

FACTORS AFFECTING THE ACCURACY OF INTRAORAL SCANNERS-A SYSTEMATIC REVIEW

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ABSTRACT

The technological advances in the field of dentistry by virtue has made dentists take a great shift from manual methods of diagnosis and treatment to digitally aided diagnosis, treatment planning, and prosthesis fabrication, therefore, increasing the need to assess the efficiency and efficacy of the digital equipment and software to obtain higher accurate results. Intraoral scanners (IOS) or laboratory model scanners form the basis of a CAD CAM fabrication because intra-oral / model scanning is the only way to digitize the oral environment. Identify the accuracy of IOS under the influence of various intra-oral and extra-oral factors. Advanced tools in the Cochrane and PUBMED database were used for the systematic search for a structured search and a hand search was done in the Google scholar database. 37 articles were included in the systematic review based on selected criteria. There were more in vitro studies on the evaluation of the accuracy of intra-oral scanners under influence of clinical and extraoral variables than in vivo studies. The studies reviewed showed a variety of variables and outcomes related to the accuracy of the IOS. Several extra-oral and intra-oral factors had a significant difference in terms of trueness and precision when compared between different intra-oral systems. The factors also had an impact on the efficiency of the intra-oral scanners. Though intraoral scanners are said to have comparable results to conventional techniques it is still vulnerable to inaccuracies due to several intraoral and extra-oral variables.

Key words: Intraoral scanners, Digital impressions, Optical impressions, Accuracy, Precision, Trueness.

Introduction

Three-dimensional imaging as a part of digital dentistry has gained popularity in the dental market due to its nature of minimum invasiveness as a procedure to create a positive replica of the patient's oral cavity [1-4]. The two methods of digital acquisition that are currently employed to generate digital images are intraoral scanning of patient's tissue which is done on the chair side and model scanning done by the model scanners in dental laboratories. One additional benefit of digital impressions is the ease of storage and retrieval of the data even after years, unlike the stone models that can chip, break or consume clinical/laboratory working space [5]. Accuracy of the dental impressions plays a major role in producing an accurate prosthesis which will lead to the success of the treatment with a better prognosis. Just like conventional impressions, digital impressions should also record the finish lines, the surroundings, and the occlusal surface of the adjacent teeth with high precision to eliminate errors in the final prosthesis. Several in vitro and in vivo studies have been carried out to test the performance of the intra-oral scanners and have concluded that clinically acceptable and relatively precise impressions can be made with intra-oral scanners when compared to manual impressions [6]. Many factors are said to affect intra-oral scanners which include both intra-oral and extra-oral factors (environmental conditions/ scanner software and hardware). The studies carried out to

assess the accuracy are mostly in vitro, which is observed under controlled laboratory conditions which leave behind very less literature on in vivo results. However better understanding of the in vitro studies will pave a way for better study design for invivo studies because the results will have a great impact in terms of standardization of ideal conditions to carry out a close-to-perfect in vivo study. Multiple clinical conditions can cause inaccuracies in the intra-oral scanner. This review aims to assess the factors affecting the accuracy of intra-oral scanners.

Materials and Methods

The search for articles was initiated with the keywords chosen based on the MeSH (Medical Subject Headings) terms. The search terms were used in an electronic search of clinical trials published in English literature and carried in 3 databases: Cochrane, PubMed, and Google Scholar. The articles obtained from the search were subjected to screening based on the inclusion and exclusion criteria sequentially with the analyses of the Title followed by the abstract and full article text. Literature from all times was considered but the search was restricted to only studies that measured the reliability of the IOS under the influence of a minimum of one variable.

Structured question

What are the factors affecting the accuracy of intra-oral scanners?

PICO (Population, Intervention, Comparison, Outcome)

P-Dentulous model

I-Intraoral scanners

O-Accuracy (Trueness/ Precision)

Outcome variables

Accuracy

Closeness of a measured value to a standard or a known (true) value and to each other. (Measured by the difference in distance deviation in µm)

Precision

Proximity of measurements between independent results of measurements obtained under specified conditions.

Measure the reproducibility and reproducibility of the results.

Trueness

The degree of agreement between the mean value obtained from repeated measurements and the true value. It depends on the reproducibility of the results.

Results and Discussion

The search in the databases yielded (3100 articles in google scholar, 28 articles in Cochrane library, and 73 articles in PubMed database). Screening based on title, and abstract yielded a total of 37 articles that were included in the systematic review (**Table 1**). All the collected articles were analyzed using a customized data extraction design (**Figure 1**).

