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EPA Consensus Project Paper: Optical Impression Accuracy of Preparations for Fixed Prosthodontics: A Systematic Review

Keywords

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Accuracy
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Authors

Mehmet Ali Kılıçarslan *
(DDS, PhD, Professor)

Ece İrem Oğuz *
(DDS, Associate Professor)

Address for Correspondence

Mehmet Ali Kılıçarslan *

Email: mmkilicarslan@yahoo.com

* *Ankara University, Faculty of Dentistry, Department of Prosthodontics, Emniyet Mahallesi Mevlana Bulvarı Yenimahalle, Ankara, Türkiye*

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ABSTRACT

Introduction: This systematic review aimed to evaluate the accuracy of different optical impressions of tooth preparations. Methods: An electronic search in PubMed, Web of Science, Scopus, Medline Complete, and ScienceDirect was performed to identify articles comparing the accuracy of different optical impressions (OI) published up to the 1st of March 2022. The inclusion criteria enclosed the accuracy of optical impressions acquired for tooth-supported fixed prosthodontics. Exclusion criteria were defined as studies focused on orthodontic impressions and implant-supported restorations. This review was registered to Prospero; CRD42021287758. Results: Eleven included studies had in vitro design and a low risk of bias. Considering scanned objects, 5 studies evaluated the accuracy based on a single preparation, 2 studies evaluated the accuracy of OIs based on fixed partial denture (FPD) restoration, 3 studies included both single preparation and preparations to receive FPD restorations, and 1 article included a full-arch scan. Mean values of the trueness and precision of OI systems varied according to methodological differences. Conclusions: Optical impression has certain advantages. However, stating a particular optical impression system as the most accurate or superior to conventional impression is not feasible because of the heterogeneity of the accuracy results presented in this systematic review.

INTRODUCTION

Computer-aided design (CAD) and computer-aided manufacturing (CAM) applications began in the 1980s with the introduction of data acquisition by digitizing the impression process and producing restorations with fast-grinding milling machines.[1,2] Recent advances in digital technology have increased the popularity of these applications among dentists and dental technicians.[3,4] These systems provide comfortable, fast, efficient, and predictable treatment outcomes. Thus, CAD/CAM is utilized in a wide range of applications from treatment planning for implant surgery, prosthetic rehabilitation, and orthodontic treatments to maxillofacial prostheses.[5]

Scanning of the teeth and edentulous spans via optical impression (OI) is the first step of the digital workflow.[1,3] OI can be acquired by two different methods: direct scanning and indirect scanning.[3] The first method is applied by intraoral scanners (IOSs), which enables the clinician to obtain data directly from the intraoral tissues.[2] The second method is utilized by laboratory scanners (LS) which are designed for data capturing by scanning physical impressions or gypsum casts.[6,7]

Laboratory scanners are available in various types including white-light scanners, blue-light scanners, and laser scanners.[6,8] On the other hand, IOSs use individual photographic techniques or video sequence systems based on the data capture mode.[2] According to the data collection principle, IOSs may also be defined as active triangulation, parallel confocal laser scanning, confocal microscopy, optical coherence tomography, active wavefront sampling or optical cameras.[9,10] IOSs can be further classified by the need for powder coating as a contrast medium before scanning.[10,11] Accuracy of IOSs may vary depending on these parameters.[2,3,7]

The success of fixed prosthodontics primarily depends on its adaptation to the prepared teeth.[6,12] The adaptation is interpreted by internal and marginal fit expressed in gap values between the preparation and the restoration.[12] Restoration misfit and the marginal discrepancy may result in poor mechanical retention, plaque accumulation, secondary caries, periodontal disease, and restoration fracture.[7,12] The adaptation is directly related to the accuracy of the impression, thus the scanner.[12] An accurate digital scan is the first step for a successful prosthesis in a digital workflow.[13,14]

Accuracy evaluation has been performed by superimposing the standard tessellation language (STL) file of the tested scan with the reference STL obtained by micro-computed tomography (micro-CT) or a high-precision scanner with known precision.[3,5,10] Precision and trueness parameters are employed together to describe the accuracy.[10] According to ISO Norm 5725-1, trueness refers to the closeness of agreement between the arithmetic mean of the test results and the reference value.[15] In other words, trueness is the ability to capture the real entity of a measure. Therefore, a scanner with high trueness indicates that the scanner delivers a result that is close to or equal to the actual dimensions of the scanning object.[16,17] The term precision refers to the closeness between the test results.[15] Precision represents the ability to catch the same measure with repetitive scans. Thus, a scanner with high precision correlates to a more repeatable and consistent scan.[16-18]

The accuracy of an OI is affected by many factors such as the scanning technology and protocol, the scanning distance, ambient light, he scan pattern, and the size of the scanners' head.[3,9-11,13,14,16,18-20] Also, the factors related to the prepared teeth such as the geometry, outline form, undercuts, and the divergence of axial walls on intracoronal and the convergence on extracoronal preparations are critical to the scanning accuracy.[10,21-23] Several *in vivo* and *in vitro* studies have subjected the effect of these influencing factors on the accuracy of OIs. Previous reviews analyzing these studies exist,[24-26] yet few have focused on the preparation related factors and their influence on the accuracy. Moreover, considering that technological advances in this field have accelerated recently, an up-to-date review is required. Therefore, the aim of this study was to systematically review the literature considering the accuracy of optical impressions acquired for preparations of fixed prosthodontics.

