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Review

Factors Affecting Trueness of Intraoral Scans: An Update

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Abstract: Background: Intraoral scanning (IOS) technologies have been constantly developed and improved. This systematic review aimed at assessing studies in the recent literature describing factors that influence the trueness of intraoral scans. Methods: Comparative in vitro and in vivo (i.e., interventional and observational) studies that quantitatively assessed the trueness of intraoral scans and that identified factors significantly affecting IOS trueness values were considered eligible for inclusion. The PUBMED and EMBASE databases were searched for articles published in the last two years (from February 2020 to February 2022). Data assessment and extraction were performed according to the guidelines of the PRISMA statement. Results: The present search strategy yielded 13 publications. An initial screening of the publications was performed using abstracts and key words, and after application of exclusion criteria, a total of nine studies were finally identified as eligible to be discussed. Several factors significantly affecting IOS were identified. Conclusions: Studies using current IOS technologies revealed that the device, scanning distance, operator experience, rescanning and post-processing scans, conditions of the preparations and presence of adjacent teeth are factors significantly affecting IOS trueness.

Keywords: intraoral scanning; computer-aided design; software

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1. Introduction

The continuous development of computer-aided design and computer-aided manufacturing (CAD-CAM) has led to the creation of several new techniques and methodologies in oral rehabilitation [1–8]. In consequence, recent studies have aimed at addressing the accuracy of CAD-CAM methods [9,10] and its impact on the quality of the resulting CAD-CAM prostheses [11,12]. CAD-CAM accuracy, however, can also be affected by factors associated with the image acquisition procedures [13].

In comparison to conventional impressions, intraoral scanning (IOS) has been considered more accurate in regard to outcomes of resulting CAD-CAM crowns and short-span fixed partial dentures [13–15]. A previous systematic review reported mean internal gap values varying between 30 and 154 µm for IOS and between 42 and 183 µm for conventional impressions [13]. However, most of the aforementioned studies used different CAM materials and methods. The actual IOS accuracy (i.e., trueness and precision) can also be calculated for IOS devices in comparison to reference industrialized or desktop scanners. A previous study found mean IOS trueness (distance from the reference scan) values ranging between 19 and 26 µm, while mean IOS precision (distance between two consecutive scans performed with the same device) values ranged between 12 and 21 µm, approximately [15].

Despite the fact that IOS accuracy has been developing along with the technology, it is still considered challenging to obtain accurate intraoral scans of long-span and completely edentulous arches [16]. Furthermore, updated information on the influence of the different factors affecting IOS accuracy is lacking for the most recent IOS technologies described in the literature.

Thus, the aim of this systematic review was to identify factors that influence the trueness of intraoral scans from studies in the literature published in the last two years.

2. Materials and Methods

This literature review adopted a systematic design to identify factors affecting IOS trueness. The PUBMED and EMBASE databases were searched for articles published in the last two years (from February 2020 to February 2022), restricted to the English language, based on the following search strategy using keywords developed for PUBMED and used in both databases: "(IOS OR intraoral scanning) AND (trueness OR accuracy)". Reference lists of all potential articles were also screened. In addition, the OpenGrey database was screened for relevant unpublished studies or papers not identified by electronic searching [17].

The present inclusion criteria considered original articles but not systematic reviews or case reports for the analysis. To be considered eligible for inclusion, studies should have performed statistical comparisons addressing the impact of variables affecting IOS trueness. Studies on implant digital impressions using scan bodies and studies that did not assess 3D mesh trueness in relation to a reference scan/measure or that solely performed 2D linear measurements were excluded from the analysis. The review text structure followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [18].