Table 1. Inclusion and Exclusion criteria of the study

Inclusion Criteria	Exclusion Criteria
Invitro Studies and Invivo Studies	Review studies
Studies On factors affecting the Accuracy Of Ios Devices	Studies on factors affecting the mesh quality of intra-oral scanners
Studies On factors affecting the efficacy Of Ios Devices	Studies On Factors Affecting only The Efficiency Of Ios
Studies with models produced manually or digitally	Studies with models having orthodontic brackets/ appliances
Studies that also had lab scanners in the experimental group	Studies only on extraoral/ laboratory scanners
Availability of Full-text articles	Studies involving models related to implant abutments/scan bodies
Literature Available In the English Language	Literature Available In Other Languages

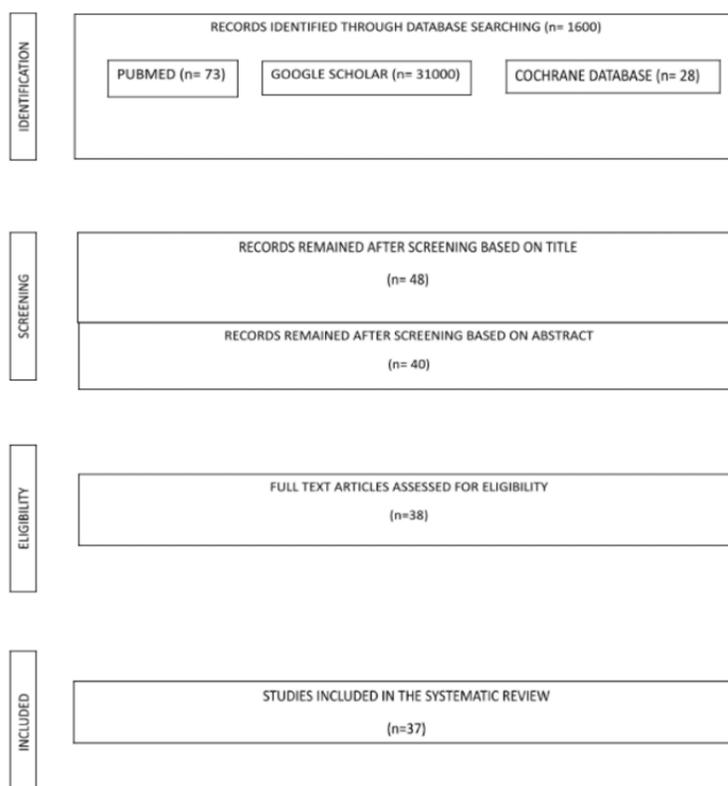


Figure 1. Illustration depicting the number of articles searched, analyzed, and included in the study

The use of CAD CAM technology as a tool in prosthesis fabrication might have been like scientific fiction decades ago but today the use of intra-oral scanners, designing softwares, and computer-aided manufacturing units like 3d printers and milling units are becoming the standards for fabrication of dental prosthesis [5]. In order to ensure that the prosthesis that is manufactured does not have many clinical inaccuracies, it is crucial to assess the reliability of the intra-oral scanners. The reliability of IOS is said to be impacted by several factors.

Light conditions

A total of 10 studies have discussed the effect of light conditions on intra-oral scanners (**Table 2**). In 3 studies which discussed more than one factor among which one study was in vivo. According to Marta Revilla-León [7], there was a prominent difference in accuracy considering the mean values observed when the scans are recorded under four different lighting conditions which are chair light (15000 lux,4100k), room light (1003 lux), zero light, and natural light (500 lux). The comparisons were made between the light conditions and within the light conditions using three intra-oral scanners Trios 3, iTero element, and CEREC Omnicam [8]. She also found in her research on the Trios 3 intraoral scanner that lighting conditions of 1000 lux are recommended for maximum scan accuracy of the Trios 3 intraoral scanner and concludes that chairside lighting should be avoided when using the Trios 3 digital impression [9]. In a study using Trios 3 as an intraoral scanner and comparing the effect of light on right quadrant scans and complete arch scans Marta Revilla-León has found that there is a significant difference in the trueness and precision in complete arch scans and the room light condition 1003 lux showing the minimum deviations whereas the right quadrant scans did not have any statistically significant differences yet the chair light