MATERIALS AND METHODS

The protocol of this systematic review was developed according to the "updated guidance and exemplars for reporting systematic reviews; PRISMA 2020"[27] and the Cochrane Handbook.[28] The review was conducted to answer the following question related to population, intervention, comparison, and outcome (PICO): When used for preparations of fixed prosthodontic, does the optical impression using any kind of digital scanners provide different accuracy values in comparison with each other or with conventional impressions? The population consisted of prepared teeth but not implants or implant scan bodies. The intervention was an OI of these prepared teeth by using a digital scanner of any kind. The comparison was different types of OIs (extraoral and/or intraoral) or conventional impressions of prepared teeth. The examined outcome was the accuracy of optical scanners considering both trueness and precision values. This review is also registered to Prospero and taken ID number as CRD42021287758.

ELIGIBILITY CRITERIA

The publications were selected according to defined inclusion and exclusion criteria. The inclusion criteria of this systematic review enclosed experimental and clinical studies that evaluated the accuracy of optical impressions with both trueness and precision values. Also, the optical impression of only prepared teeth to receive any kind of fixed prosthodontics was included. Only English-language articles in peer-reviewed journals were screened. Exclusion criteria were defined as studies focused on orthodontic impressions, only conventional impressions, only unprepared teeth, implant-supported restorations, removable prostheses, and adaptation of restorations. Also, literature reviews, case reports, editorial reports, and studies unpublished, unavailable in the databases, and those that could not be accessed to read in full or abstracts without a complete article were excluded.

INFORMATION SOURCES AND ELECTRONIC SEARCH STRATEGY

Two reviewers of this study conducted the searches in the following database: PubMed, Web of Science, Scopus, Medline Complete, and ScienceDirect using study keywords, including all articles published up to the 1st of March 2022.

The search strategy used a combination of controlled vocabulary and free-text words and these terms used on information sources except for ScienceDirect were as follows:

1. ("accuracy"[All Fields] OR "trueness"[All Fields] OR "precision"[All Fields])

AND

2. ("optical impression"[All Fields] OR "digital impression"[All Fields] OR "dental scanner"[All Fields] OR "digital scanner"[All Fields] OR "optical scanner"[All Fields] OR "intraoral

scanner"[All Fields] OR "extraoral scanner"[All Fields] OR "model scanner"[All Fields]

AND

3. ("fixed partial denture"[All Fields] OR "fixed partial dentures"[All Fields] OR "FPD"[All Fields] OR "FPDs"[All Fields] OR "dental crown"[All Fields] OR "dental bridge"[All Fields] OR "dental crowns"[All Fields] OR "dental bridges"[All Fields] OR "full arch"[All Fields]))

NOT

4. ("implant"[Title] OR "cleft"[Title] OR "orthodontic"[Title] OR "removable"[Title] OR "edentulous"[Title])

The terms used in ScienceDirect due to technical limitations were: ("accuracy" OR "trueness" OR "precision") AND ("optical impression" OR "digital impression" OR "optical scanner" OR "intraoral scanner" OR "extraoral scanner") AND ("fixed partial denture").

DATA EXTRACTION

Two reviewers independently performed the eligibility evaluation. Initially, the title and abstract of publications obtained from the database search were selected according to these criteria. The publications obtained by this search strategy were imported to EndNote (X9; Clarivate Analytics) for duplicate removal and reference management. Duplicates were eliminated following the authors' names, titles of studies, and year of publication. Eligible studies were included in the second step, in which the full text of all articles was read. At the end of the final screening step, only studies fulfilling all the inclusion and exclusion criteria were included and considered for data extraction of this review. The electronic search was complemented by a manual search from the references of the selected articles that were read in full. Two reviewers (M.A.K., E.İ.O.) screened all articles independently and selected potential studies. Then, the authors reviewed and read the full texts of selected articles. At the final step, authors determined the articles to be included together. After the selection of the studies, the quality and risk of bias for the included studies were assessed by 2 reviewers (M.A.K., E.İ.O.), independently. The Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool was used to assess the risk of bias.

RESULTS

A total of 595 articles were revealed from the initial search in the online database search (*Figure 1*). (PubMed: 94 articles, Web of Science: 104 articles, Scopus: 184 articles, Medline: 162 articles, and Science Direct: 51 articles). After duplicate elimination, a total of 422 articles remained. Based on the assessment of the titles and abstracts, 410 articles were excluded and the full texts of 12 articles were reviewed. Among these, five studies did not meet inclusion criteria as the accuracy evaluation of optical impressions did not include tooth-supported fixed restorations. Searching through the references lists of the included studies resulted in an addition of 4 relevant articles. Consequently, a total of 11 articles were included in this systematic review.[2,6,13,16,21-23,29-32]

Manufacturer details and abbreviations for the evaluated digital scanner systems of included studies were given in Table 1. The studies included in this systematic review were summarized in Table 2. All studies had *in vitro* design except the study by Morsy *et al.*[32] in which both *in vivo* and *in vitro* experiments were conducted. However, only *in vitro* results of this study were included in this systematic review because the accuracy evaluation of *in vivo* part did not meet the inclusion criteria. All included articles were assessed with a low risk of bias *(Table 3)*. The *in vivo* part of the study by Morsy *et al.*[32] showed a high risk of bias but only *in vitro* results were included in this systematic review. Therefore, this study was also evaluated as low risk of bias. Considering accuracy comparisons, 5 studies compared OIs of direct scanning by IOS,[2,13,22,23,31] 2 studies compared OIs obtained by LS vs direct scanning obtained by IOS,[6,29] 1 study compared LS vs LS,[30] 1 study compared conventional impression vs IOS, and 2 studies compared conventional impression vs LS vs IOS.[16,21] All studies included different types of prepared teeth to receive prosthetic restorations (extracoronal and/or intracoronal) as the scanned object. Scanned surfaces were typodont teeth made of plastic,[13,29] steel,[16] acrylic,[6,21,23,31] polyurethane,[2] and polyetheretherketone (PEEK).[30] One study used a coordinate measuring machine with a touch probe,[30] while the others used a high-precision industrial, research, or laboratory scanner for reference scanning. All studies employed reverse engineering software to superimpose and align the reference data with the STL data of optical impressions for the trueness evaluation or to superimpose STL data of optical impressions within the same group to measure precision. The included studies were divided into 3 groups according to the outcome variables: OI of single restoration preparation, OI of preparations for fixed partial denture (FPD), and OI of full-arch preparations.

