were observed in terms of trueness. However, a significant difference in precision was noted, with strategy A demonstrating the lowest precision values when compared to strategies B and C.	In vitro study, the feasibility of applying these strategies intraorally in a patient's mouth needs to be evaluated.

J Adv Prosthodont, 2020	In vitro	The Scan R strategy began at the occlusal surface of the right molar, moving across to the left occlusal side, then proceeded along the buccal side toward the palatal side, finishing with the soft tissue. The Scan L strategy started from the left side and followed the reverse direction.	Typodont model with canine preparation scanned using an industrial scanner (ATOS Core 80, GOM GmbH)	Accuracy	Trios, iTero, Planmeca Emerald, Cerec Omnicam, Primescan Virtuo Vivo	The Prime scan exhibited the lowest values for both trueness and precision, with Trios, Omnicam, Virtuo Vivo, iTero, and Emerald following in that order. When scanning from the right, iTero showed a greater deviation in trueness (P = .009).	Factors such as saliva, limited mouth opening, patient movement, and differing refractive indices of teeth and gingiva were not considered in the study.
Int J Prosthodont, 2021	In vitro	The Scan R method commenced at the occlusal surface of the right molar, progressing to the left molar's occlusal side, and then moved along the buccal surface in reverse, transitioning towards the palatal side, ultimately ending at the soft tissue. On the other hand, the Scan L method started from the left side and followed a reverse scanning path.	Class I and class IV Kennedy's classification models were scanned using ATOS Core 80, GOM.	Accuracy	Trios 3 iTero Element 2 CEREC Omnicam Emerald PlanmecaCEREC Prime Scan Virtuo Vivo	A substantial disparity in accuracy and precision was observed among the intraoral scanners, with Trio and Trio Prime Scan Itero demonstrating notably higher accuracy. Emerald exhibited the lowest accuracy values.	The study did not account for intra-oral variables such as saliva, patient movements, the varying reflective properties of the teeth and gingiva, or the movement of soft tissues. Additionally, the study focused solely on two types of partial edentulism.

Scanning strategies

One study involving implant components was excluded from the review based on the study's criteria. Andreas Ender's research highlighted the significant impact of scanning strategies on the accuracy of intra-oral scanners. He compared the Lava COS, CEREC Bluecam, and Cadent iTero scanners using six different strategies. The results showed a notable difference in trueness, with the BC rot impression, which covered all aspects, achieving the highest trueness, while the COC cross impression, made using a zig-zag motion, displayed the lowest trueness. However, no significant difference in precision was found [26]. In Luigi Vito Stefanelli's study using the Medit i500, two scanning strategies and 2 types of tips were tested across three groups. The study found no statistically significant differences in accuracy, although the new tip with the first strategy yielded better accuracy results. Stefanelli also suggested comparing Medit iOS software with 3D comparison software for accuracy evaluations [27]. Philipp Muller's research with the Medit i500, using three scanning strategies, found no important difference in trueness, but there was an important difference in precision [28]. Burcu Diker's study, involving six intra-oral scanners—iTero, Prime Scan, Emerald, Omnicam, and Virtuo Vivo—used two strategies to improve the accuracy of partially edentulous anterior and posterior models. The findings showed that precision varied between scanners, with Trios achieving the highest precision and Emerald the lowest, exhibiting significantly higher variance. The scan sequence impacted the accuracy of the partially edentulous model, with certain scanners such as Virtuo Vivo, Emerald, Prime Scan, and iTero being affected by this. Diker emphasized the need for manufacturers to develop improved scanning strategies to minimize the impact of scan sequences on accuracy [29]. In another study, using the same scanner and strategy with dogs, Prime Scan was found to have the lowest precision and accuracy.

Additionally, iTero exhibited a significant deviation in accuracy when scanning began from the right (P = 0.009) [30].

Conclusion

A comprehensive review of the studies investigating factors influencing the accuracy of intraoral scanners highlights that a variety of factors contribute to determining their accuracy. Both intraoral factors, such as saliva or oral fluids, the angle, position, and geometry of healthy teeth, the preparation geometry, the positioning of tooth preparation margins, and interproximal spacing, as well as extra-oral factors like lighting conditions, significantly impact the accuracy of these scanners. It is crucial to consider all these factors when purchasing and utilizing intraoral scanners. Based on the limitations observed in the studies, it is clear that in vivo research should be conducted to validate the findings from in vitro studies, as clinical conditions can influence the outcomes observed in controlled environments. Furthermore, standardizing software and methodologies to assess deviations is essential, as variations in these factors could affect study results.

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