condition 10000 lux showed minimum discrepancies [10]. Christian Wesemann in his study using six intraoral scanners has concluded that Ambient light has been found to affect the accuracy and scan time of Intraoral scanners and the influence of the lighting conditions varies depending on the intraoral scanning system used. However, for 4-unit scans, the effect of lighting conditions was not clinically significant, but for full-arc scans, scanning accuracy and scan time can be improved with proper illumination [11]. Toshio Arakida has found that 500 lux, 3900 K conditions is the most appropriate lighting condition for taking a digital impression using a True definition intra-oral scanner and high illuminance ambient light conditions increased the scanning time of true definition intra-oral scanner that was used in the study [12]. Anca Jivanescu in his article using planmeca plans can as the experimental intra-oral scanner it was found that there was the minimum difference in trueness values of the IOS under six different test light conditions yet the best values of trueness were observed at 10000 lux and the least at 400 lux whereas there was a significant difference in the precision with p=0.016 with best values obtained at 3300 lux whereas 1100 lux had the most deficient values [13]. Merve Koseoglu and Hakan Akin in their study have compared the trueness of the Medit I500 intra-oral scanner under the influence of two ambient light conditions and two scanning light modes concluding that there was a significant difference in trueness of the intra-oral scanner Medit i500 with p<0.0001with least deviations being recorded with the room light condition (1003lux, blue light mode) [14]. Marta Revilla-León in her invivo study with trios 3 as an intraoral scanner tested the accuracy under three different light conditions and two arch lengths; The larger the range of the digital scan that is performed, the lower the accuracy value obtained.

Table 2. Description of articles on light conditions affecting the accuracy of intra-oral scanners

Journal Name/ Year	Type of Study	Comparison Group	Model	Parameters Assessed	Intra Oral Scanners Used	Outcome Values	Draw Backs
J Prosthet Dent, 2019	in vitro	chair light, room light, natural light, and no light	Mandibular typodont (NISSIM Type 2; Nissim) scanned with L2 Scanner; Imetric	Accuracy (precision and trueness)	iTero element, CEREC Omnicam, Trios 3	Accuracy was better for itero element in chair light (10000 lux) and room light (1003 lux) conditions, CEREC Omnicam in zero light and TRIOS 3 in room light (1003 lux) condition,	Invitro study, a Study done on dentate models, intra-oral edentulous environments might have higher levels of unattached tissues leading to inaccuracies.

<p>jopr, 2020</p> <p>in vitro</p> <p>Illuminance: chair light(10000 lux), room light (1003 lux) natural light (500 lux), no light (0 lux).</p> <p>Maxillary arch Model scanned using laboratory scanner E4 Dental Scanner; 3Shape</p> <p>Trueness and Precision</p> <p>Trios 3</p>	<p>Hindawi, 2021</p> <p>in vitro</p> <p>400 lux; 1000 lux; 3300 lux; 3800 lux; 10 000 lux; 11 000 lux</p> <p>Using an extraoral scanner, a dental mannequin (Phantom head PK-2 TSE; Frasaco) was scanned. (D700 3D scanner, 3Shape)</p> <p>Accuracy</p> <p>Planmeca PlanScan</p> <p>The value was best for the 10,000lux group and the lowest level of trueness was found in the 400 lux group.</p> <p>There is a statistically significant result between the groups concerning precision and the value was best for the 3300 lux group</p> <p>Being an in vitro study, it disregards additional influencing factors like saliva, blood, or patient movement.</p>	<p>JPD, 2020</p> <p>in vitro</p> <p>100,500, 1000 l 5000 lux</p> <p>maxillary model printed in (Model resin, Form 2 - Formlabs) scanned by an Optical coordinate measuring software (ZEISS)</p> <p>Accuracy scanning time of intra-oral scanners</p> <p>Trios 3, CEREC omnica, iTero element, CS 3600, Planmeca Emerald, GC Aadva.</p> <p>A significant difference in accuracy with all the intra-oral scanners used for 4-unit scans whereas in full arch scans, a significant difference was found in all other IOS systems used except for Trios 3 AND GC Aadva. At all illumination, the fastest scans were obtained with Trios 3 IOS.</p> <p>Clinical conditions and different scanning substrates like the presence of metal, ceramic, or polyether ketone scan bodies intra orally might influence the scanning accuracy.</p>	<p>Jopr, 2021</p> <p>in vitro</p> <p>Ten groups between 1000lux to 10000 lux.</p> <p>Mandibular typodont (Nissin Type 2; Nissin) scanned using a laboratory scanner L2 scanner; Imetric.</p> <p>Trueness and Precision</p> <p>Trios 3</p> <p>For trios 3 ios, the 1000-lux group had the lowest discrepancy values, while the 5000-lux group had the highest discrepancy values.</p> <p>Invitro study, only one ios is used. Clinical environments can cause inaccuracies.</p>	<p>J Prosthodontic Research, 2018</p> <p>in vitro</p> <p>0, 500, 2500 lux color</p> <p>Mandibular dentulous model (500H-1; Nissin Dental Products)</p> <p>precision and true scanning time</p> <p>True Definition</p> <p>Trueness values were better for True Definition: 3M under 500 lux AND 3900K. The time needed for the digital impression was longer at 2500 lux than at 0 lux or 500 lux for true definition IOS.</p> <p>In a clinical setting, the model will be unable to assess the impact of ambient light. In clinical settings, additional elements like saliva and patient movement may have an impact on the precision of the impressions.</p>
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<p>J.Pers.Med, 2020</p> <p>in vitro</p> <p>Lower incisor crowding, lower molar mesial tipping, surface material, ambient light conditions</p> <p>Ideal lower model created using ortho analyzer software (3 Shape)</p> <p>Efficiency and Efficacy</p> <p>Trios 3</p> <p>Digital acquisition is influenced by the degree of crowding and molar inclination ($p < 0.05$)</p> <p>2. Scanning surface material affects efficiency and efficacy and is lower with calcium sulfate hemihydrate a modified compound scanning surface ($p < 0.05$)</p> <p>3. Higher intensities of ambient light in the scanning room was associated with reduced scanning efficacy ($p < 0.05$)</p> <p>4. The scanner showed greater amounts of undetected volume as the degree of crowding and mesial tipping of the lower second molar increased over 25°.</p> <p>In vitro study, intra-oral scanning in patients' mouths could have light and dark zones depending upon the oral conditions that cannot be reproduced in the in vitro conditions and this might represent additional errors and inaccuracies during scanning</p>	<p>ACP Journal of Prosthodontics, 2021</p> <p>in vitro</p> <p>room light, 1003 lux, and zero light, 0 lux, scanning light modes</p> <p>blue [B] and white [W]</p> <p>Maxillary arch model scanned using dental LS (E4 Scanner:3Shape</p> <p>Trueness</p> <p>Medit i500</p> <p>There was a significant difference in the trueness values of the intra-oral scanner.Medit i500 with $p < 0.0001$, room light 1003 lux and blue mode had the lowest deviations</p> <p>Only two light conditions were used leaving behind chair light and no light conditions. The precision of the ios device was not evaluated.</p>
<p>jopr, 2020</p> <p>Invivo study</p> <p>Scanning distance: Complete arch scan, right quadrant</p> <p>Illuminance: chair light(10000 lux), room light (1003 lux) natural light (500 lux), no light (0 lux)</p> <p>Model scanned using laboratory scanner (E4 Dental Scanner; 3Shape)</p> <p>Trueness and precision of complete and partial arch scans</p> <p>Trios 3</p> <p>Significant differences in the trueness and precision values were found across different lighting conditions where room light condition obtained the lowest absolute error compared to other lighting conditions</p> <p>Only one intra-oral scanner was used. Other clinical conditions like the presence of moisture and metallic/ ceramic surfaces were not discussed. Reference scan used as a model scan.</p>	