OUTCOME

OI of Single Restoration Preparation

Eight studies included the accuracy evaluation of OIs of single prosthetic restorations based on different parameters *(Table 2)*.[6,16,21-23,29,30,32]

Ashraf *et al.*[23] compared the accuracy of three IOSs based on 6° and 12° divergent and convergent angles for inlay and full-crown preparations, respectively. They indicated that T3 (trueness 35.70 ±14.12; precision 44.7 ±32) and i500 (trueness 44.7 ±32; precision 45.3 ±32) showed similar trueness and precision values, but both had better results than CO (trueness57.83 ±22.14; precision 72.0 ±51). Preparation variables had significant effects on both trueness and precision. OI accuracy for crown preparations (trueness 32.30 ±11.23; precision 16.3 ±5) was better than inlay preparations (trueness 59.61 ±16.42; precision 91.7 ±21). Considering opposing wall angles, trueness

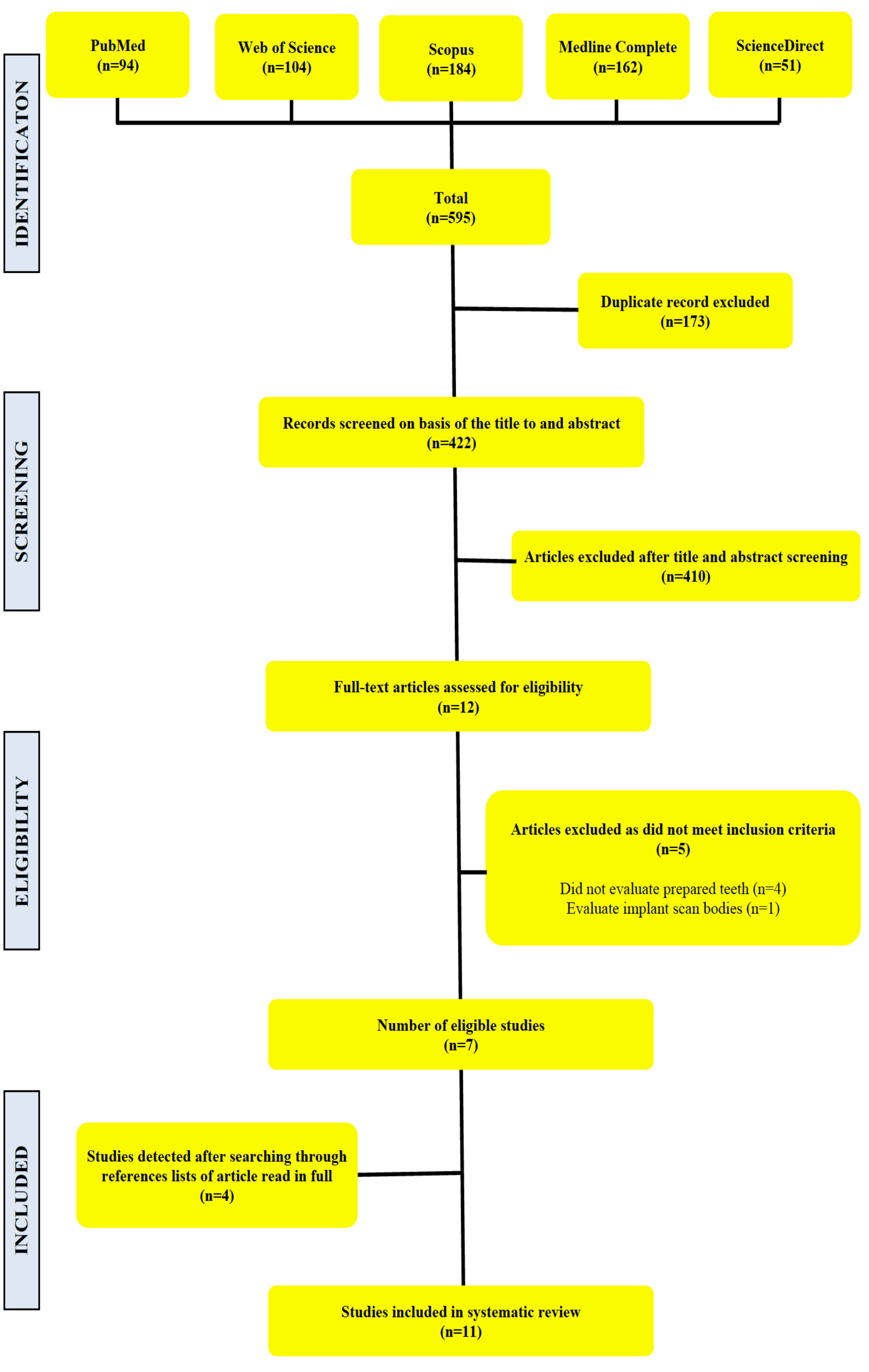

Figure 1: Flowchart of the literature search according to PRISMA guidelines.

increased as the convergence or divergence between opposing walls increased for both inlay and crown preparations. However, precision did not change according to this parameter.