Two reviewers with expertise in digital dentistry screened the titles and abstracts as well as the full texts of the studies identified. The following data were extracted and recorded: year of publication, type of study, comparisons performed, statistical findings and identified factors that were affecting IOS trueness. A quality assessment protocol was developed and conducted exclusively by the authors who are experts in research about intraoral scanning. Following this protocol, articles had to clearly explain the method of 3D mesh superimposition, describe the type of reference scanner used for control values and provide statistical data on 3D discrepancy measurements (i.e., trueness volumetric assessment) following best fit algorithm analyses. In addition, quantitative data of IOS trueness and precision (reproducibility) were also collected and compared among the studies. Risk of bias of individual studies was assessed by the same reviewers using an adapted scale for in vitro and in vivo studies described by a previous study [13]. Briefly, this adapted scale consisted of 12 items that should be adequately reported in non-randomized studies. Each item receives a score varying from 0 to 2, with 0 indicating that the item was not reported, 1 indicating that the content of the item was reported but inadequately and 2 indicating that it was adequately and sufficiently reported. Scores higher than 20 for in vitro studies and 24 for in vivo studies were considered high risk. Detection of high risk of bias was considered an exclusion criterion. Discrepancies between the two reviewers were resolved by means of discussion and consensus.

3. Results

The present search strategy yielded 34 publications. After initial screening of the publications using titles, abstracts and keywords, 13 articles were considered within the inclusion criteria. After the application of exclusion criteria, a total of nine studies (6 in vitro and 3 in vivo) were finally identified (Figure 1) as eligible to be discussed [19–27]. All papers assessed were available on both databases used in this study. No unpublished studies were included in the analyses. In addition, none of the nine eligible studies presented any relevant selection, observational or confounding bias in relation to the analyses proposed by the present study. All studies included assessed IOS trueness by comparing 3D data from IOS meshes to reference scans taken with desktop or industrialized optical scanners. The characteristics of the studies included are summarized in Table 1. Studies on IOS of dental implants did not meet the inclusion criteria since the outcomes compared were not deviations or trueness of the actual 3D mesh acquired by the IOS, but of the final result on the linear and angular accuracy of the implants placed in the alveolar bone. The reason for this difference is that the purpose of performing IOS of scan bodies is to have not only its location in the dental arch but also its shape recognized by the software library of the same implant system. This has been considered predictable and differs from the outcomes related to the purpose of the present study.

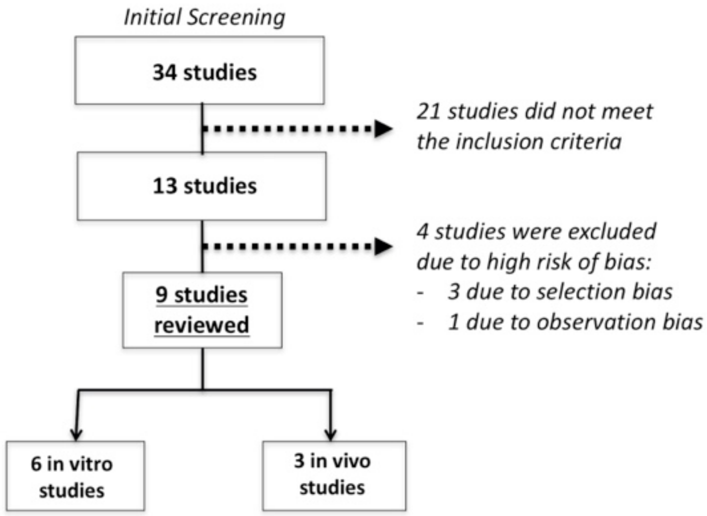

Figure 1. Flowchart of the systematic review.

Table 1. Characteristics of the studies assessed.