Saliva/oral liquids

There are a total of 3 studies on saliva/ oral liquids as a factor affecting the accuracy of intra-oral scanners in which one study was invivo (**Table 3**). Yuming Chen, DDS, Ph.D. in his study evaluated the effect of liquids on the tooth surface. He carried out the scanning with Trios 3 and CEREC Prime Scan under three different oral conditions namely wet, dry, and blow dry with two kinds of liquid ultra pure water and artificial saliva. It was found that the wet conditions have mean RMS values significantly higher than the dry and blow dry conditions indicating that the presence of liquids on the tooth surface can cause potential inaccuracies in the digital impression with Trios3 and Prime Scan also blow drying with a three-way syringe can reduce the scanning errors [15]. Biagio Rapone in his study with intra-oral scanners CS 3600, Trios 3 and CEREC

Omnicaam has observed a prominent difference in accuracies between three different scanners in the presence and absence of salivary conditions with the highest accuracy values observed in CS 3600 and Trios 3 and the least accurate values observed in CEREC Omnicam. This study concludes that biological fluids have a significant impact on the accuracy of digital impressions corresponding to the intraoral scanners used, the values of which are clinically unacceptable in wet conditions [16]. Camcı and Salmanpour in their invivo study tested the accuracy of trios 3 under different levels of light and salivary conditions. They observed no significant differences between the test groups, but deviations were higher in the group with saliva and reduced light intensity [17].