Carbajal Mejía *et al.*[21] evaluated the effect of different occlusal convergence angles (−8, −6, −4, 0, 4, 8, 12, 16, and 22 degrees) on the accuracy of direct (master dies were scanned with TR), conventional (polyvinyl siloxane impressions of master dies were poured and scanned with a reference scanner), and indirect (casts were scanned with KAV) optical impressions for single crown preparations. Considering different OIs, the highest trueness and precision values were obtained for direct OI with TR (trueness 19.1 ±2.0; precision 11.9 ±2.3). The trueness of conventional OI (26.2 ±6.6) was lower than indirect OI (23.5 ±5.5). However, the opposite was found for precision (conventional OI 18.0 ±3.9; indirect OI 20.7 ±4.4). When the occlusal convergence angle was below 8°, direct

Table 1. Details of scanners tested in the included articles and abbreviations used in this systematic review.

Scanner type	Scanner name	Abbreviation	Manufacturer
Intraoral (IOS)	Cerec Bluecam	CB	Sirona, Bensheim, Germany
	Cerec Omnicam	CO	Sirona, Bensheim, Germany
	Cerec Primescan	CP	Sirona, Bensheim, Germany
	Cadent iTero	CiT	Cadent Inc., Carstadt, New Jersey, USA
	Lava C.O.S	COS	3M ESPE, Seefeld, Germany
	Lava True Definition	TD	3M ESPE, Seefeld, Germany
	TRIOS	TR	3Shape, Copenhagen, Germany
	TRIOS 2nd Generation	T2	3Shape, Copenhagen, Germany
	TRIOS 3	T3	3Shape, Copenhagen, Germany
	Medit i500	i500	Medit Corp, Seoul, Korea
	E4D	E4D	D4D Technologies, Texas, USA
	PlanScan	PS	Planmeca, Richardson, Texas, USA
	Carestream 3500	CS3500	Carestream Dental, Atlanta, Georgia, USA
	Carestream 3600	CS3600	Carestream Dental, Atlanta, Georgia, USA
	iTero Element 2	iT2	Align Technology Inc, Arizona, USA
	İTero 1st Genaration	iT1	Align Technology Inc, Arizona, USA
	Zfx intrascan	ZFX	Zfx GmbH, Dachau, Germany
	Planmeca Emerald	PE	Planmeca Oy, Helsinki, Finland
	Virtuo Vivo	VV	Dental Wings Inc, Montréal, Canada
	i700	i700	Medit Corp, Seoul, Korea
	Fastscan	FS	IOS Technologies, California, USA
Extraoral (EO)	KaVo Arctica Scan	KAV	Smart Optics, Bochum, Germany
	iSeries	iS	Dental Wings Inc., Montréal, Canada
	Renishaw Incise	RI	Renishaw, Gloucestershire, UK
	D640	D640	3Shape, Copenhagen, Germany
	Activity 101	AC	Smart Optics, Bochum, Germany
	ZENO Scan S100	ZS	Wieland, Pforzheim, Germany
	Imetric IScan D101	IM	Imetric 4D, Courgenay, Switzerland
	Lava Scan ST	ST	3M ESPE, Seefeld, Germany
	Identica Blue	IB	Dental Wings Inc, Montréal, Canada
	Ceramill map 400	C400	Amann Girrbach AG, Koblach, Austria

OI was the most accurate technique. Also, direct OI showed the best precision irrespective of occlusal convergence angle. Moreover, direct OI showed a homogenous deviation pattern compared to other OI types. Conventional and indirect OIs showed inaccuracies when the occlusal convergence angles were below 0°. However, they indicated that occlusal convergence of the prepared abutment teeth did not affect the accuracy of impressions.

The study by Ender and Mehl[16] compared the accuracy of 4 conventional impressions (POE, VSES, VSE, and ALG) of a model with two full crowns and one inlay preparation which were poured and scanned with a reference scanner, 4 direct OIs (CB, CO, CiT, and COS), and an indirect OI (VSES impression was scanned by iS). Although the reference model contained preparations for single restorations, the accuracy was evaluated based on a full-arch scan. They did not find any significant difference between direct and indirect OIs considering trueness. The precision evaluation revealed that CB (19.5 ±3.9) was more precise than COS (63.0 ±32.8).

A study conducted by Gonzales de Villaumbrosio[30] compared 6 different extraoral scanners (ZS, ST, AC, D640, IM, and RI) based on a single crown preparation. ZS showed better trueness and precision than D640, ST, and Im. Also, AC showed better trueness and Incise showed better precision than D640, ST, and IM.

Table 2. Trueness and precision values reported and a brief summary of included studies.

Article	Author, Year	Number of References	N	Scanned object	Accuracy comparison	Reference measurement	Experimental Groups		Trueness (µm) (Mean ±SD)	Precision (µm) (Mean ±SD)
Influence of preparation type and tooth geometry on the accuracy of different intraoral scanners	Ashraf *et al.*, 2020	38	10	Four typodont teeth with full-crown and inlay preparations with 6° and 12° axial wall tapers	Three IOSs were compared based on preparation type and convergence angle	LS- InEos X5; Dentsply Sirona	T3		35.70 ±14.12	44.7 ±32
							i500		44.31 ±11.41	45.3 ±32
							CO		57.83 ±22.14	72.0 ±51
							Crown		32.30 ±11.23	16.3 ±5
							Inlay		59.61 ±16.42	91.7 ±21
Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions	Carbajal Mejía *et al.*, 2017	36	5* 10**	Nine acrylic resin maxillary central incisors prepared with different total occlusal convergence angles (−8, −6, −4, 0, 4, 8, 12, 16, and 22 degrees)	Gypsum casts obtained by pouring conventional 2-step polyvinyl siloxane impressions were scanned via a reference scanner (conventional impression scanning-RS) and a laboratory scanner (indirect digital scanning-KAV) and compared with direct scanning of acrylic teeth with an IOS (Direct digital scanning-TR)	RS- Rexcan DS; Solutionix	IS – RS		26.2 ±6.6	18.0 ±3.9
							Indirect digital scanning - KAV		23.5 ±5.5	20.7 ±4.4
							DS -TR		19.1 ±2.0	11.9 ±2.3
Accuracy of six intraoral scanners for scanning complete-arch and 4-unit fixed partial dentures: An *in vitro* study	Diker and Tak, 2021	33	10	A maxillary typodont model containing bilaterally prepared canines and first molars, and edentulous spans between the prepared teeth	Six IOSs were compared based on complete arch and 4-unit FPD preperation scans	RS- ATOS Core 80; GOM GmbH	Accuracy for complete arch-scan	T3	48 ±8.25	41 ±52.5
								iT2	60 ±11.5	70.5 ±38.75
								PE	105.5 ±19	84 ±48.5
								CO	84.5 ±16.25	77 ±49
								CP	56 ±6.25	68.5 ±39.5
								VV	59 ±5.75	58.5 ±29.25
							Accuracy for 4-unit FPD preperations	T3	57.5 ±4	29 ±9
								iT2	60.5 ±24	60 ±15
								PE	101 ±12.75	64 ±12
								CO	92.5 ±23.25	45 ±16
								CP	43 ±3.5	23 ±8
								VV	54.5 ±7	28 ±3