Study	Study/Scan Type	Main Comparisons	Variables Compared	Best Trueness	Reference Scan	Significant Factors *
Ashraf et al. (2020) [19]	In vitro/ crown and inlay preparations	IOS devices	Trios (3Shape A/S) vs. Omnicam (Dentsply-Sirona) vs. i500 (Medit)	Trios	Ineos X5	IOS device, preparation type and preparation angles
		Preparation types	Intra-coronal vs. Extra-coronal	Extra-coronal		
Kim et al. (2021) [20]	In vitro/inlay preparations	IOS devices	Trios 3 (3Shape A/S) vs. Primescan (Dentsply-Sirona) vs. i500 (Medit)	Primescan	3Shape E3	IOS device, presence of adjacent teeth
		Adjacent teeth	Present vs. Absent	Absent		
Radeke et al. (2021) [21]	In vitro/ dental arches	Types of tooth position	Normal dental arch vs. Anterior crowding vs. Flared incisors	None	Breuckmann dStation3D	None
		Operators	Dentists vs. Non-graduate	None		
Resende et al. (2021) [22]	In vitro/ crown preparations and dental arches	IOS devices	Trios 3 (3Shape A/S) vs. Omnicam (Dentsply-Sirona)	Trios 3 for preparations	3Shape D2000	IOS device, scan size, operator's experience
		Operators' experience	High vs. Medium vs. Low	High		
Kontis et al. (2021) [23]	In vitro/ edentulous arch	IOS devices	Primescan vs. Omnicam (Dentsply-Sirona)	Primescan	InfiniteFocusG5 Alicona Imaging GmbH	IOS device
Kernen et al. (2021) [24]	In vivo/ dental arches	IOS devices	Trios 3 (3Shape) vs. Omnicam (Dentsply-Sirona) vs. True Definition (3 M)	Trios 3	Zirkonzahn S600 Arti	IOS device, span length
		Span	Short vs. Long	Short		
Revilla-León et al. (2021) [25]	In vivo/ partial dental arch	Number of mesh holes	1 vs. 2 vs. 3 holes	1 hole	3Shape, Trios 4	Mesh holes Rescanning
		Mesh hole diameter	2 vs. 4 vs. 6 mm	2 mm		
Kontis et al. (2022) [26]	In vitro/ dental arches	IOS devices	Primescan vs. Omnicam (Dentsply-Sirona)	Primescan (x- and z-axes); Omnicam (y-axis)	Mitutoyo Crysta Apex C754 (measurements)	IOS device, span disposition
		Span disposition	Different span locations	Anterior or no span		
Revilla-León et al. (2022) [27]	In vivo/partial dental arch	Strategy for rescanning mesh holes	With vs. Without overlapping	Without overlapping	3Shape, Trios 4	Overlapping scans

* Significance level was always set at 5% ($p < 0.05$).

In response to the constant technological development of IOS devices, this systematic review aimed at updating the knowledge on factors that still affect the trueness of current IOS technologies, as published in the last two years. Among the factors significantly affecting the IOS trueness of dental arches were the device, scan size, span length and disposition, operator's experience and rescans. In addition to these, preparation type and angles as well as presence of adjacent teeth were also found to significantly affect the IOS trueness of tooth preparations.

This systematic review only analyzed articles assessing actual IOS trueness values of IOS systems. However, precision (reproducibility) values were also recorded since it shows how liable different scans of the same object performed by same operators could be. It was noted that trueness and precision values varied considerably among the included studies (Table 2).

Table 2. Table of articles showing general trueness in relation to desktop/industrial scanners.

Study	IOS	Categories	Mean ± SD Trueness (μm)	Mean ± SD Precision (μm)
Ashraf et al. (2020) [19]	Trios (3Shape A/S)	Preparations	37.70 ± 14.12	44.7 ± 32
	Omnicam (Dentsply-Sirona)		57.83 ± 22.14	72.0 ± 521
	i500 (Medit)		44.31 ± 11.41	45.3 ± 32
Kim et al. (2021) [20]	Trios 3 (3Shape A/S)	Without adjacent tooth With adjacent tooth	10.35 ± 0.22 11.61 ± 0.91	4.95 ± 0.30 6.20 ± 0.86
	Primescan (Dentsply-Sirona)	Without adjacent tooth With adjacent tooth	7.44 ± 0.17 10.67 ± 0.96	3.74 ± 0.60 4.21 ± 1.07
	i500 (Medit)	Without adjacent tooth With adjacent tooth	10.48 ± 0.34 11.69 ± 0.27	3.98 ± 0.58 3.89 ± 0.49
Radeke et al. (2021) [21]	Trios 3 (3Shape A/S)	Dental arches	114	n/a
Resende et al. (2020) [22]	Trios 3 (3Shape A/S) Complete Arch	High operator experience Medium operator experience Low operator experience	61 ± 17 58 ± 6 74 ± 24	73 ± 0.039 52 ± 37 113 ± 57
	Trios 3 (3Shape A/S) Prepared Arch	High operator experience Medium operator experience Low operator experience	31 ± 3 33 ± 6 34 ± 5	26 ± 0.43 25 ± 17 25 ± 15
	Omnicam (Dentsply-Sirona) Complete Arch	High operator experience Medium operator experience Low operator experience	120 ±10 135 ± 19 121 ± 28	97 ± 19 120 ± 61 161 ± 121
	Omnicam (Dentsply-Sirona) Prepared Arch	High operator experience Medium operator experience Low operator experience	71 ± 35 58 ± 9 82 ± 43	42 ± 19 38 ± 47 39 ± 18
Kernen et al. (2021) [24]	Trios 3 (3Shape)	Short span extraoral Short span intraoral	28 ± 120 38 ± 214	22 ± 123 23 ± 125
	Trios 3 (3Shape)	Long span extraoral Long span intraoral	132 ± 413 147 ± 461	81 ± 421 80 ± 281
	Omnicam (Dentsply-Sirona)	Short span extraoral Short span intraoral	36 ± 146 45 ± 190	23 ± 231 43 ± 244
	Omnicam (Dentsply-Sirona)	Long span extraoral Long span intraoral	118 ± 496 198 ± 499	103 ± 626 198 ± 538
	True Definition (3M)	Short span extraoral Short span intraoral	40 ± 174 47 ± 195	29 ± 129 31 ± 179
	True Definition (3M)	Long span extraoral Long span intraoral	581 ± 1387 433 ± 1029	165 ± 392 153 ± 448