Table 3. Description of articles on oral moisture affecting the accuracy of intra-oral scanners

Journal Name/Year	Type of Study	Comparison Group	Model	Parameters Assessed	Intra Oral Scanners Used	Inference/Clinical Implication	Draw Backs
ACP, Journal of Prosthodontics, 2021	in vitro	Ultra-pure water, artificial saliva	Mandibular jaw model (NISSIN) scanned using industrial computed tomography device Zeiss Metrotom 800	Accuracy	Trios 3, Prime scan	The mean RMS values were higher than those of the dry conditions (p=0.001) indicating less accuracy in wet conditions for trios 3 and prime scan	Invitro study. Frame-by-frame analysis was not done during the superimposition.
Appl.Sci, 2020	in vitro	Without saliva, with artificial saliva	two molars and two premolars scanned with an optical scanner S600 ART scanner, Zirkozahn	Accuracy	CS 3600, Trios 3, CEREC	The accuracy between the 3 intraoral scanners was statistically significant with CS 3600 AND Trios 3 having higher accuracy levels when compared to CEREC Omnicam in both presence and absence of salivary conditions	Invitro study Scarcity of samples Absence of biological environment Use of an opaque film that might cause loss of accuracy on the reference scans in both the 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	The presence of saliva alone caused 13 percent of deviations and a decrease in light levels increased the deviations	The study was done only on maxillary arches stating that the movement of the soft tissues in the lower arch might affect the scanning.

Studies that discussed more than one factor

In his study, César Martínez-Rodríguez demonstrated the impact of intraoral clinical variables such as molar tilt, and anterior crowding, and extraoral clinical variables such as surface materials and ambient light conditions on the effectiveness and efficiency of the Trios 3 intraoral scanners. I checked. The results of this study showed that there was a significant difference in intraoral scanner efficiency and effectiveness (scan chair time, scan error, undetected volume) with $p < 0.05$, for a scanning procedure using an intraoral scanner, the digital acquisition is sensitive to clinical factors such as the degree of cambering, the mesial inclination of the mandibular second

molars, and external factors such as the scan surface material and external light source. lead to the conclusion that they are affected [18]. In a study determining the accuracy of intraoral scanners using different crowns and scanning strategies, Ji-won Anha found no statistically significant differences between scanners for varying degrees of tooth irregularity. I found that there was a significant difference between the scanners. A strategy used in terms of accuracy, iTero is less accurate than Trios (Table 4) [19].

Table 4. Description of articles on Tooth preparation/ tooth types/ preparation geometry affecting the accuracy of intra-oral scanners

Journal Name/ Year	Type of Study	Comparison Group	Model	Parameters Assessed	Intra Oral 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 printed with ProJet 3500HD Max; 3D Systems and scanned using a reference scanner Rexcan DS; Solutions	Accuracy (Trueness and precision)	Trios 3	Significant higher accuracy values were observed with the intra-oral scanner TRIO 3 when compared to the manual impression and desktop model scanner impressions when the total occlusal coverage angle was less than 8 degrees with $p < 0.05$	Ideal preparation geometries were used. 3D printing resin models can be different from the actual human tooth with enamel and dentin in terms of hardness, surface roughness, light reflection, and wettability. The absence of oral fluids, movements caused by patients, and distortions that may arise due to temperature conditions are not discussed.
Jopr, 2020	in vitro	PC prep with adjacent teeth, CC prep with adjacent teeth, PC prep without adjacent teeth, CC prep without adjacent teeth	A maxillary typodont (Columbia Dentoform) was scanned using a desktop lab scanner (D900L, 3Shape)	Accuracy	Trios 3, True Definition	Difference was found between the average absolute discrepancy and the maximum absolute discrepancy of trios 3 and true definition intra-oral scanners with ($P < 0.001$)	Study was not performed intraorally. The oral cavity may present challenges that can limit the access for scanning with the intra-oral scanner. Presence of oral fluids can interfere with the accuracy of the ios. The preparation design and adjacent teeth were standardized actual oral conditions might show variations in the position of adjacent teeth and changes in preparation design leading to inaccuracies.
MDPI materials, 2020	in vitro	2 model scanners ad 5 intra-oral scanner groups	scanner use: industrial 3D scanner Solutionix C500, MEDIT. Typodont model (ANKA-4 V CER, Frasco)	Accuracy	CS 3500, CS 3600, Trios 2, Trios 3, Medit i500	The intraoral scanner showed a statistically significant difference in accuracy according to tooth type with $p < 0.001$, and the trend for the intraoral scanner tended to decrease from front to back.	Tooth shapes like steep inclination of cusps, depth of the pits and fissures, and presence of very less occlusal morphologies in the actual intra-oral conditions can have a major impact on the intra-oral scans that were not considered in the study since it was done on a standard model.