Table 2 continued overleaf

Table 2. Continued...

In-vitro evaluation of the accuracy of conventional and digital methods of	Ender and Mehl, 2015	32	5	A steel reference model fabricated from a patient's maxillary impression with two full crown and one inlay preparations	Three conventional impressions (ALG, POE, VSE, and VSES) were poured and casts were scanned with a RS. Impression with VSES was scanned directly with a LS and scanned with the RS after sputtering. Four DSs with IOSs were obtained from reference model. Those 9 groups were compared.	RS- Infinite Focus Standard; Alicona Imaging	CB - DS CO - DS CiT - DS COS - DS VSES-iS - IS VSES-RS (conventional) ALG-RS (conventional) POE-RS (conventional) VSE-RS (conventional)	29.4 ±8.2 37.3 ±14.3 32.4 ±7.1 44.9 ±22.4 35.1 ± 5 11.5 ± 1.3 37.7 ± 34.9 60.2 ± 25.0 13.0 ± 2.9	19.5 ±3.9 35.5 ±11.4 36.4 ±21.6 63.0 ±32.8 39.6 ± 19.7 14.6 ± 2.6 59.6 ± 43.6 66.7 ± 18.5 12.3 ± 2.5
In vitro comparison of the accuracy (trueness and precision) of six extraoral dental scanners with different scanning technologies	González de Villaumbrosia *et al.*, 2016	47	10	A single polyetheretherketone master die in the shape of a prepared premolar	Six LSs were compared	Coordinate measuring machine Global Performance 7.10.7 SF; Hexagon Metrology	ZS AC RI D640 IM ST	29 35.7 37.1 42.1 43.2 46	37.5 44 43.8 46.6 50.2 50.6
Is there a significant difference in accuracy of four intraoral scanners for short-span fixed dental prosthesis? A comparative *in vitro* study	Jivănescu *et al.*, 2021	32	10* 45**	A mandibular typodont model with prepared left 2nd premolar and left 2nd molar and an edentulous span between the prepared teeth	Four IOSs were compared based on a 3-unit all ceramic FPD preperation scan	RS- Medit T500; Medit Corp.	CP CO i700 PS	23.25 ±3.97 32.3 ±8.62 25.55 ±1.85 75.8 ±18.42	6.5 ±1.3 15.4 ±4 9.1 ±3.8 68 ±15.1
Accuracy of single-abutment digital cast obtained using intraoral and cast scanners	Lee *et al.*, 2017	27	6* 15**	A poly (methyl methacrylate) maxillary first molar tooth prepared for full-covarage restoration	Two IOSs (direct scanning) and a laboratory scanner (direct scanning of the model-DS and cast scanning-CS) were compared	High-precision engineering scanner SmartSCANr5; AICON 3D Systems	CB - DS CO - DS IB - DS IB - CS	17.5 ±1.8 13.8 ±1.4 12.3 ±0.1 17.4 ±1.7	12.7 ±2.6 12.5 ±3.7 6.9 ±2.6 9.2 ±1.2

Table 2 continued overleaf

Table 2. Continued...

Fit of monolithic multilayer zirconia fixed partial dentures fabricated by conventional versus digital impression: a clinical and laboratory investigations	Morsy *et al.*, 2021	38	5	Additively manufactured maxillary master model from opaque resin with prepared upper central, upper canine, upper second premolars, and upper second molar (a crown and 2 bridge preparations)	Conventional impression taken with a one-step technique using monophase polyether was poured and the cast was scanned with a LS and the resultant data were compared with DS of the master model with IOS	DS of the master model with C400	CS3500-DS C400-CS	62.72 ±12.01 62.8 ±5.45	60.9 ±14.5 56.47 ±27
Accuracy of Three Digitization Methods for the Dental Arch with Various Tooth Preparation Designs: An *In Vitro* Study	Oh *et al.*, 2019	39	10	A maxillary typodont model without the left first molar and with inlay preparation on the right second molar and full-crown preparations on the right and left second premolars, and left second molar	The accuracy of an IOS by DS of the model and a laboratory scanner by IS and CS were compared based on complete-arch scan	industrial optical scanner, ATOS Triple Scan; GOM GmbH	CS3600 - DS IB- CS IB - IS	89.73 ± 16.96 66.34 ± 4.91 54.4 ±3.62	104 41.9 35.8
Comparative analysis on reproducibility among 5 intraoral scanners: sectional analysis according to restoration type and preparation outline form	Park, 2016	27	4	A maxillary typodont model without right lateral and with full-crown preparations on right central and canine, and with an inlay cavity on right maxillary second molar; a mandibular typodont model with a full-crown preparation on right second molar	DS with 5 IOSs were compared	LS - 7series; Dental Wings Inc.	E4D FS iT1 T2 ZFX	114.2 ±80.7 45.2 ±29.8 52.1 ± 38.8 49.7 ± 36.6 89.4 ± 64.2	97.6 ±109.2 26.0 ±24.4 25.8 ± 22.5 13.0 ± 12.1 132.3 ± 124.4
Accuracy of full-arch scans using intraoral scanners	Patzelt *et al.*, 2014	33	5	Full arch polyurethane maxillary model with 14 prepared teeth	Four IOSs were compared	industrial scanner, IScan D101, Imetric 3D GmbH	CiT- 3shape compatible STL CiT- Dental Wings compatible CB COS ZFX	49.0 ±13.6 49.6 ±14.0 332.9 ±64.8 38.0 ±14.3 73.7 ±26.6	40.4 ±11.3 40.5 ±11.2 99.1 ±37.4 37.9 ±19.1 90.2 ±26.7