4. Discussion

There is controversy among the studies analyzed regarding trueness comparison among IOS devices. Both studies that assessed crown preparations described that TRIOS scanners (3Shape A/S) presented the best trueness (lowest difference values) [19,22]. This finding is in accordance with a previous study comparing IOS devices for preparations [14]. On the other hand, another study on inlay preparations described that Primescan (Dentsply-Sirona) had the best trueness [20]. Regarding IOS of dental arches, it was found that the IOS devices included by the studies varied considerably, which prevented this review from drawing any conclusions about which devices actually have the best trueness. On the other hand, one study comparing two different devices (Primescan and Omnicam) of the same brand (Dentsply-Sirona) found that the device with the newest technology (Primescan) had the best IOS trueness for edentulous arches [23]. This can be interpreted as evidence that IOS technologies are significantly improving to scan an edentulous patient, which has been considered the biggest challenge for IOS as compared to conventional impressions [28].

Despite the abovementioned promising findings for IOS of edentulous patients, there is agreement among the articles assessed herein regarding the fact that span length is inversely proportional to IOS trueness [24,26]. This finding is also in agreement with previous studies [14,28] and with another article assessed herein that described the scan size as a factor significantly inversely associated with IOS trueness [22]. Furthermore, the operator's experience with IOS has also been found to be directly proportional to IOS trueness [22]. The operator's educational level, however, is suggested not to be a factor affecting IOS trueness, as similar results were reported for dentists and dental students [21]. This can be considered evidence of the usefulness of IOS and digital dentistry in dental education [29].

Besides the abovementioned factors, rescanning and post-processing scans as well as the conditions of the preparations and the presence of adjacent teeth are also considered in this review as significant factors affecting IOS trueness. Furthermore, research published prior to the dates considered in the present inclusion criteria had also identified IOS scanning strategy as a factor affecting IOS trueness [30]. This contrasts with the present update review, which did not find any trueness comparisons among different scanning strategies. Instead, most of the included studies used the main scanning strategies recommended by the manufacturers, which are usually scientifically validated for clinical use.

Among the main limitations of the present systematic review is that only a short time span was covered in an attempt to include only recent studies using the most novel IOS technologies. Furthermore, not all IOS devices available in the market were assessed by the studies included. It is also important to note that this systematic review did not include studies assessing the indirect impact of the trueness of IOS systems on the accuracy of implant placements and other clinical outcomes. For this purpose, further clinical long-term prospective studies would still be recommended to address each type of clinical impact occurring due to changes in IOS trueness. Finally, only three studies were in vivo, which suggests that future prospective in vivo studies are recommended to confirm the clinical impact of the factors described herein on IOS trueness.

In conclusion, within the limitations of this systematic review, the present findings on current IOS technologies suggest that the device, scanning distance, operator experience, rescanning and post-processing scans, conditions of the preparations and presence of adjacent teeth are factors significantly affecting IOS trueness.

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