IIP, 2020	<p>in vitro</p> <p>FDI 15- full crown with chamfer margin and layer thickness approx 1.5mm</p> <p>FDI 11- veneer with chamfer margin thickness 0.5mm</p> <p>FDI 24- MOD shoulder prep</p> <p>FDI 26- onlay with occlusal chamfer layer thickness 1.5mm</p>	Jopr	<p>in vitro</p> <p>3 is groups</p> <p>2 subgroups with intra-coronal preparation and extra-coronal preparation and 2 subgroup divisions with a total of two divergent and convergent angles of 6 and 12 degrees</p>
<p>Typodont model (ANA-4 Frasco, Tettnang, Germany) and scanned using a laboratory scanner Lava ST, 3M ESPE</p>	<p>Typodont model (Nissin Dental Product, Kyoto, Japan) scanned with extraoral desktop scanner InEos X5 (Dentsply Sirona)</p>	Accuracy	Accuracy
Accuracy (Trueness and Precision)	<p>Trios 2, Omnicam, True definition, PrimaScan</p>	<p>Cerec AC Omnicam Trios Medit i500</p>	<p>1. Intra-coronal preparations showed lesser values of accuracy when compared to the extra-coronal preparations.</p> <p>2. Trios and medit i500 have better accuracy than Omnicam</p> <p>3. The increase in tapering of the axial wall has a direct impact on the trueness of the IOS.</p>
<p>The values of precision and trueness were different in IOS and preparation geometries (p<0.05)</p>	<p>In vitro study clinical variables may have a significant effect on the results.</p>	<p>The results might differ in the intra-oral conditions due to the presence of living tissues such as enamel, dentin, soft tissue movements, etc. Tooth preparation geometries intra-orally under clinical conditions might have higher inaccuracies. Reference scan was made with a dental model scanner better results might have been produced if an industrial scanner was used.</p>	

Tooth preparation geometry

There are 4 articles on the effect of tooth geometry on the accuracy of intra-oral scanners . From the results of the study conducted by Jeison B. Carbajal with a Trios 3 intra-oral scanner under the influence of nine occlusal clearance angles -8, -6, -4, 0, 4, 8, 12, 16, and 22 degrees it was observed that Trios 3 intraoral scanner can record abutment tooth preparations independent of their geometry [20]. The increase in tapering of the axial wall is said to have a direct effect on the trueness of the intra-oral scans and the type of intra-oral scanning system is said to influence the accuracy of the scan even in simple single tooth restorations. Kamal Ebeid in his article has used three intraoral scanners Trios 3, Medit i500, and Omnicam under different conditions with intra-coronal and extra-coronal preparations having two convergent and divergent angles 6 and 12 degrees. The results of the study show that the extra-coronal preparation has higher accuracy values when compared to intra-coronal preparations and Trios 3 and Medit i500 show better accuracy than Omnicam with statistically significant results [21]. Alexander Schmidt in his study with four intra-oral scanners Trios 2, Prime Scan, Omnicam, and True Definition under the influence of four types of preparation

geometries in different teeth observed that Simple geometries achieved much more accurate values than more complicated geometries and a significant difference was observed between the intraoral scanners under different preparation geometry with clinically acceptable positive and negative deviations [22].

Location of gingival margins

The position of the tooth preparation margins can have a negative effect on the accuracy of intra-oral scanners. Keunbada Son in his study using two intraoral scanners Medit i500 and EZIS PO under the influence of three margin placement conditions subgingival, supra, and subgingival margins it was found that there was a significant difference in the accuracy of the intra-oral scanners with p<0.001 with equi gingival and subgingival margins showing lower levels of accuracies. The gingival accuracy improved to p<0.05 with the use of a retraction cord. There was a significant difference between the intra-oral scanners used with Medit i500 having better values than EZIS PO with p<0.00 [23].

Preparation design and scan angulation limitation due to the presence of adjacent teeth

Rami Ammoun in his study with Trios3 and True Definition intra-oral scanners, created 4four different conditions with partial coverage and complete coverage crowns with and without adjacent teeth revealed that there is a significant difference between the two intra-oral scanning devices under different preparation designs and adjacent teeth conditions with Trios 3 showing higher accuracy than True Definition for partial coverage crowns with $p < 0.001$. Also, there was a statistically significant difference within the groups in the presence and absence of adjacent teeth and preparation design with $p < 0.001$ [24].

Tooth types

Tooth types are said to have an adverse effect on the accuracy of intra-oral scanners. Keunbada Son in his article used five IOS (CS3500, CS3600, Trios2, Trios3, and Medit i500) to determine the impact of different tooth types on IOS accuracy. The results of the study showed that intra-oral scanners show better accuracy in the anterior teeth and

worse results in the second molars. The increased inaccuracy of full arch scans in the posterior region may be because arches tend to widen buccally compared to the midline. The Medit i500 intraoral scanner tends to narrow towards the lingual side. There is a statistically significant difference in accuracy when comparing between groups with $p < 0.001$ Inaccuracy trend decreases from front to back [25].