For scanner abbreviations, please see Table 2. #IOS: intraoral scanner, DS: direct scanning, LS: laboratory scanner, RS: reference scanner, ALG: alginate, POE: polyether, VSE: vinylsiloxanether, VSES: scannable VSE, FPD: fixed partial denture, CS: cast scanning, IS: impression scanning, * Refers to trueness values Refers to precision values.**

Table 3. Risk of bias evaluation according to Quadas-2 domains.

Study	Risk of bias			
	Patient selection	Index test	Reference standard	Flow and timing
Ashraf *et al.*	+	+	+	+
Carbajal Mejía *et al.*	+	+	+	+
Diker and Tak	+	+	+	+
Ender and Mehl	+	+	+	+
González de Villaumbrosia *et al.*	+	+	+	+
Jivănescu *et al.*	+	+	+	+
Lee *et al.*	+	+	+	+
Morsy *et al.* *in vivo/ in vitro*	?/+	?/+	-/+	+/+
Oh *et al.*	+	+	+	+
Park	+	+	+	+
Patzelt *et al.*	+	+	+	+

+ Low Risk; - High Risk; ? Unclear Risk

A single abutment was selected in the study by Lee *et al.*[6] for the accuracy evaluation of direct scanning with 2 IOSs (CB and CO) and 1 LS (IB), and indirect scanning with LS of stone casts obtained by pouring PVS impressions of the abutment tooth. Direct scanning with CO (13.8±1.4) and LS (12.3 ±0.1) yielded similar trueness values which were better than other groups. However, direct scanning with LS showed the best precision (6.9 ±2.6) among all groups.

The study by Morsy *et al.*[32] included a clinical trial in addition to *in vitro* part. However, the clinical trial evaluated the fit of zirconia crowns and did not evaluate the accuracy based on trueness and precision. Therefore, only the *in vitro* part of this study was included in this review. This study included a model with a crown and two 3-unit FPD preparations, but the accuracy evaluation was made based on the full-arch scans. The accuracy comparison of DS of the model with an IOS (CS3500) and indirect scanning with a LS (C400) of the casts obtained by pouring monophase polyether impression resulted in no difference considering both trueness and precision.

A study by Oh *et al.*[29] also evaluated the accuracy of 3 digitization methods using a maxillary typodont with a single crown and a disto-occlusal inlay preparation in addition to a 3-unit FPD. Digitization methods included DS with an intraoral scanner (CS3600), monophase polyether IS with a LS (IB), and CS with the same LS. The authors provided both trueness and precision results for full-arch evaluation. However, only trueness values were given for individual abutments. Considering full-arch evaluation, the lowest and the highest trueness and precision values were obtained for DS (trueness 89.73 ± 16.96; precision 104) and IS (trueness 54.4 ±3.62; precision 35.8), respectively. For inlay preparation, direct scanning (97.76 ±19.63) resulted in lower trueness than impression (41.08 ±2.83) and cast scanning (54.87 ± 8.19) which was not statistically different. Also, DS of crown preparation resulted in better trueness with a mean of 70.62 ±13.62 than that of inlay preparation while CS and IS did not generate any difference. Trueness comparison for the FPD preparation is given in the next subtitle of the results section.

Park[22] compared direct scanning of a mesiodistal inlay, a single crown, and 3-unit FPD preparations with five intraoral scanners (iT1, E4D, ZFX, T2, and FS) and provided accuracy results for overall evaluation and trueness results for individual abutment preparations. The overall comparison revealed that the lowest trueness was obtained for E4D (114.2 ±80.7) followed by ZFX (89.4 ± 64.2). The trueness values of other groups were comparable to each other. T2 (13.0 ± 12.1) showed the highest and ZFX (132.3 ± 124.4) showed the lowest precision values. In comparison to the restoration type, T2 and ZFX showed better trueness for crown preparation compared to inlay. The trueness of other groups did not differ regarding the type of single-unit preparation.

OI of Preparations for Fixed Partial Denture Preparation

Five studies compared the accuracy of OIs based on FPD restorations.[13,22,29,31,32] All studies provided accuracy results of scanners for both complete-arch and individual preparations, but Morsy *et al.*[32] evaluated the accuracy only for the complete-arch scan. The results for overall evaluations for 3 studies[22,29,32] were given in the previous section. Therefore, only the results related to FPD preparations are provided in this part for these studies.

Diker and Tak[13] investigated the accuracy of 6 IOSs (T3, iT2, CO, PE, CP, and VV) for two pieces of 4-unit FPD based on bilaterally prepared maxillary canine and first molar teeth. Accuracy results for both complete-arch and individual prepared teeth were provided. Considering complete-arch trueness evaluation; T3, iT2, CP, and VV were not statistically different from each other, but they showed higher trueness than CO and PE which were also statistically comparable. Differences between the precision comparison of complete-arch scans were not significant irrespective of IOS type. Evaluation for prepared teeth showed that CP had the highest trueness (43 ±3.5). However, precision values for prepared teeth were not statistically different for CP, CO, VV, and T3.