Scanning distance

Scanning distance (**Table 5**) has a significant difference in the accuracy of IOS as stated by Kim in his study with three intra-oral scanners Trios, CS3600, and Plan Scan. The accuracy values were significant in two-dimensional comparisons with 5 mm being the most accurate to 0mm being the least accurate. In three-dimensional analysis there was no significant difference in trueness but there was a significant difference observed in precision with 5mm yielding better results for Trios, 3 mm better for CS3600, and 2.5 mm better for Plan Scan [26].

Table 5. Description of articles on Scanning distance and Scanning strategies affecting the accuracy of intra-oral scanners

Journal Name/ Year	Type of Study	Comparison Group	Control Group	Parameters Assessed	Intra Oral Scanners Used	Inference/ Clinical Implication	Draw Backs
Wiley Periodicals, 2019	in vitro	4 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 at 2.5mm 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	Invitro study, Actual oral factors might affect the accuracy. It is difficult to scan all the teeth at the same distance and it could be challenging to reproduce intra-orally and for full arch scans.

<p>Quintessence international , 2016</p> <p>in vitro</p> <p>3 scan strategies</p> <p>A- distobuccal of max 2nd right molar to returning from occlusal- palatal side</p> <p>B- occlusal palatal surface of max right 2nd molar to returning from buccal side of the arch</p> <p>C- s type movement covering all the surfaces of the tooth simultaneously</p>	<p>Int. J. Environ. Res. Public Health 2021</p> <p>in vitro</p> <p>3 groups with 2 types of tips and two scanning strategies. Group 1 new tip, group 2 old tip, and group 3 second strategy. Strategy 1- the movement of scan starting from left posterior side occlusal moving zigzag in anterior reach right posterior after which right posterior to the left posterior lingual region was covered, Strategy 2- left canine to right canine, occlusal surface till posterior right, the lingual surface of right posterior to left canine and buccal of left canine to right posterior. Repeat the same from the right canine to left posterior.</p>	<p>International journal of computerized dentistry. 2013</p> <p>in vitro</p> <p>4 scanning strategies</p> <p>COS Straight- straight movement occlusal, lingual, buccal</p> <p>Coc cross- move in a zigzag motion for the whole arch</p> <p>Bc top impression was taken only concentrating on the occlusal surface</p> <p>Bc diag 30 degrees tilt of scanner and cover only in a buccal and lingual direction</p> <p>Bc rot- the impression from all aspects</p> <p>CiT- as recommended by the manufacturer</p>
<p>Maxillary model industrial scanner infinite focus standard alicona imaging</p> <p>Accuracy in terms of trueness and precision.</p> <p>Trios pod scanner</p> <p>There were no statistically significant results in terms of trueness.</p> <p>There was a significant difference in precision with strategy a having the lowest precision values compared to b and c respectively.</p>	<p>Models scanned with lab scans Medit T 710</p> <p>Trueness and Precision</p> <p>Medit i 500</p> <p>There is no significant difference in trueness and precision but the use of new tips with the first strategy gives better values in terms of accuracy than the 2 other groups.</p>	<p>Maxillary steel model scanned with Alicona infinite focus Alicona imaging, Graz</p> <p>Trueness and precision</p> <p>Lava cos, CEREC Bluecam, Cadent itero</p> <p>There is a significant difference in the trueness of the groups with BC rot showing the highest trueness and coc cross showing the lowest trueness values</p> <p>No statistically significant difference is present in precision.</p>
<p>Invitro study the practicality of using the strategies intraorally in a patient's mouth have to be checked</p>	<p>Invitro study, the ios scan was only done by one operator, there should be studies comparing the results between two different inspection software.</p>	<p>In the Vitro study, factors like patient movements, saliva, and space limitation were not considered. The scanning technology and scanning substrates might have a negative impact on the accuracy which is not considered in the study.</p>