Jivănescu *et al.*[31] reported accuracy levels of 4 IOSs in increased order as PS, CO, i700, and CP for a full-arch maxillary scan containing a 3-unit FPD preparation. Oh *et al.*[29] compared DS and CS with CS3600, and IS with IB of a 3-unit maxillary FPD preparation. Considering individual abutment-based evaluation of the FPD preparations, they reported that DS showed lower accuracy than CS and IS groups for which comparable results were obtained for the anterior abutment. However, for the distal abutment, the highest and the lowest trueness values were obtained for IS (37.24 ± 6.68) and DS (138.76 ± 38.19), respectively. When comparing anterior and distal abutments, CS and IS did not differ in terms of trueness. However, DS of the distal abutment resulted in lower trueness than the anterior abutment tooth.

Park[22] compared the accuracy based on both a single (crown and inlay) and a 3-unit FPD preparation and the results for single-unit preparations were provided in the previous section. Unlike other studies, they compared single-unit and FPD preparations. The results showed that significantly lower trueness was observed for the FPD than for single-unit preparations in E4D, FS, and iT1. On the other hand, T2 and ZFX provided higher trueness for single crown preparation compared to inlay and FPD preparations for which the results were comparable.

OI of Full-Arch Preparations

Among the studies included in this systematic review, only Patzelt *et al.*[2] evaluated accuracy based on full-arch preparation. Fourteen prepared teeth of an upper-jaw study model were scanned directly with 4 IOSs (CB, COS, CiT, and ZFX). The authors reported the highest and the lowest accuracy for COS (38.0 ±14.3) and CB (332.9 ±64.8), respectively. Also, the authors compared the trueness of CiT scanner by STLs compatible with 3shape and Dentalwings; however, they did not report any significant differences between them.

DISCUSSION

In this systematic review, the included articles evaluated the accuracy of optical impressions for fixed prosthodontics based on distinct variables and conducted different methodologies. Performing a meta-analysis was not rational due to the heterogeneity of the outcomes. However, it was evident that regardless of the scanner type used, all forms of optical impressions resulted in varying amounts of inaccuracy.

Reports of OI for prepared teeth to receive fixed prosthodontics were systematically searched up to March 2022 from the Pubmed, Web of Science, Scopus, and Medline databases. The search parameters and design for each database were clearly explained based on certain inclusion and exclusion criteria. A total of 11 articles were included in this systematic review. The reason for the relatively low number of articles was that inclusion criteria required OI of prepared abutment teeth to receive fixed prosthodontics and that both trueness and precision parameters were sought for accuracy evaluation according to ISO.[15]

Optical impressions can be performed by the direct scanning of the intraoral structures or indirect scanning of the impression or cast. Optical impression by direct scanning is performed using intraoral scanners. On the other hand, indirect scanning can be performed by scanning the conventional impression or scanning the cast after pouring the impression using a laboratory scanner. Therefore, indirect digitization possesses limitations related to impression materials because the duplicating stage was reported to cause inaccuracies in contrast to direct scanning of the area.[6,29] A fully digital restorative workflow with direct scanning has become popular in the dental field due to its advantages as avoiding multistep data acquisition and the production process of conventional methods.[21,23,33] However, errors related to direct intraoral scanning were also reported when the camera tilt angle exceeded the axial wall angle of convergence of the prepared tooth.[21,34] Such errors are less likely to occur with indirect data capturing because scanning the tooth from different directions is possible.[21] Among the 5 studies that compared direct vs indirect scanning, 2 studies[6,21] reported better accuracy for direct scanning and 2 studies[16,32] did not find any difference between them, while 2 studies[6,29] found indirect scanning more accurate than direct scanning. The difference between results may have derived from the difference in scanned objects. The studies that reported better accuracy for direct scanning evaluated single die preparations while the other studies included full-arch scanning of models containing single crown preparations in combination with inlay or FPD preparations. Scanning single-die preparation without adjacent teeth may have eliminated the limitations of scanners.[13,29] However, scanning the prepared tooth away from the intraoral soft tissues and adjacent teeth is not possible intraorally. Also, the accuracy of direct full-arch scanning is limited with IOS due to the lack of fixed references and overlapping problems of the subsequent images.[21,32,35] Stitching problems that occur locally may derive cumulative errors for IOSs when the scanned area exceeds a 4-unit span or quadrant.[13,21,32] Such error is not reported for laboratory scanners which take multiple large field images of the full-arch and automatically process them into a single 3D image.[32] On the other hand, contradictory results for different IOS were reported by Lee *et al.*[6] who stated that direct scanning of a single abutment with the CEREC Bluecam resulted in lower trueness than indirect scanning, but higher trueness values were obtained for direct scanning with the CEREC Omnicam. It can be assumed that each system has individual advantages and disadvantages that differ according to variables related to scanning technology or parameters. Therefore, considering direct scanning with IOS or indirect scanning with laboratory scanners superior to one another would be misleading.

All authors except Gonzalez de Villaumbrosio[30] compared the accuracy of IOSs with each other, with conventional impressions, and/or with LSs. IOSs possess several advantages over conventional impressions including less discomfort for the patient, time efficiency, simplified clinical and laboratory procedures, and better communication with both patient and dental technician.[36] On the other hand, superior accuracy over conventional PVS or polyether impressions is not among the advantages of IOS.[16,32] However, Carbajal Mejía *et al.*[21] stated lower accuracy for PVS impression compared to OI with Trios. Although there is no consensus regarding the superiority of accuracy for conventional impressions or OIs, material-dependent dimensional changes and error-prone multistep manufacturing processes in the conventional methods would lead to a misfit of the definitive restoration.[21]

Included studies subjected to several different IOSs and reported various accuracy values even for the same IOS. In general, the most recent IOSs in terms of software and release date resulted in better accuracy than older versions;[2,6,13,22,31] however, making a definite deduction would be misleading. Therefore, the superiority of a particular system regarding current IOSs is debatable and no recommendations can be made according to the present systematic review.