<p>J Adv Prosthodont, 2020</p> <p>in vitro</p> <p>Scan R strategy scanning was started from the occlusal side of the right molar to the left occlusal side, continued on the buccal side to the palatal side in the opposite direction, ending with the soft tissue.</p> <p>Scan L strategy scan started from the left side and opposite direction</p>	<p>Int J Prosthodont, 2021</p> <p>in vitro</p> <p>Scan R strategy scan started from the occlusal side of the right molar to the left occlusal side continued on the buccal side in the reverse direction, towards the palatal side, finishing with soft tissue.</p> <p>Scan L strategy scan started from the left side and in the reverse direction</p>	<p>The Korean Association of Orthodontists, 2016</p> <p>in vitro</p> <p>Model C1 represents an ideal arched dentition (ALD, 0 mm). Model C2 showed mild crowding (ALD, 3mm). model C3</p> <p>Represents moderate congestion (ALD, 7 mm). Model C4 represents severe congestion (ALD, 10mm), and the scanning sequence proposed by the manufacturer itero</p> <p>Two subgroups with right and left groups, first, the right molar is scanned, then the left molar is scanned, and the same for the left group, but the left molars are scanned first. For the trio's group right started from the right molars to left occlusal completed in the left lingual surface. And the reverse for the group left.</p>
<p>Typodont model with canine preparation scanned using an industrial scanner (ATOS Core 80, GOM GmbH).</p> <p>Accuracy</p> <p>Trios, iTero, Planmeca Emerald, Cerec Omnicam, Primescan Virtuo Vivo</p> <p>The Prime scan had the lowest trueness and precision values, followed by Trios, Omnicam, Virtuo Vivo, iTero, and Emerald. When scanning from the right, iTero displayed more deviation in terms of trueness (P=0.009).</p> <p>Saliva, a small mouth opening, patient movement, and various tooth and gingival refractive indices were not taken into account.</p>	<p>Class I and class IV Kennedy's classification models were scanned using ATOS Core 80, GOM</p> <p>Accuracy</p> <p>Trios 3 iTero Element 2 CEREC Omnicam Emerald PlanmecaCEREC Prime Scan Virtuo Vivo</p> <p>There was a large difference in accuracy and precision between the intraoral scanners, with significantly higher accuracy for Trio and Trio prime scan itero. Emerald showed the lowest accuracy.</p> <p>Intra-oral factors like the saliva movement of patients, different reflective properties of the teeth gingiva, and movement of soft tissues are not considered in the study. Only 2 types of partial edentulousness were considered for the study.</p>	<p>precision</p> <p>iTero, Trios</p> <p>There were no statistically significant differences between the scanners for different tooth irregularities, but there was a significant difference between the scanners in the strategies used in terms of accuracy, with itero being less accurate than trios.</p> <p>Scanning was more difficult at the incisal surfaces of the anterior and distal surfaces of the last molars, which had limited reflected light and light scattering occurred. Recording these areas was difficult and errors occurred during recording. Therefore, when scanning intraoral structures, attention should be paid to tooth geometry and prosthetic materials.</p>

Scanning strategies

There was one study with implant components that was excluded from the review according to the study criteria. Scanning strategies can have a major impact on the accuracy of intra-oral scanners, stated Andreas Ender in his study with Lava cos, CEREC Bluecam, and Cadent iTero

intraoral scanners with six different scanning strategies. A significant difference in the trueness of the groups with BC rot impression taken from all aspects showing the highest trueness and COC cross impression made with a zig-zag motion across the dental arch showed the lowest trueness values. No statistically significant difference was present in

precision [27]. Luigi Vito Stefanelli in his study with Medit i500 has adopted two scanning strategies in three groups with two types of tips and two scanning strategies observed no statically significant results in accuracy yet the new tip with the first strategy produced better accuracy values and also suggests Medit compare a Medit ios software as a 3d comparison software to be used for accuracy studies [28]. Philipp Muller in his study with Medit i500 adopting three scan strategies had observed no statistically significant difference in trueness whereas there is a statistically significant difference in precision [29]. In his study, Burcu Diker used a trio of six intraoral scanners, iTero, Prime Scan Emerald, Omnicam, andVirtuo vivo, in two different strategies, to improve the accuracy of partially edentulous anterior and posterior models in the oral cavity. We have observed that it varies between scanners and consequences. Trios had the highest precision across all test groups, while Emerald had the lowest precision with significantly higher variance. Using virtual vivo, Emerald, Prime Scan, and iTero, the accuracy of the partially edentulous model was affected by the scan sequence. Manufacturers are expected to develop new Sakan strategies for partially edentulous cases to prevent scan sequences from affecting accuracy [30]. In another study, where he groomed dogs and used the same scanner and strategy, Primescan was observed to have the lowest accuracy and precision values. Regarding accuracy, iTero showed a large deviation when scanning started from the right (P=0.009) [31].

Conclusion

A review of the studies on factors affecting intraoral scanner accuracy reveals that a great many factors play a role in determining intraoral scanner accuracy. Intraoral factors like saliva/ oral fluids, inclination, position and geometry of the sound teeth, preparation geometry, the position of the tooth preparation margins, interproximal distance, and extra-oral factors like light conditions, have had a significant effect on the accuracy of the intraoral scanners. It is necessary that all the factors have to be considered during the purchase and use of the intra-oral scanners. From the limitations of the studies, it is evident that there should be in vivo studies carried out to confirm the results of the in vitro studies as multiple clinical conditions can affect the results observed in vitro. Also, it is understood that more standard softwares and methods should be used to derive the results of deviations because that might also be a variable affecting the results of the studies.

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