There is no consensus regarding a clinically acceptable range for the accuracy of IOSs but previous studies considered up to the 200 μm threshold as acceptable.[21,37,38] Most of the included studies reported trueness and precision levels below this value, except the study by Patzelt *et al.*[2] The authors specified a trueness value of 332.9 ±64.8 μm for CEREC Bluecam. They assumed that this difference may have derived from the scanning technologies and data processing algorithms as CEREC Bluecam is based on confocal microscopy and triangulation technique with blue light-emitting diodes and requires reflective powder coating on the scanned area.[6] However, Ender and Mehl[16] and Lee *et al.*[6] reported considerably higher accuracy for the same scanner. The main difference between these studies was the scanned objects as the later studies evaluated the accuracy based on single preparations but Patzelt *et al.*[2] scanned a full-arch maxillary model with 14 prepared teeth. As mentioned earlier, accuracy decreases with the increased scanned area which was attributed to matching or stitching errors that increases with the lengthening of the scan.[31,39,40] In light of this information, scanning technology and the length of the scanned span are important parameters in comparison of IOSs accuracy.

The scanning technology affects the accuracy of not only intraoral scanners but also laboratory scanners. Gonzalez de Villaumbrosia *et al.*[30] reported higher accuracy for laser scanners compared to contact scanners and structured light scanners at the axial surfaces. However, they specified that this was not valid for all aspects of the scanned surface and that the overall reliability was not related to the scanning technology. Also, Carbajal Mejía *et al.*[21] stated that the lower accuracy values for the laboratory scanner used may have derived from the scanner type which was white-light for this study. Nevertheless, the same confusion regarding the best accuracy is also regnant for extraoral scanners as well as intraoral scanners.

According to the outcomes of this systematic review, preparation parameters of abutment teeth influence OI accuracy. Ashraf *et al.*[23] indicated that the occlusal convergence angle of the preparation is an important factor for accuracy. Generally, undercuts or negative angles of the opposite walls may exceed the camera tilt angle and restrict an accurate impression in areas under the undercuts.[41,42] Although Carbajal Mejía *et al.*[21] reported otherwise, they found inaccuracy for indirect impressions below 8 degrees of occlusal convergence angles. Nevertheless, undercuts should be avoided during preparation and a tapered preparation should be performed to enable an accurate digital impression.

Another factor that influences OI accuracy for IOS regarding preparations is the type of restoration to be received. Ashraf *et al.*[23] reported better accuracy and Oh *et al.*[29] and Park[22] reported better trueness for single crown preparations than for inlay preparations. Crown and inlay preparations differ in terms of preparation guidelines, design, and preparation walls. Crowns are extracoronal restorations, whereas inlays are intracoronal restorations which means that they possess inner cavity walls.[43] Beveling or rounding axio-pulpal angles and internal line angles that do not exist with crown preparations are of importance for inlay preparations considering the success of OI of such preparations as much as the longevity of the restoration.[44] Gonzalez de Villiaumbrosia *et al.*[30] reported that sharp edges of the preparation lower the scanning capacity and result in inaccuracies. Therefore, preparations with complex designs like inlays require extreme caution. Also, the scan distance or depth recognized by the scanner was reported to differ according to the scanner system used.[45] Studies showed that different scanner systems might provide different results for the pulpal floor depths of the inlay cavities from the actual depths.[44,46] Therefore, the accuracy of single preparations may vary depending on cavity and preparation variables and as the complexity of the design increases, the accuracy decreases due to scan errors.[23,44]

On the other hand, Park[22] found better accuracy for single crown preparations than for FPD preparations. This can also be attributed to the complexity of the scanned object as camera misalignment errors may occur due to conflicting opposing wall angles with FPD preparations.[23,29] Moreover for the OI of FPD preparations with IOS, Oh *et al*.[29] indicated that distal abutment resulted in lower trueness. Patzelt *et al*.[2] reported horizontal deviations in the distal parts of the arch which is in line with the findings of Ender and Mehl.[16] They attributed these findings to errors in software stitching processes and matching errors of the captured data during processing in the posterior areas. These results regarding different preparation parameters such as occlusal convergence angle, preparation type, and abutment location point out that the functional and technical challenges may differentiate the accuracy of OI with IOS.[16]

The included studies and the present systematic review have certain limitations. Digital optical impression devices update hardware and software frequently. However, not all the studies included in this systematic review evaluated the latest software. Also, ensuring the homogeneity of the scanned object, scanning device, and the software of the OI device used was not applicable. The data provided in this systematic review should be interpreted in clinical practice with caution since all the articles included had *in vitro* setups with low evidence. Further studies evaluating clinical adaptation based on digital findings should be warranted.

CONCLUSIONS

Although OI is attractive considering the advantages of digital systems, stating superior accuracy for a type of OI over conventional impressions or recommending a particular system for either direct or indirect scanning is not feasible. However, all types of optical impressions resulted in varying amounts of inaccuracy. Clinicians should choose a suitable scanning device and technique in accordance with the specific clinical requirements of the case. The accuracy of the OI depends on multiple variables such as the scanner type, scanned object, preparation parameters, the length of the scanned area, and hardware and software updates. Included articles not only differed in terms of these variables but also employed distinct methodologies. Therefore, the outcomes of the included studies were different from each other, making it hard to dedicate a most accurate system. The variety in outcomes restricted drawing strong conclusions. A standardized methodology for the accuracy assessment should be warranted to better compare future results.

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